



EUROPEAN COMMISSION

Integrated Pollution Prevention and Control (IPPC)
Reference Document on
Best Available Techniques in the Pulp and Paper Industry

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EXECUTIVE SUMMARY

This Reference Document on best available techniques in the pulp and paper industry reflects the information exchange carried out according to Article 16(2) of Council Directive 96/61/EC. The document has to be seen in the light of the preface, which describes the objectives of the document and its use.

Paper is essentially a sheet of fibres with a number of added chemicals that affect the properties and quality of the sheet. Besides fibres and chemicals, manufacturing of pulp and paper requires a large amount of process water and energy in the form of steam and electric power. Consequently, the main environmental issues associated with pulp and paper production are emissions to water, emissions to air, and energy consumption. Waste is expected to become a gradually increasing environmental issue of concern.

Pulp for papermaking may be produced from virgin fibre by chemical or mechanical means or may be produced by the re-pulping of recovered paper. A paper mill may simply reconstitute pulp made elsewhere or may be integrated with the pulping operations on the same site.

This document covers the relevant environmental aspects of pulp and papermaking from various fibrous materials in integrated and non-integrated pulp and paper mills. Non-integrated pulp mills (market pulp) are only manufacturing pulp that is then sold on the open market. Non-integrated paper mills are using purchased pulp for their paper production. In integrated pulp and paper mills the activities of pulp and papermaking are undertaken on the same site. Kraft pulp mills are operating in both non-integrated and integrated manner whereas sulphite pulp mills are normally integrated with paper production. Mechanical pulping and recycled fibre processing is usually an integrated part of papermaking but has become a stand-alone activity in a few single cases.

Neither environmentally relevant upstream processes like forestry management, production of process chemicals off-site and transport of raw materials to the mill nor downstream activities like paper converting or printing are included in this document. Environmental aspects which do not specifically relate to pulp and paper production such as storage and handling of chemicals, occupational safety and hazard risk, heat and power plants, cooling and vacuum systems and raw water treatment are not or only briefly treated.

This BREF consists of an introductory section (general information, Chapter 1) and five major parts:

- the kraft pulping process (Chapter 2),
- the sulphite pulping process (Chapter 3),
- mechanical pulping and chemi-mechanical pulping (Chapter 4),
- recycled fibre processing (Chapter 5), and
- papermaking and related processes (Chapter 6).

Each of these chapters has five main sections according to the general outline of IPPC BAT Reference Documents. For most readers it will not be necessary to read the whole document but only those chapters or sections that are of interest for the mill in question. For example, market kraft pulp mills are only concerned by Chapter 2; integrated kraft pulp and paper mills are concerned by Chapter 2 and 6, relevant information on integrated recycled paper processing mills can be found in Chapter 5 and 6.

At the end of the document there is a list of references and a glossary of terms and abbreviations that facilitates understanding.

The general information (Chapter 1) include statistical data about paper consumption in Europe, the geographical distribution for pulp and paper production across Europe, some economic aspects, a rough overview about pulp and paper production and major environmental issues, and a classification of pulp and paper mills in Europe. The chapter on general information closes with some general remarks on the determination of BAT for the sector that is characterised by a high diversity of products and (combinations of) processes involved and a high degree of process-integrated technical solutions.

For each of the major 5 chapters information on the following aspects are presented: applied processes and techniques; major environmental concerns such as resource and energy demand, emissions and waste; description of relevant techniques for emission abatement, waste minimisation and energy savings; identification of best available techniques; and emerging techniques.

As for the reported emission and consumption figures, it should be borne in mind that, due to the use of some different measurement methods in the various Member States, data are not always strictly comparable from country to country. (See Annex III for more information on this issue but the different methods used do not alter the conclusions drawn in this document).

The discussion of the techniques to consider in determination of BAT all follow the same structure and cover a short description of the technique, main achieved environmental performance, applicability, cross-media-effects, operational experiences, economics, driving forces for implementing this technique, example plants and reference literature. The section on Best Available Techniques includes ranges of emission and consumption levels that are associated with the use of BAT. The conclusions on BAT are based on experiences from real world examples and the expert judgement of the TWG.

Pulp and papermaking is a complex area that consists of quite many process stages and different products. However, the wide range of raw materials used, processes involved in pulp and papermaking can be broken down into a number of unit operations for the sake of discussion. In this document, environmental concerns and relevant techniques for prevention and reduction of emissions/waste and reducing consumption of energy and raw materials are described separately for five major classes (Chapter 2 to 6). Where appropriate and considered as necessary, these main classes are further sub-divided in sub-classes.

The document reflects at sector level the variety in terms of raw materials, energy sources, products and processes in the European paper industry. However, in specific cases within each main product category there is a certain range of raw materials and product specification that differ from production of standard qualities and may have an impact on operational conditions and the potential for improvement. This is especially true for special paper mills producing a high number of different qualities in sequential manner on their machines or for paper mills producing „special qualities“ of paper.

The exchange of information has allowed conclusions on BAT. The sections in each of the Chapters that describe BAT should be referred to for a complete understanding of BAT and the associated emissions. The key findings are summarized below.

General BAT for all processes

During the information exchange it emerged that the most effective measure for the reduction of emissions/consumption and the improvement of economic performance is the implementation of the best available process and abatement technologies in combination with the following: -

- Training, education and motivation of staff and operators;
- Process control optimisation;

- Sufficient maintenance of the technical units and the associated abatement techniques;
- Environmental management system which optimises management, increases awareness and includes goals and measures, process and job instructions etc.

BAT for Kraft pulp processing (Chapter 2)

The sulphate or kraft process is the dominating pulping process worldwide due to the superior pulp strength properties and its application to all wood species. In kraft pulping the wastewater effluents, the emissions to air including malodorous gases and the energy consumption are the centres of interest. In some countries also waste is expected to become an environmental issue of concern. The main raw materials are renewable resources (wood and water) and chemicals for cooking and bleaching. Emissions to water are dominated by organic substances. Effluent from bleach plant, where chlorine-containing bleaching chemicals are used, contains organically bound chlorine compounds, measured as AOX. Some compounds discharged from mills show toxic effects on aquatic organisms. Emissions of coloured substances may effect the living species in the recipient negatively. Emissions of nutrients (nitrogen and phosphorus) can contribute to eutrophication in the recipient. Metals extracted from the wood are discharged in low concentrations but due to high flows the load can be of significance. A significant reduction of both chlorinated and non-chlorinated organic substances in the effluent of pulp mills have been achieved to a large extent by in-process measures.

Best available techniques for kraft pulp mills are considered to be

- Dry debarking of wood;
- Increased delignification before the bleach plant by extended or modified cooking and additional oxygen stages;
- Highly efficient brown stock washing and closed cycle brown stock screening;
- Elemental chlorine free (ECF) bleaching with low AOX or Totally chlorine free (TCF) bleaching;
- Recycling of some, mainly alkaline process water from the bleach plant;
- Effective spill monitoring, containment and recovery system;
- Stripping and reuse of the condensates from the evaporation plant;
- Sufficient capacity of the black liquor evaporation plant and the recovery boiler to cope with the additional liquor and dry solids load;
- Collection and reuse of clean cooling waters;
- Provision of sufficiently large buffer tanks for storage of spilled cooking and recovery liquors and dirty condensates to prevent sudden peaks of loading and occasional upsets in the external effluent treatment plant;
- In addition to process-integrated measures, primary treatment and biological treatment is considered BAT for kraft pulp mills.

For bleached and unbleached kraft pulp mills the BAT emission levels to water that are associated with the use of a suitable combination of these techniques are the following:

	Flow m ³ /Adt	COD kg/Adt	BOD kg/Adt	TSS kg/Adt	AOX kg/Adt	Total N kg/Adt	Total P kg/Adt
Bleached pulp	30 - 50	8-23	0.3-1.5	0.6-1.5	< 0.25	0.1-0.25	0.01-0.03
Unbleached pulp	15 - 25	5-10	0.2-0.7	0.3-1.0	-	0.1-0.2	0.01-0.02

These emission levels refer to yearly averages. The water flow is based on the assumption that cooling water and other clean water are discharged separately. The values refer to the contribution of pulping only. In integrated mills emissions from papermaking (see Chapter 6) have to be added according to product mix manufactured.

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Off-gas emissions from different sources are considered as the other relevant environmental issue. Emissions to the atmosphere originate from recovery boiler, lime kiln, bark furnace, chip storage, cooking digester, pulp washing, bleaching plant, bleaching chemical preparation, evaporation, screening, washing, white liquor preparation, and various tanks. A part of this is the diffuse emissions that escape from various points of the process. The main point sources are the recovery boiler, the lime kiln and auxiliary boilers. Emissions consist mainly of nitrogen oxides, sulphur-containing compounds such as sulphur dioxide, and malodorous reduced sulphur compounds. In addition there are emissions of particulates.

Best available techniques for reducing emissions to air are

- Collection and incineration of concentrated malodorous gases and control the resulting SO₂ emissions. The strong gases can be burnt in the recovery boiler, in the lime kiln or a separate, low NO_x furnace. The flue gases of the latter have a high concentration of SO₂ that is recovered in a scrubber.
- Diluted malodorous gases from various sources are also collected and incinerated and the resulting SO₂ controlled.
- TRS emissions of the recovery boiler are mitigated by efficient combustion control and CO measurement;
- TRS emissions of the lime kiln are mitigated by controlling the excess oxygen, by using low-S fuel, and by controlling the residual soluble sodium in the lime mud fed to the kiln.
- The SO₂ emissions from the recovery boilers are controlled by firing high dry solids concentration black liquor in the recovery boiler and/or by using a flue gas scrubber;
- BAT is further the control of NO_x emissions from the recovery boiler (i.e. ensuring proper mixing and division of air in the boiler), lime kiln and from auxiliary boilers by controlling the firing conditions, and for new or altered installations also by appropriate design;
- SO₂ emissions from auxiliary boilers are reduced by using bark, gas, low sulphur oil and coal or controlling S emissions with a scrubber.
- Flue gases from recovery boilers, auxiliary boilers (in which other biofuels and/or fossil fuels are incinerated) and lime kiln are cleaned with efficient electrostatic precipitators to mitigate dust emissions.

For bleached and unbleached kraft pulp mills the BAT emission levels to air from the process that are associated with a combination of these techniques are shown in the following table. The emission levels refer to yearly averages and standard conditions. Emissions from auxiliary boilers e.g. due to production of steam used for drying of pulp and/or paper are not included. For emission levels from auxiliary boilers it is referred to the section BAT for auxiliary boilers further below.

	Dust kg/Adt	SO₂ (as S) kg/Adt	NO_x (NO+NO₂ as NO₂) in kg/Adt	TRS (as S) kg/Adt
Bleached and unbleached kraft pulp	0.2-0.5	0.2-0.4	1.0-1.5	0.1-0.2

The values refer to the contribution of the pulp production only. That means that in integrated mills the figures for the process emissions are related to the kraft pulp production only and do not include air emissions from steam boilers or power plants that might be operated to provide the energy needed for paper production.

Best available techniques for reducing waste is to minimise the generation of solid waste and recover, recycle and re-use these materials, wherever practicable. Separate collection and intermediate storage of waste fractions at source can be beneficial to meet this aim. When the collected waste is not re-usable in the process external utilisation of residuals/waste as substitutes or incineration of organic materials in suitably designed boilers with energy recovery is considered as BAT.

In order to reduce the consumption of fresh steam and electric power, and to increase the generation of steam and power internally, a number of measures are available. In energy efficient non-integrated pulp mills the heat generated from black liquor and incineration of bark exceeds the energy required for the entire production process. However, fuel oil will be needed at certain occasions like start-up and also at many mills in the lime kiln.

Energy efficient kraft pulp and paper mills consume heat and power as follows:

- Non-integrated bleached kraft pulp mills: 10-14 GJ/Adt process heat and 0.6-0.8 MWh/Adt of power;
- Integrated bleached kraft pulp and paper mills (e.g. uncoated fine paper): 14-20 GJ/Adt process heat and 1.2-1.5 MWh/Adt of power;
- Integrated unbleached kraft pulp and paper mills (e.g. kraftliner): 14-17.5 GJ/Adt process heat and 1-1.3 MWh/Adt power.

BAT for Sulphite pulp processing (Chapter 3)

The production of sulphite pulp is much smaller than the production of kraft pulp. The pulping process can be carried out with different cooking chemicals. The document focuses on magnesium sulphite pulping because of its importance in terms of capacity and numbers of mills running in Europe.

In many respects the kraft and sulphite processes have similarities not least regarding the possibilities of applying different internal and external measures to reduce emissions to environment. The major differences between the two chemical pulping processes from an environmental point-of-view are to be found in the chemistry of the cooking process, the chemical preparation and recovery system and the reduced bleaching required because of better initial brightness of sulphite pulp.

As in kraft pulping also in sulphite pulping the wastewater effluents and the emissions to air are the centres of interest. The main raw materials are renewable resources (wood and water) and chemicals for cooking and bleaching. Emissions to water are dominated by organic substances. Some compounds discharged from mills show toxic effects on aquatic organisms. Emissions of coloured substances may effect the living species in the recipient negatively. Emissions of nutrients (nitrogen and phosphorus) can contribute to eutrophication in the recipient. Metals extracted from the wood are discharged in low concentrations but due to high flows the load can be of significance. For bleaching of sulphite pulp the use of chlorine containing bleaching chemicals is normally avoided, i.e. TCF-bleaching is applied. Therefore, the effluents from the bleach plant do not contain relevant amounts of organically bound chlorine compounds.

Information on techniques to consider in the determination of BAT is generally much weaker for sulphite mills than for kraft pulp mills. Therefore, from the limited information supplied by the members of the TWG in the course of the information exchange on BAT only a few techniques could be described to the same extent as for kraft pulping. The available data set is relatively small. This could be partly compensated because of the inherent similarities between sulphite and kraft pulping. A number of techniques for pollution prevention and control for kraft pulping are also valid in most respects for sulphite pulping. Where there are particular differences between kraft and sulphite technologies attempts have been made to collect the necessary information. However, only information from Austria, Germany and Sweden could be used for the description of the techniques and the conclusion on BAT. A significant reduction of emissions to water has been achieved by in-process measures.

Best available techniques for sulphite pulp mills are considered to be:

- Dry debarking of wood;
- Increased delignification before the bleach plant by extended or modified cooking;
- Highly efficient brown stock washing and closed cycle brown stock screening;
- Effective spill monitoring containment and recovery system;
- Closure of the bleach plant when sodium based cooking processes is being used;
- TCF bleaching;
- Neutralising of weak liquor before evaporation followed by re-use of most condensate in the process or anaerobic treatment;
- For prevention of unnecessary loading and occasionally upsets in the external effluent treatment due to process cooking and recovery liquors and dirty condensates sufficiently large buffer tanks for storage are considered as necessary;
- In addition to process-integrated measures, primary and biological treatment is considered BAT for sulphite pulp mills.

For bleached sulphite pulp mills the BAT emission levels to water that are associated with the use of a suitable combination of these techniques are the following:

	Flow m³/Adt	COD kg/Adt	BOD kg/Adt	TSS kg/Adt	AOX kg/Adt	Total N kg/Adt	Total P kg/Adt
Bleached pulp	40 - 55	20-30	1-2	1.0-2.0	-	0.15-0.5	0.02-0.05

These emission levels refer to yearly averages. The waste water flow is based on the assumption that cooling water and other clean water are discharged separately. The values refer to the contribution of pulping only. In integrated mills emissions from papermaking (see Chapter 6) have to be added according to product mix manufactured.

Off-gas emissions from different sources are considered as the other relevant environmental issue. Emissions to the atmosphere originate from different sources the most relevant being the recovery boiler and the bark furnace. Less concentrated SO₂ containing releases originate from washing and screening operations and from vents of the evaporators and from various tanks. A part of these emissions escapes diffuse from various points of the process. Emissions consist mainly of sulphur dioxide, nitrogen oxides and dust.

Best available techniques for reducing emissions to air are:

- Collection of concentrated SO₂ releases and recovery in tanks with different pressure levels;
- Collection of diffuse SO₂ releases from various sources and introducing them in the recovery boiler as combustion air;
- Control of SO₂ emissions from the recovery boiler(s) by use of electrostatic precipitators and multi-stage flue gas scrubbers and collection and scrubbing of various vents;
- Reduction of SO₂ emissions from auxiliary boilers by using bark, gas, low sulphur oil and coal or controlling S emissions;
- Reduction of odorous gases by efficient collection systems;
- Reduction of NO_x emissions from the recovery boiler and from auxiliary boilers by controlling the firing conditions;
- Cleaning of the auxiliary boilers flue gases with efficient electrostatic precipitators to mitigate dust emissions;
- Emission optimised incineration of residues with energy recovery.

The BAT emission levels from the process associated with a combination of these techniques are depicted in the following table. Emissions from auxiliary boilers e.g. due to production of

steam used for drying of pulp and/or paper are not included. For these installations emission levels that are associated with BAT are presented in the section BAT for auxiliary boilers further below.

	Dust kg/Adt	SO₂ (as S) kg/Adt	NO_x (as NO₂) kg/Adt
Bleached pulp	0.02 - 0.15	0.5 - 1.0	1.0 – 2.0

These emission levels refer to yearly averages and standard conditions. The values refer to the contribution of the pulp production only. That means that in integrated mills the figures for the process emissions are related to the pulp production only and do not include air emissions from auxiliary boilers or power plants that might be operated to provide the energy needed for paper production.

Best available techniques for reducing waste is to minimise the generation of solid waste and recover, recycle and re-use these materials, wherever practicable. Separate collection and intermediate storage of waste fractions at source can be beneficial to meet this aim. When the collected waste is not re-usable in the process, external utilisation of residuals/waste as substitutes or incineration of organic materials in suitably designed boilers with energy recovery is considered as BAT.

In order to reduce the consumption of fresh steam and electric power, and to increase the generation of steam and power internally, a number of measures are available. Sulphite pulp mills are heat and power self-sufficient by using the heat value of the thick liquor, bark and wood waste. In integrated mills there is a need for additional steam and electricity that is generated in on- or off-site power plants. Integrated sulphite pulp and paper mills consume 18 - 24 GJ/Adt process heat and 1.2 - 1.5 MWh/Adt electricity.

BAT for Mechanical pulping and chemi-mechanical pulping (Chapter 4)

In mechanical pulping the wood fibres are separated from each other by mechanical energy applied to the wood matrix. The objective is to maintain the main part of the lignin in order to achieve high yield with acceptable strength properties and brightness. There are two main processes to be distinguished:

- The groundwood process where logs are pressed against a rotating grinder stone with simultaneous action of water and:
- refiner mechanical pulp that is produced by defiberizing wood chips between disc refiners.

The characteristics of the pulp can be affected by increasing the process temperature and, in the case of refining, by the chemical pre-treatment of the wood chips. The pulping process in which the wood is pre-softened with chemicals and refined under pressure is called chemo-thermo-mechanical pulping and is also covered by this document.

Most mechanical pulping is integrated with paper manufacture. Therefore, the emission levels associated with the use of BAT are given for integrated pulp and paper mills (except for CTMP).

In mechanical pulping and chemi-mechanical pulping the wastewater effluents and consumption of electricity for the drives of grinders or refiners are the centres of interest. The main raw materials are renewable resources (wood and water) and some chemicals for bleaching (for CTMP also for chemical pre-treatment of the chips). As processing aids and to improve the product properties (paper auxiliaries) various additives are applied during paper manufacturing. Emissions to water are dominated organic substances that are lost in the water phase in the form of dissolved or dispersed substances. If mechanical pulp is bleached in one or two alkaline

peroxide steps the releases of organic pollutants increase significantly. Peroxide bleaching result in additional COD-loads before treatment of about 30 kg O₂/Adt. Some compounds discharged from mills show toxic effects on aquatic organisms. Emissions of nutrients (nitrogen and phosphorus) can contribute to eutrophication in the recipient. Metals extracted from the wood are discharged in low concentrations but due to high flows the load can be of significance.

A big part of techniques to consider in the determination of BAT refer to the reduction of emissions to water. In mechanical pulping processes the water systems are usually quite close. Surplus clarified waters from the paper machine are usually used to compensate for the water leaving the circuit with the pulp and the rejects.

Best available techniques for mechanical pulp mills are considered to be:

- Dry debarking of wood
- Minimisation of reject losses by using efficient reject handling stages
- Water recirculation in the mechanical pulping department
- Effective separation of the water systems of the pulp and paper mill by use of thickeners
- Counter-current white water system from paper mill to pulp mill depending on the degree of integration
- Use of sufficiently large buffer tanks for storage of concentrated wastewater streams from the process (mainly for CTMP)
- Primary and biological treatment of the effluents, and in some cases also flocculation or chemical precipitation.

For CTMP mills a combination of an anaerobic and aerobic treatment of the wastewater is also regarded as an efficient treatment system. Finally, evaporation of the most contaminated wastewater and burning of the concentrate plus activated sludge treatment of the rest might be especially an interesting solution for upgrading mills.

The emission levels that are associated with a suitable combination of these techniques are presented separately for non-integrated CTMP mills and integrated mechanical pulp and paper mills. These emission levels refer to yearly average values.

	Flow m ³ /t	COD kg/t	BOD kg/t	TSS kg/t	AOX kg/t	Total N kg/t	Total P kg/t
Non-integrated CTMP mills (contribution of pulping only)	15-20	10-20	0.5-1.0	0.5-1.0	-	0.1-0.2	0.005-0.01
Integrated mechanical pulp & paper mills (such as newsprint, LWC and SC paper mills)	12-20	2.0-5.0	0.2-0.5	0.2-0.5	< 0.01	0.04-0.1	0.004-0.01

In case of integrated CTMP mills, emissions from papermaking (see Chapter 6) have to be added according to product mix manufactured.

For integrated mechanical pulp and paper mills the emission levels refer to both pulping and papermaking and are related to kg pollutant per tonne of paper produced.

In mechanical pulping, the ranges for COD depend especially on the share of the fibre furnish that is bleached with peroxide because peroxide bleaching results in higher initial loads of organic substances before treatment. Therefore, the upper end of the emission range associated with BAT is valid for paper mills with a high proportion of peroxide bleached TMP.

Emissions to the atmosphere are mainly emissions from heat and electricity generation in auxiliary boilers and volatile organic carbons (VOC). Sources of VOC emissions are chip heaps and evacuation of air from chests from wood-chip washing and from other chests and condensates from the steam recovery from refiners that are contaminated with volatile wood components. A part of these emissions escapes diffuse from various points of the process.

Best available techniques for reducing emissions to air is efficient heat recovery from refiners and abatement of VOC emissions from contaminated steam. Apart from VOC emissions, mechanical pulping generate releases to the atmosphere that are not process-related but caused by energy generation on-site. Heat and power is produced by combustion of different types of fossil fuels or renewable wood residuals like bark. BAT for auxiliary boilers is discussed further below.

Best available techniques for reducing waste is to minimise the generation of solid waste and recover, recycle and re-use these materials, wherever practicable. Separate collection and intermediate storage of waste fractions at source can be beneficial to meet this aim. When the collected waste is not re-usable in the process external utilisation of residuals/waste as substitutes or incineration of organic materials in suitably designed boilers with energy recovery is considered as BAT, thus minimising the disposal of rejects to landfill.

In order to reduce the consumption of fresh steam and electric power a number of measures are available. Energy efficient mechanical pulp and paper mills consume heat and power as follows:

- Non-integrated CTMP: For pulp drying recovered process heat can be used i.e. no primary steam is needed. The power consumption is 2 - 3 MWh/ADt.
- Integrated newsprint mills consume 0 - 3 GJ/t process heat and 2 - 3 MWh/t of electricity. The steam demand depends on the fibre furnish and the degree of steam recovery from the refiners.
- Integrated LWC paper mills consume 3 - 12 GJ/t process heat and 1.7 - 2.6 MWh/t of electricity. It has to be noted that the fibre furnish of LWC consists usually only of about one third of PGW or TMP the rest being bleached kraft pulp and fillers and coating colours. If the production of bleached kraft pulp is carried out at the same site (integrated) the contribution of the energy demand of kraft pulping have to be added according to fibre furnish mix manufactured.
- Integrated SC paper mills consume 1 - 6 GJ/t process heat and 1.9 - 2.6 MWh/t of electricity.

BAT for Recycled fibre processing (Chapter 5)

Recovered fibre has become an indispensable raw material for the paper manufacturing industry because of the favourable price of recovered fibres in comparison with the corresponding grades of virgin pulp and because of the promotion of recovered paper recycling by many European countries. The recovered paper processing systems vary according to the paper grade to be produced e.g. packaging paper, newsprint, testliner, or tissue paper and the type of furnish used. Generally, recycled fibre (RCF) processes can be divided in two main categories:

- processes with exclusively mechanical cleaning i.e. without deinking. They comprise products like testliner, corrugating medium, board and cartonboard
- processes with mechanical and chemical unit processes i.e. with deinking. They comprise products like newsprint, tissue, printing and copy paper, magazine papers (SC/LWC), some grades of cartonboard or market DIP.

The raw materials for RCF based paper production consist mainly of recovered paper, water, chemical additives, and energy in the form of steam and power. Large quantities of water are used as process water and cooling water. As processing aids and to improve the product properties (paper auxiliaries) various additives are applied during paper manufacturing. The

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environmental impact of recovered paper processing comprises basically emissions to water, solid waste (especially if wash de-inking is applied as e.g. in tissue mills) and atmospheric emissions. Emissions to the atmosphere are mainly related to energy generation by combustion of fossil fuels in power plants.

Most recovered paper processing mills are integrated with paper manufacture. Therefore, the emission levels associated with the use of BAT are given for integrated mills.

A big part of techniques to consider in the determination of BAT refer to the reduction of emissions to water.

Best available techniques for recovered paper processing mills are considered to be:

- Separation of less contaminated water from contaminated one and recycling of process water;
- Optimal water management (water loop arrangement), water clarification by sedimentation, flotation or filtration techniques and recycling of process water for different purposes;
- Strict separation of water loops and counter-currents flow of process water;
- Generation of clarified water for de-inking plants (flotation);
- Installation of an equalisation basin and primary treatment;
- Biological effluent treatment. An effective option for de-inked grades and depending on the conditions also for non-de-inked grades is aerobic biological treatment and in some cases also flocculation and chemical precipitation. Mechanical treatment with subsequent anaerobic-aerobic biological treatment is the preferable option for non-deinked grades. These mills usually have to treat more concentrated wastewater because of higher degree of water circuit closure;
- Partial recycling of treated water after biological treatment. The possible degree of water recycling is depending on the specific paper grades produced. For non-deinked paper grades this technique is BAT. However, the advantages and drawbacks need to be carefully investigated and will usually require additional polishing (tertiary treatment).
- Treating internal water circuits

For integrated recovered paper mills, the emission levels associated with the use of a suitable combination of best available techniques are the following:

	Flow m³/t	COD kg/t	BOD kg/t	TSS kg/t	Total N kg/t	Total P kg/t	AOX kg/t
Integrated RCF paper mills without de-inking (e.g. wellenstoff, testliner, white topliner, cartonboard etc.)	< 7	0.5-1.5	<0.05-0.15	0.05-0.15	0.02-0.05	0.002-0.005	<0.005
RCF paper mills with de-inking (e.g. newsprint, printing & writing paper etc.)	8 - 15	2-4	<0.05-0.2	0.1-0.3	0.05-0.1	0.005-0.01	<0.005
RCF based tissue mills	8-25	2.0-4.0	<0.05-0.5	0.1-0.4	0.05-0.25	0.005-0.015	<0.005

The BAT emission levels refer to yearly averages and are presented separately for processes with and without de-inking. The waste water flow is based on the assumption that cooling water and other clean water are discharged separately. The values refer to integrated mills i.e. recovered paper processing and papermaking is carried out at the same site.

Common treatment of wastewater from a RCF paper mill or a consortium of RCF paper mills in the municipal wastewater treatment plant is also considered as BAT when the common treatment system is appropriate for dealing with paper mill effluents. The removal efficiencies of the common waste water treatment system should be calculated and the comparable removal efficiencies or concentrations of releases established before considering this option as BAT.

Air emissions in RCF based paper mills are mainly related to plants installed for the production of heat and in some cases for co-generation of electricity. Saving of energy corresponds therefore with reduction of air emissions. The power plants are usually standard boilers and can be treated like any other power plants. To decrease energy consumption and air emission the following measures are considered as BAT: Co-generation of heat and power, improving existing boilers and when equipment is replaced use of less energy consuming equipment. For emission levels associated with the use of BAT it is referred to the section BAT for auxiliary boilers further below.

Best available techniques for reducing waste are to minimise the generation of solid waste and recover, recycle and re-use these materials, wherever practicable. Separate collection and intermediate storage of waste fractions at source can be beneficial to meet this aim. When the collected waste is not re-usable in the process external utilisation of residuals/waste as substitutes or incineration of organic materials in suitably designed boilers with energy recovery is considered as BAT. Reduction of solid waste can be achieved by optimising the fibre recovery by upgrading of stock preparation plants, optimisation of the amount of cleaning stages in the stock preparation, application of dissolved air flotation (DAF) as in-line treatment of water-loops to recover fibres and fillers and to clarify process water. A balance between cleanliness of stock, fibre losses and energy requirements and costs has to be found and are usually depending on the paper grades. The reduction of the amount of solid waste to be landfilled is BAT. This can be achieved by efficient reject and sludge handling on-site (de-watering) to enhance dry solids content and subsequent incineration of sludge and/rejects with energy recovery. Produced ash can be used as raw material in the building materials industry. Different options for incineration of rejects and sludge are available. The applicability is limited by the size of the mill and to a certain extent by the fuel used for generation of steam and power respectively.

Energy efficient recovered paper mills consume process heat and power as follows:

- Integrated non-deinked RCF paper mills (e.g. testliner, fluting): 6 - 6.5 GJ/t process heat and 0.7 - 0.8 MWh/t of power;
- Integrated tissue mills with DIP plant: 7 - 12 GJ/t process heat and 1.2 - 1.4 MWh/t of power;
- Integrated newsprint or printing and writing paper mills with DIP plant: 4 - 6.5 GJ/t process heat and 1 - 1.5 MWh/t of power.

BAT for Papermaking and related processes (Chapter 6)

The manufacturing of fibres used for papermaking has been described in the Chapters 2 to 5. In Chapter 6 paper and board manufacturing is described independently from pulp manufacturing. This approach has been chosen because the same unit processes around the paper and board machine are required in every paper mill whether it is integrated with pulp production or not. The description of papermaking as part of integrated pulp mills would increase the complexity of the technical description. Finally, in numbers, most paper mills in Europe are non-integrated mills.

For integrated paper mills this chapter is relevant as far as the papermaking is concerned.

Paper is made from fibres, water and chemical additives. Furthermore, a lot of energy is needed to drive the whole process. Electric power is mainly consumed for the operation of various motor drives and for refining in stock preparation. Process heat is mainly used for heating of

water, other liquors, and air, evaporating water in the dryer section of the paper machine, and conversion of steam into electric power (in case of co-generation). Large quantities of water are used as process water and cooling water. As processing aids and to improve the product properties (paper auxiliaries) various additives may be applied during paper manufacturing.

The environmental issues of paper mills are dominated by emissions to water and by the consumption of energy and chemicals. Solid waste is also generated. Atmospheric emissions are mainly related to energy generation by combustion of fossil fuels in power plants.

Best available techniques for reducing emissions to water are

- Minimising water usage for different paper grades by increased recycling of process waters and water management;
- Control of potential disadvantages of closing up the water systems;
- Construction of a balanced white water, (clear) filtrate and broke storage system and use of constructions, design and machinery with reduced water consumption when practicable. This is normally when machinery or components are replaced or at rebuilds;
- Application of measures to reduce frequency and effects of accidental discharge;
- Collection and reuse of clean cooling and sealing waters or separate discharge;
- Separate pre-treatment of coating wastewaters;
- Substitution of potentially harmful substances by use of less harmful alternatives;
- Effluent treatment of wastewater by installation of an equalisation basin;
- Primary treatment, secondary biological, and/or in some cases, secondary chemical precipitation or flocculation of wastewater. When only chemical treatment is applied the discharges of COD will be somewhat higher but mainly made up of easily degradable matter.

For non-integrated paper mills the emissions levels that are associated with the use of BAT are presented for uncoated and coated fine paper and tissue separately in the table below. However, the differences between the paper grades are not very distinct.

Parameters	Units	Uncoated fine paper	Coated fine paper	Tissue
BOD ₅	kg/t of paper	0.15-0.25	0.15-0.25	0.15-0.4
COD	kg/t of paper	0.5-2	0.5-1.5	0.4-1.5
TSS	kg/t of paper	0.2-0.4	0.2-0.4	0.2-0.4
AOX	kg/t of paper	< 0.005	< 0.005	< 0.01
Total P	kg/t of paper	0.003-0.01	0.003-0.01	0.003-0.015
Total N	kg/t of paper	0.05-0.2	0.05-0.2	0.05-0.25
Flow	m ³ /t of paper	10-15	10-15	10-25

The BAT emission levels refer to yearly averages and exclude the contribution of pulp manufacturing. Although these values refer to non-integrated mills they can also be used to approximate emissions caused by papermaking units in integrated mills. The waste water flow is based on the assumption that cooling water and other clean water are discharged separately.

Common treatment of wastewater from a paper mill or a consortium of paper mills in the municipal wastewater treatment plant is also considered as BAT when the common treatment system is appropriate for dealing with paper mill effluents. The removal efficiencies of the common wastewater treatment system should be calculated and the comparable removal efficiencies or concentrations of releases established before considering this option as BAT.

Air emissions from non-integrated paper mills are mainly related to steam boilers and power plants. These plants are generally standard boilers and do not differ from any other combustion

plants. It is assumed that they are regulated like any other auxiliary boiler of the same capacity (see below).

BAT concerning solid waste is the minimisation the generation of solid waste and recovery, re-use and re-cycle of re-usable materials as far as possible. Separate collection of waste fractions at source and intermediate storage of residuals/waste can be beneficial to allow for a greater proportion to be reused or recycled rather than landfilled. Reduction of fibre and filler losses, the application of ultra-filtration for coating wastewater recovery (only for coated grades), efficient de-watering of the residues and sludge to high dry solids are further available techniques. BAT is the reduction of the amount of waste to be landfilled by identification of possibilities for recovery operations and - if feasible - utilisation of waste for material recycling or incineration with energy recovery.

In general in this sector BAT is considered to be the use of energy efficient technologies. A lot of options for energy saving in many stages within the manufacturing process are available. Usually these measures are linked with investments to replace, rebuild or upgrade process equipment. It should be noticed that energy saving measures are mostly not applied only for energy saving. Production efficiency, improvement of product quality and reduction of overall costs is the most important basis for investments. Energy savings can be achieved by implementation of a system for monitoring energy usage and performance, more effective dewatering of the paper web in the press section of the paper machine by using wide nip (shoe) pressing technologies and use of other energy efficient technologies as e.g. high consistency slushing, energy efficient refining, twin wire forming, optimised vacuum systems, speed adjustable drives for fans and pumps, high efficiency electric motors, well sized electric motors, steam condensate recovery, increasing size press solids or exhaust air heat recovery systems. A reduction of direct use of steam can be achieved by careful process integration by using pinch analysis.

Energy efficient non-integrated paper mills consume heat and power as follows:

- Non-integrated uncoated fine paper mills have a process heat demand of 7 - 7.5 GJ/t and a power demand of 0.6 - 0.7 MWh/t;
- Non-integrated coated fine paper mills have a process heat demand of 7 - 8 GJ/t and a power demand of 0.7 - 0.9 MWh/t;
- Non-integrated tissue mills based on virgin fibre have a process heat demand of 5.5 - 7.5 GJ/t and a power demand of 0.6 - 1.1 MWh/t.

BAT for auxiliary boilers

Depending on the actual energy balance of the given pulp or paper mill, the type of external fuels used and the fate of possible biofuels as bark and wood-waste there are atmospheric emissions from auxiliary boilers to consider. Pulp and paper mills manufacturing pulp from virgin fibres are normally operating bark boilers. For non-integrated paper mills and RCF paper mills air emissions are mainly related to steam boilers and/or power plants. These plants are generally standard boilers and do not differ from any other combustion plant. It is assumed that they are regulated like any other installation of the same capacity. Therefore, generally acknowledged BAT for auxiliary boilers are only briefly mentioned in this document. Those techniques are:

- application of cogeneration of heat and power if the heat/power-ratio allows it
- use of renewable sources as fuel such as wood or wood waste, if generated, to reduce the emissions of fossil CO₂
- control of NO_x emissions from auxiliary boilers by controlling the firing conditions, and installation of low-NO_x burners
- reducing SO₂ emissions by using bark, gas or low sulphur fuels or controlling S emissions
- In auxiliary boilers burning solid fuels efficient ESPs (or bag filters) are used for the removal of dust.

Executive Summary

BAT associated emission levels from auxiliary boilers in pulp and paper industry that incinerate different kind of fuels are summarized in the table below. The values refer to yearly average values and standard conditions. However, the total product specific releases to air are very site specific (e.g. type of fuel, size and type of installation, integrated or non-integrated mill, production of electricity).

Released substances	Coal	Heavy fuel oil	Gas oil	Gas	Biofuel (e.g. bark)
mg S/MJ fuel input	100 - 200 ¹ (50 - 100) ⁵	100 - 200 ¹ (50-100) ⁵	25-50	<5	< 15
mg NO _x /MJ fuel input	80 - 110 ² (50-80 SNCR) ³	80 - 110 ² (50-80 SNCR) ³	45-60 ²	30 -60 ²	60 -100 ² (40-70 SNCR) ³
mg dust/Nm ³	10 - 30 ⁴ at 6% O ₂	10 - 40 ⁴ at 3 % O ₂	10-30 3% O ₂	< 5 3% O ₂	10 - 30 ⁴ at 6% O ₂
Notes: 1) Sulphur emissions of oil or coal fired boilers depend on the availability of low-S oil and coal. Certain reduction of sulphur could be achieved with injection of calcium carbonate. 2) Only combustion technology is applied 3) Secondary measures as SNCR are also applied; normally only larger installations 4) Associated values when efficient electrostatic precipitators are used 5) When a scrubber is used; only applied to larger installations					

It has to be noted that auxiliary boilers within the pulp and paper industry are of a very variable size (from 10 to above 200 MW). For the smaller only the use of low-S fuel and combustion techniques can be applied at reasonable costs while for the larger also control measures. This difference is reflected in the table above. The higher range is considered BAT for smaller installations and is achieved when only quality of fuel and internal measures are applied; the lower levels (in brackets) are associated with additional control measures like SNCR and scrubbers and are regarded as BAT for larger installations.

Use of chemicals and additives

In the pulp and paper industry a large number of chemicals are used depending on the paper grade produced, the process design and operation and the product qualities to be achieved. On the one hand process chemicals for the production of pulp are required, on the other hand chemical additives and auxiliaries are applied in paper production. Chemical additives are used to give paper various characteristics while chemical auxiliaries are used to increase efficiency and reduce disruption of the production process.

For chemical usage the availability of a database for all used chemicals and additives and the application of the principle of substitution is considered as BAT. That means that less hazardous products are used when available. Measures to avoid accidental discharges to soil and water from handling and storage of chemicals are applied.

Degree of consensus

This BREF has met support from most members of the TWG and participants at the 7th meeting of the Information Exchange Forum. However, CEPI – representing the pulp and paper industry – and a few Member States did not express their full support for this final draft and contested some of the conclusions presented in the document. Mention is made below of some of the key areas of contention and Chapter 7 provides further detail.

CEPI and one Member State took the view that the economic difference between new/existing and large/small mills had not been sufficiently considered and that clear differences should have been established in the BREF. Furthermore, CEPI and three Member States believe that a typical mill will not be able to, at the same time, reach all the presented emission and consumption levels associated with the use of a suitable combination of the various techniques that are considered as BAT. In their view, no sufficiently integrated assessment of all

parameters has been carried out. Contrary to this view, however, mills have been identified who do achieve all the presented levels at the same time and this minority view above was not shared by most members of the TWG.

Apart from these general issues, there are also a few specific issues where the final conclusions did not receive unanimous support in the TWG. CEPI and two Member States consider that for TSS for bleached kraft pulping, the upper end of the range associated with the use of BAT should be 2.0 kg/Adt instead of 1.5 kg/Adt. CEPI and one Member State also consider that some of the ranges associated with the use of BAT for the various paper grades are too stringent. Conversely, there are TWG members who consider that certain concluded BAT associated levels are excessively lenient bearing in mind the more recent achievements of some pulp and paper mills.

The European Environmental Bureau – representing environmental organisations – expressed some further dissenting views, including that ECF-bleaching in kraft pulp mills does not meet the BAT criteria regarding the precautionary and the prevention principles and that, in general, tertiary treatment of effluents should include treatment with ozone, peroxide or UV radiation followed by a biofiltration step.

PREFACE

1. Status of this document

Unless otherwise stated, references to “the Directive” in this document means the Council Directive 96/61/EC on integrated pollution prevention and control. This document forms part of a series presenting the results of an exchange of information between EU Member States and industries concerned on best available techniques (BAT), associated monitoring, and developments in them. It is published by the European Commission pursuant to Article 16(2) of the Directive, and must therefore be taken into account in accordance with Annex IV of the Directive when determining “best available techniques”.

2. Relevant legal obligations of the IPPC Directive and the definition of BAT

In order to help the reader understand the legal context in which this document has been drafted, some of the most relevant provisions of the IPPC Directive, including the definition of the term “best available techniques”, are described in this preface. This description is inevitably incomplete and is given for information only. It has no legal value and does not in any way alter or prejudice the actual provisions of the Directive.

The purpose of the Directive is to achieve integrated prevention and control of pollution arising from the activities listed in its Annex I, leading to a high level of protection of the environment as a whole. The legal basis of the Directive relates to environmental protection. Its implementation should also take account of other Community objectives such as the competitiveness of the Community’s industry thereby contributing to sustainable development.

More specifically, it provides for a permitting system for certain categories of industrial installations requiring both operators and regulators to take an integrated, overall look at the polluting and consuming potential of the installation. The overall aim of such an integrated approach must be to improve the management and control of industrial processes so as to ensure a high level of protection for the environment as a whole. Central to this approach is the general principle given in Article 3 that operators should take all appropriate preventative measures against pollution, in particular through the application of best available techniques enabling them to improve their environmental performance.

The term “best available techniques” is defined in Article 2(11) of the Directive as “the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole.” Article 2(11) goes on to clarify further this definition as follows:

“techniques” includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;

“available” techniques are those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator;

“best” means most effective in achieving a high general level of protection of the environment as a whole.

Furthermore, Annex IV of the Directive contains a list of “considerations to be taken into account generally or in specific cases when determining best available techniques ... bearing in mind the likely costs and benefits of a measure and the principles of precaution and prevention”. These considerations include the information published by the Commission pursuant to Article 16(2).

Competent authorities responsible for issuing permits are required to take account of the general principles set out in Article 3 when determining the conditions of the permit. These conditions must include emission limit values, supplemented or replaced where appropriate by equivalent parameters or technical measures. According to Article 9(4) of the Directive, these emission limit values, equivalent parameters and technical measures must, without prejudice to compliance with environmental quality standards, be based on the best available techniques, without prescribing the use of any technique or specific technology, but taking into account the technical characteristics of the installation concerned, its geographical location and the local environmental conditions. In all circumstances, the conditions of the permit must include provisions on the minimisation of long-distance or transboundary pollution and must ensure a high level of protection for the environment as a whole.

Member States have the obligation, according to Article 11 of the Directive, to ensure that competent authorities follow or are informed of developments in best available techniques.

3. Objective of this Document

Article 16(2) of the Directive requires the Commission to organise “an exchange of information between Member States and the industries concerned on best available techniques, associated monitoring and developments in them”, and to publish the results of the exchange.

The purpose of the information exchange is given in recital 25 of the Directive, which states that “the development and exchange of information at Community level about best available techniques will help to redress the technological imbalances in the Community, will promote the world-wide dissemination of limit values and techniques used in the Community and will help the Member States in the efficient implementation of this Directive.”

The Commission (Environment DG) established an information exchange forum (IEF) to assist the work under Article 16(2) and a number of technical working groups have been established under the umbrella of the IEF. Both IEF and the technical working groups include representation from Member States and industry as required in Article 16(2).

The aim of this series of documents is to reflect accurately the exchange of information which has taken place as required by Article 16(2) and to provide reference information for the permitting authority to take into account when determining permit conditions. By providing relevant information concerning best available techniques, these documents should act as valuable tools to drive environmental performance.

4. Information Sources

This document represents a summary of information collected from a number of sources, including in particular the expertise of the groups established to assist the Commission in its work, and verified by the Commission services. All contributions are gratefully acknowledged.

5. How to understand and use this document

The information provided in this document is intended to be used as an input to the determination of BAT in specific cases. When determining BAT and setting BAT-based permit conditions, account should always be taken of the overall goal to achieve a high level of protection for the environment as a whole.

The rest of this section describes the type of information that is provided in each section of the document.

Chapters 1 provide general information on the industrial sector concerned and the first sections of Chapter 2 to 6 give information on the industrial processes used within the sector. Data and information concerning current emission and consumption levels are then presented in the second sections of Chapter 2 to 6 reflecting the situation in existing installations at the time of writing.

The third sections of Chapter 2 to 6 describe in more detail the emission reduction and other techniques that are considered to be most relevant for determining BAT and BAT-based permit conditions. This information includes the consumption and emission levels considered achievable by using the technique, some idea of the costs and the cross-media issues associated with the technique, and the extent to which the technique is applicable to the range of installations requiring IPPC permits, for example new, existing, large or small installations. Techniques that are generally seen as obsolete are not included.

A conclusion section on Best Available techniques in each of Chapter 2 to 6 presents the techniques and the emission and consumption levels that are considered to be compatible with BAT in a general sense. The purpose is thus to provide general indications regarding the emission and consumption levels that can be considered as an appropriate reference point to assist in the determination of BAT-based permit conditions or for the establishment of general binding rules under Article 9(8). It should be stressed, however, that this document does not propose emission limit values. The determination of appropriate permit conditions will involve taking account of local, site-specific factors such as the technical characteristics of the installation concerned, its geographical location and the local environmental conditions. In the case of existing installations, the economic and technical viability of upgrading them also needs to be taken into account. Even the single objective of ensuring a high level of protection for the environment as a whole will often involve making trade-off judgements between different types of environmental impact, and these judgements will often be influenced by local considerations.

Although an attempt is made to address some of these issues, it is not possible for them to be considered fully in this document. The techniques and levels presented in the conclusion section on Best Available Techniques in each of Chapters 2 to 6 will therefore not necessarily be appropriate for all installations. On the other hand, the obligation to ensure a high level of environmental protection including the minimisation of long-distance or transboundary pollution implies that permit conditions cannot be set on the basis of purely local considerations. It is therefore of the utmost importance that the information contained in this document is fully taken into account by permitting authorities.

Since the best available techniques change over time, this document will be reviewed and updated as appropriate. All comments and suggestions should be made to the European IPPC Bureau at the Institute for Prospective Technological Studies at the following address:

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Best Available Techniques in the Pulp and Paper industry

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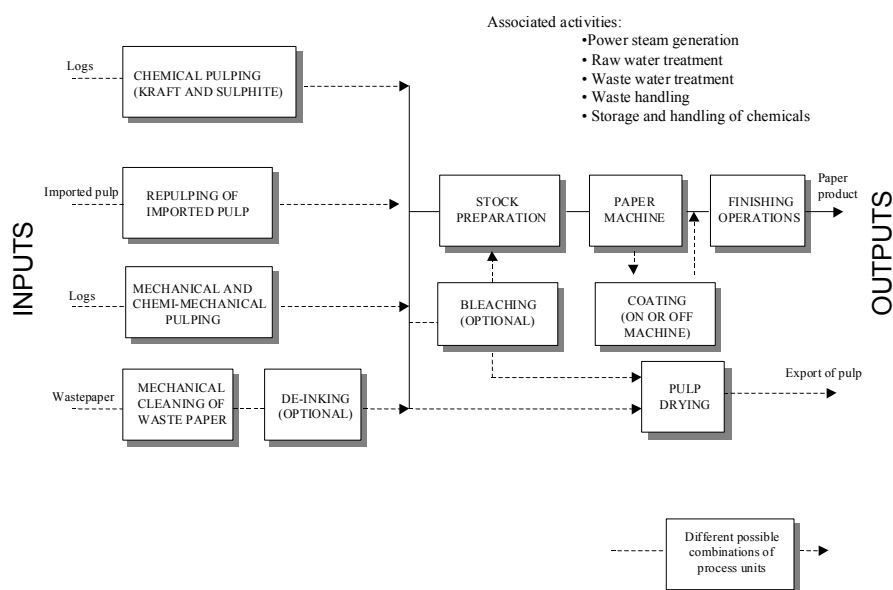
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SCOPE

A paper mill may simply reconstitute pulp made elsewhere or may be integrated with the pulping operations on the same site. That is to say, the activities involved in pulping and recovered paper processing and those involved in papermaking may be undertaken separately or in combination on the same site. Both pulp mills and paper mills are operated in non-integrated and integrated ways. Mechanical pulping and recycled fibre processing is usually an integrated part of papermaking but has now also become a stand-alone activity.

This BREF covers the processes involved in the production of pulp and paper in integrated pulp and paper mills as well as for non-integrated pulp mills (market pulp) and non-integrated papermills using purchased pulp for paper production.

The main operations covered in this BREF are illustrated in the figure below.



The main operations covered by the descriptions are:

- Chemical pulping
 - Kraft (sulphate) pulping process
 - Sulphite pulping process
- Mechanical and chemi-mechanical pulping
- Recovered paper processing with and without de-inking
- Papermaking and related processes

Upstream processes such as forestry management, production of process chemicals off-site and transport of materials used and downstream activities, such as paper converting and printing, are not included in this BREF. The latter nevertheless have an influence on the quality of the recovered paper and the processes for preparation of used paper products.

There are also a number of environmentally relevant processes and operations, which do not specifically relate to the pulp and paper production and so will only be mentioned briefly in this document. These include:

- Occupational safety and hazard risk
- Raw water treatment
- Heat and power plants
- Storage and handling of chemicals
- Cooling and vacuum systems
- Monitoring of emission

1 GENERAL INFORMATION

1.1 Paper consumption in Europe

In developed societies the use of a multitude of paper and board based products is everyday reality for most people. Paper as we know it today has been in existence for over two thousand years, and is competing successfully with modern electronic information media and advanced plastic and composite packaging materials. A look at the main functional uses of paper and board shows the diversity of products.

Functional use	Typical grade	Typical end products	Important trends
Information - collection - distribution - storing	- Newsprint - Coated and uncoated magazine (SC and LWC) - Coated and uncoated woodfree printing and writing	- Newspapers - Journals - Books - Computer printouts - Xerographic copies - Inserts - Illustrations	Increased use of multicolour printing and copying; Electronic media taking over banking and trading documents; Increased recycling as raw material; Increased use of additives.
Packaging -transportation -distribution -protection	- Liner - Sack - Corrugating medium - Folding box board - Liquid packaging board - Wrapping	- Bags - Boxes - Wrappings - Containers	Increased use for distribution of food; General increase in recycling of packaging materials; Increased use of composites.
Hygienic - personal care - cleanliness - disease prevention	Tissue - dry crepe - wet crepe	- Toilet tissue - Kitchen towels - Facial tissue - Napkins - Hand towels - Hospital clothing - Wipers	Use increases with general living standard; End of the chain for the recycling of fibres. Use of virgin fibre for top-end products
Speciality - a great variety	- Official papers - Filter paper - Fire resistant papers	- Notes - Stamps - Air filters - Coffee filters - Baking paper	An ever-increasing number of new applications.

Table 1.1: Functional use of paper and board
[Finnish BAT Report, 1997, modified by EIPPCB]

A trend not shown above is that more and more functions in many products are combined, such as printing on packages and towels.

The consumption of paper and board is strongly related to living standards and over long-term periods there is a strong correlation between the increase in the consumption of these products and the growth in the GNP (Gross National Product). As is shown in Table 1.2 there is a considerable variation in the world-wide consumption of paper per capita. Even within Europe there are big differences. The European countries with the highest paper consumption are Germany (23.4%), United Kingdom (17.5%), France (14.3%), Italy (12.6%), Spain (7.9%) and Netherlands (4.8%). It is expected that EU countries that are now below the EU average would increase their paper consumption to reach the present average. It can be predicted that paper manufacturing will be a growth industry for years to come.

Region	Country	Consumption of paper per capita [kg/year] ' 95	Paper consumption in 1000 t (1995)
Western Europe		171	65834
	Austria	192	1550
	Belgium	237	2663*
	Denmark	214	1134
	Finland	175	896
	France	164	9631
	Germany	194	15821
	Greece	82	857
	Ireland	102	361
	Italy	140	8076
	Luxembourg	168	* see Belgium
	Netherlands	201	3120
	Norway	176	756
	Portugal	82	802
	Spain	129	5147
	Sweden	210	1857
	United Kingdom	194	11288
Eastern Europe		19	
	USA	332	87409
	China	22	26499
	Indonesia	14	no data
	Japan	239	30019
	Brazil	35	5433
	Egypt	9	No data
Total world		49	276231
Note:			
* There was only a common figure for Belgium and Luxembourg available			

Table 1.2: Consumption of paper per capita 1995
[Pulp and Paper International (PPI), 1996], [Verband Deutscher Papierfabriken, Papier ' 97]

1.2 The European Pulp Industry

Europe plays an important role in the global pulp and paper industry; it is the second largest producer and consumer of paper and board, North America being the leader. Its role in pulp production is significant – the annual production of woodpulp is about 35 million t/a the amount produced representing about 1/5 of the world's total supply.

The pulp supply consists of market pulp producers and of companies using the bulk of their pulp output in their own integrated paper production and selling only the remaining part to the open market. In Western Europe, market pulp is supplied by a few large mills in Finland, Sweden, Portugal, Spain, Austria, Belgium and France. With respect to market pulp bleached kraft is the dominating grade making up more than three-quarters of whole production of 9 million tonnes. Of that, only 11.4 % sulphite pulp, 7% mechanical and semi-chemical pulp and 3.2% unbleached sulphate pulp were delivered to the open paper market.

Finland and Sweden are major producers of softwood and hardwood pulps, Portugal and Spain providing significant amounts of hardwood pulp grades. Practically all bleached softwood kraft pulp and nearly 90% of the bleached hardwood pulp used in Central Europe is market pulp. Some 3.5 million t/a of pulp come from Finland and Sweden, whereas Portugal and Spain export approximately 1.5 million tonnes of pulp annually to EC countries. The four biggest markets for market pulp are Germany, France, Italy and U.K.

The main grades of woodpulp for papermaking in 1996 across Europe were bleached sulphate (13 Mt/a corresponding to 40.8%) and mechanical & semi-chemical pulp (12.3 Mt/a corresponding to 38.3%) followed by 4.1 Mt/a unbleached sulphate (12.7%) and 2.4 Mt/a sulphite pulp (7.5%).

In terms of geographical distribution, Figure 1.1 and Figure 1.2 show how Sweden (30.2%) and Finland (29.9%) dominate the amount of woodpulp for papermaking. Iberia accounts for 9.4%, France for 8%, Norway for 7.0% and Germany for 5.6% of the woodpulp produced.

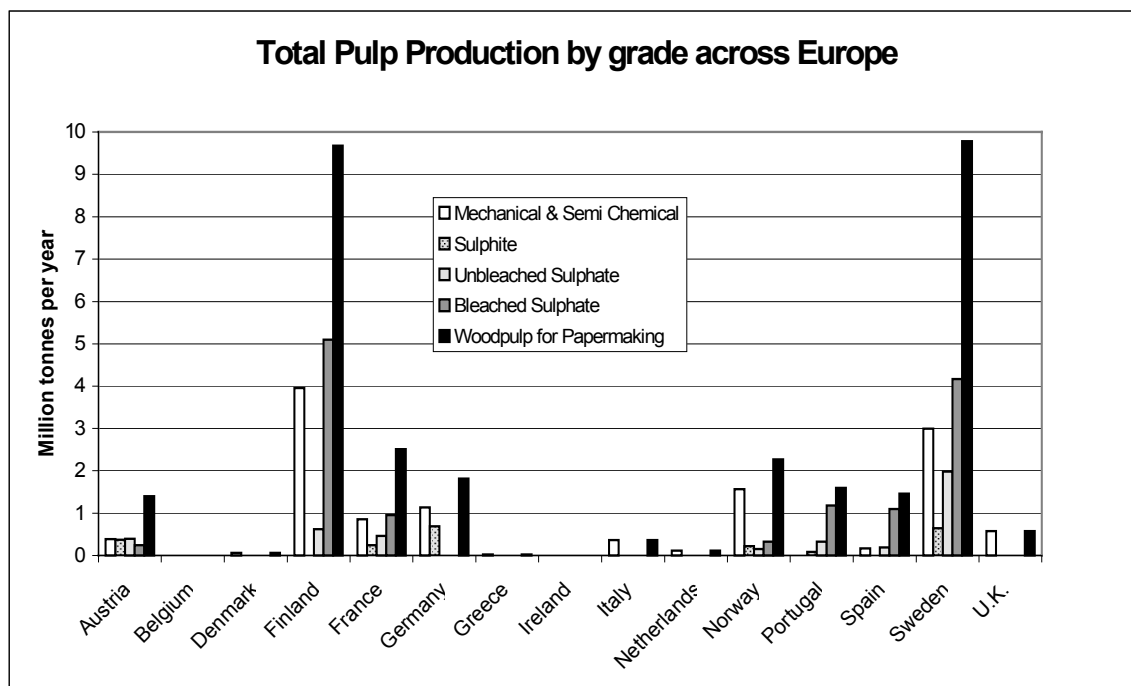


Figure 1.1: An overview of the industry distribution across Europe for pulp production [CEPI 1997, Annual Statistics 1996]

In Europe, relating to pulp grades most sulphate production (total: 67 mills) is located in Finland and Sweden with Spain, Portugal, France and Austria making up the balance. Most sulphite production (total: 24 mills) is located in Sweden, Germany, Austria and France with some more in Italy and Portugal.

In Western Europe, there are 101 mills producing mechanical pulp locating mainly in Finland, Germany, Sweden, France, Italy and Norway. The main producers of semi-chemical pulp (total: 23 mills) are Sweden, Finland, Norway and Italy.

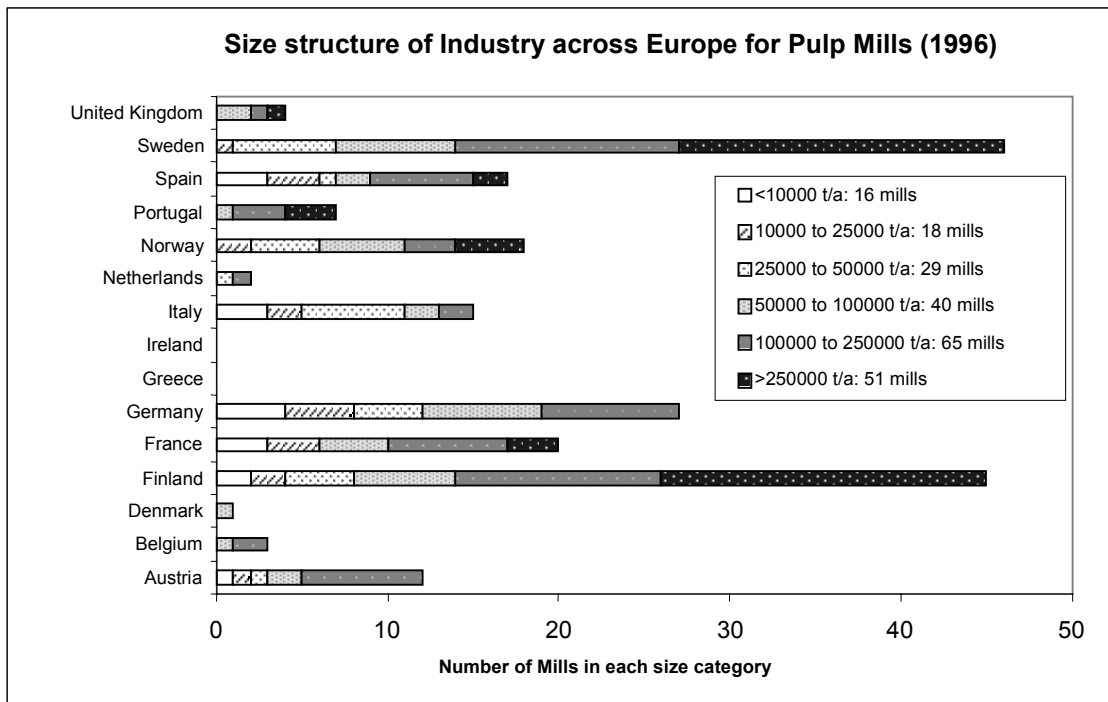


Figure 1.2: An overview of the mill size distribution across Europe for pulp production [CEPI 1997, Annual Statistics 1996]

Sweden and Finland have most of the larger mills over 250000 tonnes per year capacity and only a few small in the size range of less than 10000 tonnes per year. The average size of pulp mills in Western Europe is 180000 t/a [PPI, 1996]. Of the 222 pulp mills in Western Europe 74 are producing market pulp.

Besides virgin fibres, approximately 30 million t/a of recycled fibre – this corresponds to about 45 percent of the total fibres used for papermaking - are used in Western Europe. The utilisation rate is relatively high in newsprint (49%), tissue and other hygiene papers (66.9%), liner and fluting (85.9%) and cartonboards (52.2%). The production of recycled fibre is large in countries with a high population density and high per capita consumption, such as Germany, France, Italy and the Netherlands as shown in Figure 1.3. About two thirds of the recovered paper is used for non de-inking purposes (22 Mt) and about one third of the recovered paper (10 Mt) is used for de-inked paper grades like newsprint, other graphic papers and hygienic papers.

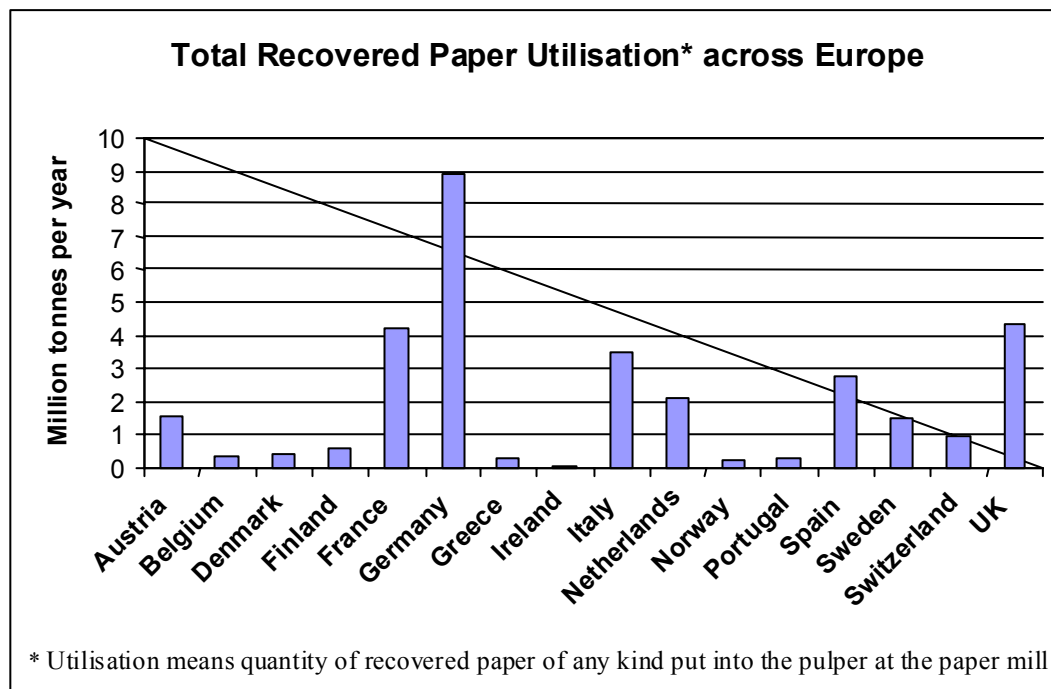


Figure 1.3: Recovered paper utilisation in Europe 1996
[CEPI, Annual statistics, 1996]

1.3 Geographical Distribution of the European Paper Industry

European paper production in 1996 totalled about 75 million tonnes, which corresponds to approximately a quarter of the world's total paper and board production. The term paper covers paper and paperboard of all grammages. The main paper producers are Germany (20.2%), Finland (14.2%), Sweden (12.4%), France (11.7%), Italy (9.6%) and UK (8.5%). In 1996 total exports amount to 41 million tonnes, imports come to 34 million tonnes (the figures of this section are mainly derived from [CEPI, Annual Statistics 1996]).

From the whole paper production about 40% was packaging; 13% was newsprint; 38% was other graphic papers (writing / printing) and 6% tissue. About half of the writing and printing production was coated (12.8 Mt/a).

The main producers of graphic papers are Germany and Finland followed by Sweden, France, Italy and U.K. Newsprint production has traditionally concentrated in Finland and Sweden. The increased use of recycled fibres by the Central European producers has caused the location of industry to shift to the large consumer centres, such as Germany. Due to the nature of newsprint as a commodity paper grade, production units are large per machine capacity, amounting to an average of 145000 t/a in total Western Europe.

Wood-containing printing and writing papers are mainly produced in Finland and Germany, which together account for approximately a 60% share of total production. Wood-containing papers are supplied by large-scale integrated mills.

In the manufacturing of woodfree printing and writing papers Germany, France, Finland, Italy, Sweden, Austria play the leading role with remarkable amount of paper produced in most other European countries. The majority of the market consists of a small number of concentrated producers.

Major producers of liner and fluting are Germany and France. They represent approximately 35% of total production. Recycled-fibre-based production, concentrating in Central Europe has grown more rapidly than virgin fibre based production.

For manufacturing of cartonboards both recovered and virgin fibres are used as raw material. Recycled fibre-based grades are dominantly supplied by the region of Central Europe, whereas the virgin fibre based folding boxboard and liquid packaging board production is concentrated in the Nordic countries. Production capacity consists of rather small mills and machines, the average machine capacity amounting to 33000 t/a, except for the mills located in Finland and Sweden, with an average machine capacity of 110000 t/a.

Tissue production is concentrated in four countries with France, Germany, Italy and the UK producing over 70% of Europe's tissue. Although there are over 60 companies in total producing tissue, three multinationals dominate; two American and one Swedish, with over 60% between them. There are still many small companies producing 10000 t/a or less, which are private or family owned businesses. The average machine size is very small, approximately 19000 t/a.

Figure 1.4 and Figure 1.5 show how paper manufacturing is more widely spread across Europe than the pulp mills.

The Figure 1.4 distinguishes graphic papers (newsprint, uncoated mechanical, uncoated woodfree, coated papers), sanitary and household papers (tissue and other hygienic papers) and packaging papers (case materials, folding boxboard, wrapping up to 150 g/m² and other papers mainly for packaging).

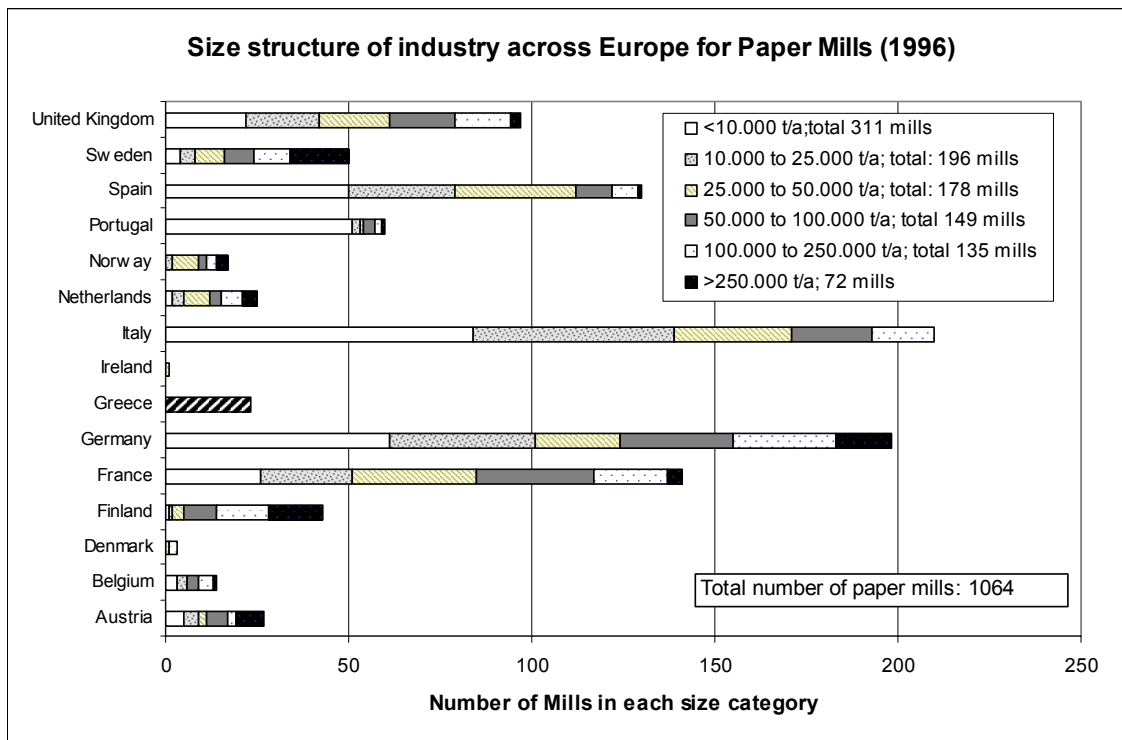


Figure 1.4: An overview of the industry distribution across Europe for paper production. No data was available on the size structure for the Greek paper mills [CEPI 1997, Annual Statistics 1996]

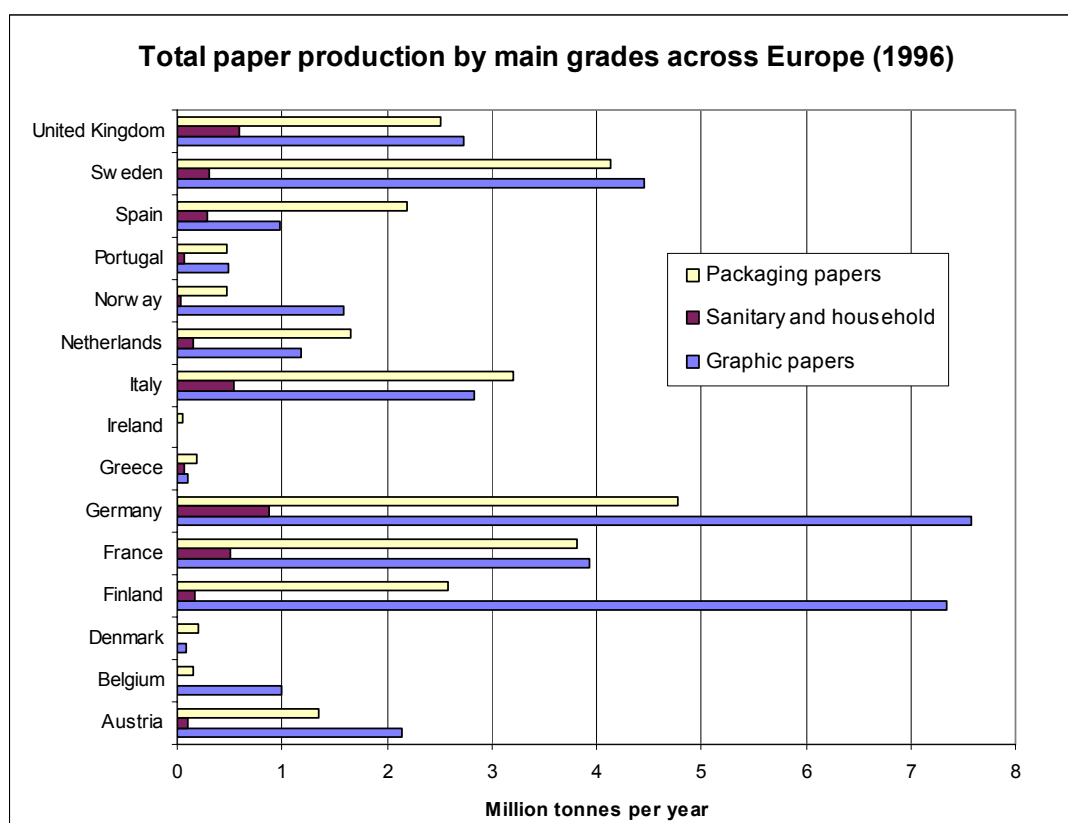


Figure 1.5: An overview of the mill size distribution across Europe for paper production [CEPI 1997, Annual Statistics 1996]

The total amount of paper mills in Western Europe accounts for 1064 most of them located in Italy, Germany, France and Spain representing together 679 mills. Only 66 very large mills are found in the category of >250000 tonnes per year but 342 mills in the small category of less than 10000 tonnes per year. Compared to pulp production a relatively high number of small and medium-sized paper manufacturing facilities are in operation.

About 30% of the paper mills are integrated with pulp production. Mechanical paper grades, like newsprint, SC and LWC, are usually integrated with mechanical pulp and often buy only small amounts of chemical pulp. Especially for recovered paper manufacturing the level of integration is high; nearly all recovered paper mills include recovered paper processing, some of them adding purchased pulp. However, fine paper production in Central Europe is mainly based on purchased pulp i.e. has a high share of non-integrated industry, whereas in Nordic countries paper mills have in many cases been built adjacent to a pulp mill.

Historically, pulp and paper mills were, and mostly still are located close to some body of water as the availability of water plays a major role in the production process. Rivers were used to generate the power needed for the pulping, to supply process water and as recipient for discharges from the mills. The waterways were used for the transportation of both raw materials and products. As consumption of paper and board increased, the size of the mills started to grow and frequently mills were developed close to the raw material source. The global marketing of pulp and the increased use of recycled fibre now tends to favour locating new paper mills close to the market.

1.4 Economic situation

Pulp and paper industries are going through a process of consolidation and globalisation, which has not yet reached a more stable status. The concentration process will lead to a reduction of companies. As a result of these moves, the industry's structure is changing markedly. In 25 years the number of paper machines in Europe has been reduced by about 60% while the total capacity has almost doubled. Many companies have grown by investing in new capacity but also by consolidating a large number of small obsolete paper and board mills. Thus, the European Paper Industry comprises a relatively small number of very large multi-national groups at one end of the scale yet a large number of small businesses at the other. The large number of relative small sized mills has developed niche strategies on the market.

There has been a significant change in the ownership structure in the last 10 years. Typical features in this development have been concentration of producers into bigger companies and integration of paper mills with the overseas pulp producers into bigger companies and integration of paper mills with the overseas pulp producers or acquisitions or financial co-operation relationships between European and overseas manufacturers. Companies from the United States, the Republic of South Africa or Indonesia have been integrated in or have established closer business relationships with European paper and board manufacturers. Likewise, there have been more regional and local integration trends inside some countries like Sweden and Finland. This reflects the global nature of the pulp and paper business today. By 2010 it is anticipated that the major markets of the USA, Europe and Japan are joined by Asia and in particular China and Indonesia. Southeast Asian markets are likely to grow and lead the world's paper consumption. International trade in paper and papermaking fibre will probably continue to be a feature of the industry with growth continuing in all main production regions. The fastest growth will be seen in the paper and paperboard trade as countries with surplus of fibre add value before exporting.

It is typical of the pulp and paper industry that extreme price variations occur e.g. the fluctuations of the price of market kraft pulp resulting from over-capacities and simultaneous temporarily demand drops. The price variation is not the same for all pulp and paper products. The closer a company is to the ultimate consumer, the smaller the price fluctuations of the product. For example, the price of pulp is much more volatile than that of tissue paper. The smaller the transactions and the smaller the customer the smaller the variations tend to be.

The overall demand for paper and board generally shows an upward trend with world-wide paper consumption increasing from 30 million tonnes in 1946 to 214 million tonnes in 1987. The rate of increase since 1987 was slightly reduced and world-wide total paper consumption in 1996 was approximately 280 million tonnes. Whether this growth will continue largely depends on developments around the world but the paper and board industry expects an average annual growth of about 3 percent up to the year 2010 although the changes would not be expected to be the same for different paper types.

Dominating pulp producers are the industrialised countries of the Northern Hemisphere, i.e. USA, Canada, Sweden, Japan and Finland. In Europe, Finland and Sweden, in particular, largely rely upon the revenue from exports of pulp and paper products. This is due to the high "nativeness" of these products i.e. very little import is needed in order to support the production.

1996 the Western European pulp and paper industry gives work to about 260000 employees i.e. arithmetically one person employed manufactures about 280 tonnes of paper per year. This marked the paper industry as a very capital-intensive branch.

1.5 Environmental issues of the pulp and paper industry

The pulp and paper industry has historically been considered a major consumer of natural resources (wood) and energy (fossil fuels, electricity), including water, and a significant contributor of pollutant discharges to the environment. However, in regions with a well-developed pulp and paper industry, by means of a number of environmental measures for improved emission control, internal as well as external ones, the emissions have typically been reduced by 80-90% or more on a specific basis since about 1980.

For pulp mills the main raw material is a renewable resource (wood). In some countries methods of sustainable forestry have been implemented. In 1996 the overall consumption of pulpwood used for pulping in Western Europe was 119.5 millions m³ (solid under bark). The consumption of raw materials for papermaking accounted to 81.6 Mt of which 45.9% were woodpulp, 39.3% recovered paper, 14.3% non-fibrous materials (like fillers, dyes etc.) and 0.5% other pulp (cotton, linen, bark, hemp, jute, straw and rags).

There is a development to close up water circuits in pulp and paper mills and a further reduction of discharges can be expected (towards effluent free mills). However, today there are no kraft mills operating full time, which completely recover all bleach plant effluent. One CTMP mill, a Na-based sulphite pulp mill and a few producers of corrugating medium and testliner using recycled fibre have realised zero effluents to water.

Since a few years, there is a debate about minimum-impact pulp manufacturing [Axegård, 1997]. This minimum-impact mill stand for a concept with a broader range of issues and challenges covering minimisation of resource consumption and emissions, minimising cross-media effects, taking into account economic aspects and working environment.

In recent years, pulp mills caused serious emissions of sulphur (acidification) but during the last years especially the sulphur air emissions has been reduced considerably by large progresses of process technology. The recycling of fibres of used paper in Western Europe has reached a quite advanced level and for some paper grades a further increase may be expected. The recovery of energy from wastes from pulp and paper manufacturing processes (rejects, sludge) is possible thereby avoiding a waste disposal problem. But in this respect there is still a high potential for increased use of efficient on-site techniques. For chemical pulping no external energy is needed but the total demand of process energy is still on a high level. Mechanical pulping is the most energy-intensive process because of the electricity demand of the refiners. Also recovered paper processing and papermaking are energy-intensive processes. This is caused by the fact that for papermaking the solid content of a dilute suspension of fibres and possibly fillers has to be brought to about 95% solids as a typical dry solid content in finished papers by means of pressing and drying (evaporation of water).

During the period before the 1970-1980s the pulp and paper industry caused substantial wastewater discharges into receiving waters. The effects observed were sometimes of dramatic character with oxygen depletion and fish kills. From the end of the 1970's until recently, the main emphasis was put on the role of chlorinated substances formed in the bleach plant. Dioxins and Furanes had been detected in some effluents of pulp mills and the public discussion focussed on the harmful effects of chlorine bleaching. The public concern about the potential environmental hazard imposed by the use of chlorine in the bleach plants has brought about a drastic decrease in the use of molecular chlorine as a bleaching chemical during the last decade. The environmental control authorities in many countries have set severe restrictions on the discharges of chlorinated organics measured as AOX into the aquatic environment. A reduction of AOX was achieved by a combination of several measures: The use of molecular chlorine has been largely replaced by chlorine dioxide and introduction of other oxygen-containing chemicals such as molecular oxygen, peroxide and ozone. Due to the strong reduction of the chloride content of the effluents a closure of the mill system and recycling of the bleach plant

effluent back to the chemical recovery system of the mill has been made possible. The reduction of both chlorinated and non-chlorinated organic substances in the effluents of pulp mills has been achieved to a large extent by in-process measures as for instance: increased delignification before the bleach plant by extended or modified cooking and additional oxygen stages, spill collection systems, efficient washing, and stripping and reuse of condensates. Another contributing factor to the decreased emissions of AOX and unchlorinated toxic organic compounds into receiving waters, was the installation of external treatment plants of different designs.

In order to comply with market and environmental demands the current trends within the pulp and paper industry is toward increased closure of the bleach plants either by using ECF (Elementary Chlorine Free) or TCF (Totally Chlorine Free) bleaching of pulp.

In paper mills an increased reuse of treated process waters by implementing production-integrated advanced wastewater treatment systems will be allowed. Wastewater discharges, environmentally friendly handling of wastes, energy saving and recovery and locally smell from kraft pulp mills are expected to remain also future priorities of environmental actions in pulp and paper industry.

1.6 Overview of pulp and paper manufacturing

Paper is essentially a sheet of cellulose fibres with a number of added constituents to affect the quality of the sheet and its fitness for intended end use. The two terms of paper and board (No. 6.1 b, Annex 1 of the IPPC-Directive) generally refer to the weight of the product sheet (grammage) with paper ranging up to about 150 g/m² and a heavier sheet regarded as board (paperboard).

The pulp for papermaking may be produced from virgin fibre by chemical or mechanical means or may be produced by the re-pulping of recovered paper (RCF). In the pulping process the raw cellulose-bearing material is broken down into its individual fibres. Wood is the main raw material but straw, hemp, grass, cotton and other cellulose-bearing material can be used. The precise composition of wood will vary according to the type and species but the most important constituents are cellulose, hemicelluloses and lignin.

Wood naturally contains around 50% water and the solid fraction is typically about 45% cellulose, 25 % hemicelluloses and 25% lignin and 5% other organic and inorganic materials. In chemical pulping, chemicals are used to dissolve the lignin and free the fibres. The lignin and many other organic substances are thus put into solution from which the chemicals and the energy content of the lignin and other organics may be recovered. The extent of this recovery is dependent upon the chemical base used and the process configuration. In mechanical pulping processes mechanical shear forces are used to pull the fibres apart and the majority of the lignin remains with the fibres although there is still dissolution of some organics.

Pulps produced in different ways have different properties, which make them suited to particular products. Most pulp is produced for the purpose of subsequent manufacture of paper or paperboard. Some is destined for other uses such as thick fibreboard or products manufactured from dissolved cellulose.

Paper produced by the use of recovered paper as fibre source will involve some cleaning of contaminants prior to use and may involve de-inking depending upon the quality of material recycled and the requirements of the end product the recycling process. The fibres are reusable a number of times depending on the quality of the recycled material and the purpose of the end product. The paper product may also comprise up to 45% of its weight in fillers, coatings and other substances.

There are many different products produced by the papermaking industry and can be broadly categorised as follows:

- Newsprint
- Uncoated printing and writing papers
- Coated printing and writing papers
- Packaging papers
- Packaging paper boards*
- Liner and fluting
- Tissue
- Speciality papers

* From high quality finished cardboard to a range of qualities of cardboard packaging

Each of these categories demands specific properties of the product and the most appropriate manufacturing route to these products may differ substantially. For instance, newsprint is a product required in high volume on a regular basis but is only required to have moderate strength, opacity, printability and a relatively short life. Thus a manufacturing route which involves a high yield of pulp at the expense of maximum achievable strength, brightness and texture can contribute to the efficient use of raw materials.

In contrast, the critical quality of packaging papers is their strength if they are to be fit for their intended use. In this case it is necessary to accept a lower yield inherent to a different manufacturing route in order to achieve this strength. Printing and writing papers need a different balance of brightness, texture and strength, and some can be required to last for great many years. Tissue papers are made to have good dry and wet strength for their weight and typically will be used once and not re-enter the fibre cycle.

1.7 Classification of pulp and paper mills

The high degree of process-integration in pulp and paper industry implies that the concept of BAT must be related not only to separate processes, systems or lines, but also to the whole integrated units. For instance, in order to reduce effluent volumes, water has to be recirculated typically from the paper mill to the pulp mill in addition to internal loops in both parts of a mill.

At the same time, a certain product may be manufactured through various different processes and systems and it may be equally relevant to compare such different options, although based on quite different processes, when considering BAT. For instance, newsprint may be manufactured from several different pulp sources such as stone groundwood (SGW), pressurised groundwood (PGW), thermomechanical pulp (TMP), refiner mechanical pulp (RMP), chemithermomechanical pulp (CTMP), sulphite pulp (Si), bleached softwood kraft pulp (BSKP), and/or deinked pulp (DIP). Different furnishes will of course give rise to different emissions.

As pulp and paper products are highly diverse and applied processes even for one and the same product may vary greatly, many factors of production technology must be taken into account to guarantee a high level of environmental protection. The best techniques for the pulp and paper industry cannot be defined solely by describing unit processes. Instead, the whole installations must be examined and dealt with as entities.

In a document supplied by Finland to the EIPPCB [J. Pöyry, 1998 b], a proposal was made how to classify the pulp and paper industry operating in the European Union by distinguishing the technical properties of the installations and their product range. Following this proposal, the technically diverse installations in the EU area are presented using a grouping of 9 main classes. This classification scheme is product-orientated i.e. distinguishes BAT for different pulp and paper products.

In Figure 1.1 the relationship between the amount of mills and capacities on a European level according to this classification is illustrated.

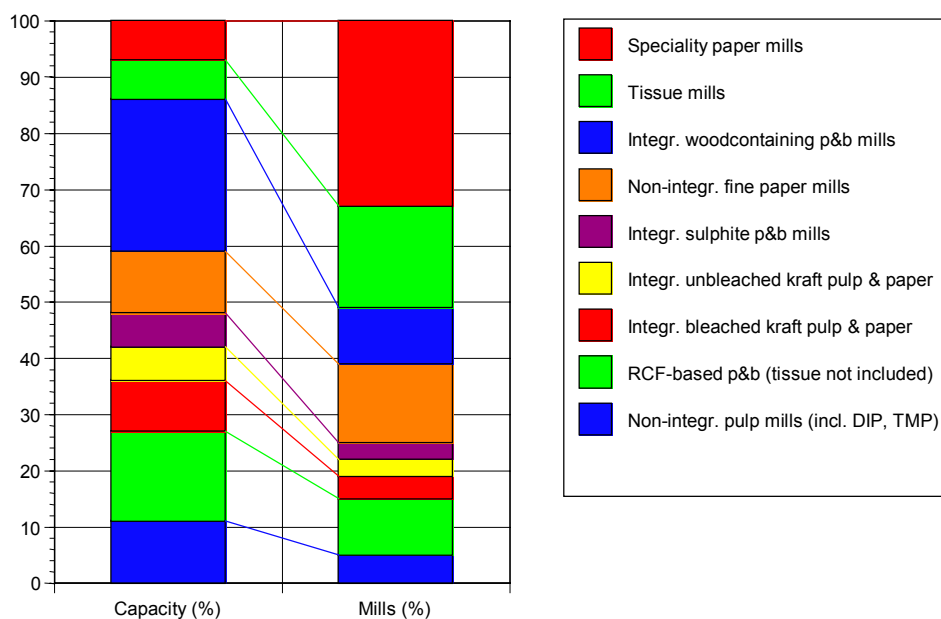


Figure 1.6: Capacities versus amount of mills in Europe
 [According to J. Pöyry, 1998; changes made by EIPPCB]. In this study the 9 main classes of the classification scheme are further subdivided in 33 subclasses according to different end products

However, In the European paper industry there is a trend to use a mixture of raw materials as fibre furnishes (e.g. mixture of different types of virgin fibres and recovered fibres). There are also a lot of mills in Europe that are only partly integrated or use fibre mixtures, which are not covered by the proposal. For example there are tissue mills using 10%, 20%, 30% and so on till 90 or 100% of recovered fibres. These mills can not only be described on a product-orientated level. Furthermore, several of the mills are conglomerates giving problems in allocating the total discharges to the different pulp and/or paper types produced when they are not strictly described on a process level as proposed within the BREF.

The process of pulp and papermaking consists of quite many stages. Besides the fibrous material different chemicals and a great amount of water and energy in the form of steam, fuel oil or electric power is required in the process. The wide range of processes involved in the manufacture of pulp and paper can be broken down into a number of unit operations for the sake of discussion. A sequence of operations can be described from raw materials to product but individual processes will not involve all the operations and some are mutually exclusive alternatives.

Bearing in mind that there is no single right or wrong proposal but only reasonable and manageable proposals preference were given to classifying the European Paper industry as described below. To obtain clearer arrangements of the variety of processes involved, the most important pulp, paper and board manufacturing processes are described separately for five main classes that are described in separate chapters in this document. The main types of pulp and paper manufacturing are sub-divided in several sub-classes. The proposed structure of the European pulp and paper industry and the composition of the BREF are shown Figure 1.7. It strikes after a description of the major differences of pulp and paper production from an environmental-point-of-view:

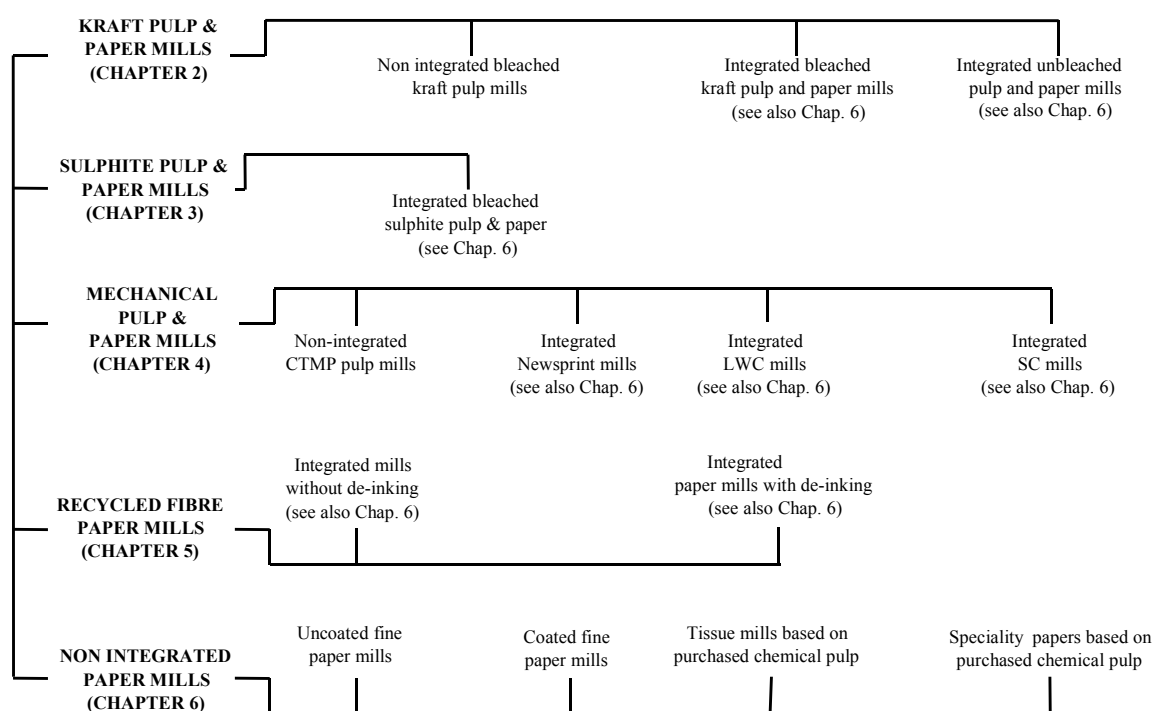


Figure 1.7: Classification of pulp and paper mills proposed by this document including cross-references to the relevant chapters for those mills

The kraft pulping process is described in Chapter 2. Within kraft pulping emission levels associated with the use of BAT for bleached and unbleached grades are distinguished. The BAT emission levels for non-integrated and integrated kraft pulp mills are both given in this chapter. The impact of the paper mill can be regarded as included for water discharges within the uncertainties given. On the other hand, as paper drying is more energy consuming than pulp drying figures for energy consumption and air emissions will differ between integrated and non-integrated pulp mills. These aspects are discussed in this chapter. However, the corresponding sections of the papermaking chapter (Chapter 6) have to be considered when determining BAT for integrated kraft pulp and paper mills (available techniques for papermaking). Some process steps of kraft pulping are similar for all ways of pulp manufacturing (e.g. wood handling, drying) and are therefore described only once and references to other parts of the documents are given.

The sulphite pulping process is described in Chapter 3. The sulphite process is much less uniform (e.g. different bases and pH-values) than the kraft pulping process which makes it more difficult to select BAT. The description is concentrated on the major sulphite pulping process in Europe, the magnesium sulphite pulping. Some additional information on NSSC and dissolving pulp will also be given in this chapter.

Mechanical and chemi-mechanical pulping is described in Chapter 4. Groundwood pulping, TMP and chemi-mechanical pulping (CTMP) has been distinguished. Most mechanical pulping is integrated with paper manufacturing. Therefore, the emission levels associated with the use of BAT for both mechanical pulping and papermaking are given in the Chapter 4. However, the corresponding chapter on papermaking (Chapter 6) has to be taken into account to identify the techniques to consider in the determination of BAT for integrated mechanical pulp and paper mills. Cross-references are given to other sections of the document to consider.

Recycled fibre processing is described in Chapter 5. BAT associated levels for processes with and without de-inking are distinguished thereby discussing some further differences in recovered fibre preparation as for e.g. tissue, LWC/SC, carton-board. The emission levels associated with the use of BAT presented are referring to integrated pulp and paper mills because most recovered fibres based mills are integrated mills. The corresponding chapter on papermaking (Chapter 6) has also to be taken into account. There, the techniques to consider in the determination of BAT as far as papermaking is concerned are described. Cross-references are given to the sections to consider.

Papermaking and related processes is described in Chapter 6 for the major paper grades being manufactured in European paper mills. Paper manufacturing at a site of its own (non-integrated paper mills) is dealt with in this separate chapter because, in numbers, most of paper mills in Europe are those mills. There is a certain overlapping to integrated pulp and paper mills that manufacture pulp and paper at the same site. Cross-references are given in those cases to the relevant sections.

No specific information on techniques to consider in the determination of BAT for board manufacturing was provided. Therefore, the document gives no separate description of the production of board. From environmental-point-of-view, the most important differences are between tissue and other paper grades and also between coated paper and board compared to uncoated paper and boards. Thus the following grades were distinguished within Chapter 6:

- Coated printing and writing paper as for instance coated fine paper used for printing, writing and copying
- Uncoated printing and writing paper as for instance uncoated fine paper.
- Tissue paper mills
- Speciality paper mills

This group (mainly woodfree paper grades) is at the same time the major types of non-integrated paper mills in Europe. Of course, there are also integrated paper mills within that group.

Speciality paper mills is an extremely diverse grouping, which covers a high amount of different products. Speciality paper mills are often producing with more than one change of type per working day. Many speciality paper mills are also non-integrated paper mills. Because of its variety of products no emission levels associated with the use of BAT will be presented for speciality paper mills. The different products have their specific "environmental problems". The values and explanations presented in the BAT chapter should be taken as examples about emission levels to be expected from some types of speciality paper mills. They are not regarded as to cover the whole group of speciality papers completely.

1.8 Presentation of BAT

To avoid repetition, some general remarks on the selection of BAT apply across the pulp and paper sector.

For describing best available techniques for pulp and paper industry the following aspects have to be considered:

- There is no single reference of best available techniques in pulp and paper industry. In contrast, the list of techniques to consider in the determination of BAT provides a lot of different options of an overall BAT for given mills, which may be combined in different ways.
- The BAT-concept is process-related because the environmental impact is caused on this level i.e. by different manufacturing processes as for instance cooking, bleaching, de-inking, coating etc. The single processes, the raw materials used and the product properties to be achieved determine the emission of a mill. That means when approaching the pulp and paper industry different types of raw materials used and processes involved have to be distinguished.
- As pulp and paper products are highly diverse and utilised processes even for one and the same product may vary greatly, many factors of production technology must be taken into account to guarantee a high level of environmental protection. For the pulp and paper industry the best available techniques cannot be defined solely by describing unit processes. Instead, the whole installations must be examined and dealt with as entities. BAT in pulp and paper industry is linked to the environmental performance of mills.
- There are different options for suitable combinations of processes depending - besides other things - on the product properties to be achieved. As a consequence, the process-oriented approach has to be extended by a product-oriented concept i.e. the BAT approach must be linked to the environmental performance of specific types of mills where specific products are manufactured. Thus, in this document best available techniques are presented for major mill classes separately (see Section 1.7).

Instead of single distinctive values the environmental performance of paper mills is expressed as a range of values. This reflects that the manufacturing of different paper grades requires different quantities and qualities of raw materials (e.g. kraft pulp, different groundwoods, mixture of furnishes etc.), with the consequence that emissions per end product are of different levels. To a certain extent, higher emissions caused by the use of more polluting raw materials or processes respectively can be compensated by higher efforts for pollution prevention and control. Presenting ranges considers also that emissions vary with time to a certain extent, e.g. between years, even if the same techniques have been used.

There may be a numerous number of mills that have concentrated first on emissions to water and water consumption and then on air achieving very good performance in the former. They might be less performing in solid waste reduction. But following the objective of IPPC mills should try to run and control the whole system in an integrated manner to reduce emissions and the impact on the environment as a whole. Following the integrated approach it is evident that BAT levels can be achieved in different ways, i.e. there are several options to achieve similar emission levels.

The final choice of a suitable combination of pollution prevention and control measures is generally somewhat different in existing mills and new mills. Furthermore, for existing mills the installation of BAT is in general more expensive. This is due to limitations in changing already fixed lay out solutions, retrofitting costs when the plant is in full operation (downtime costs) and

the fact that some techniques may be used a shorter time period than within new mills (shorter depreciation time). But beyond that and except of possible limitations in space for existing mills, the best available techniques given below are, if not stated otherwise, applicable to existing and new mills.

It should be noted that the lack of harmonisation in the methods of analysis used in Europe and the variations in the utilised process systems and fuels make the direct comparison of the emission levels between countries sometimes difficult. In the context of the information exchange on BAT there is a need to improve the comparability of data concerning environmental performance of mills.

In general prevention is the most effective and preferred measure to reduce emissions. Besides prevention, emission reduction can be achieved by implementing technologies in the process. Finally, there are a few end-of-pipe techniques for pollution control available.

2 THE KRAFT (SULPHATE) PULPING PROCESS

The sulphate or kraft process accounting for ca. 80% of world pulp production is the most applied production method of chemical pulping processes. The importance of the sulphite process has decreased steadily over the last years. Today, only 10% of the world production are obtained by this method. The term "sulphate" is derived from the make up chemical sodium sulphate, which is added in the recovery cycle to compensate for chemical losses. In the chemical pulping process the fibres are liberated from the wood matrix as the lignin is removed by dissolving in the cooking chemical solution at a high temperature. Part of the hemicellulose is dissolved as well in the cooking. In the kraft pulp process the active cooking chemicals (white liquor) are sodium hydroxide (NaOH) and sodium sulphide (Na₂S). As a result of the large amount of sodium hydroxide used, the pH value at the start of a cook is between 13 and 14 (alkaline pulping process). It decreases continuously during the course of cooking because organic acids are liberated from lignin and carbohydrates during the pulping reaction.

Today the kraft process is the dominating chemical pulping process worldwide due to the superior pulp strength properties compared with sulphite process, its application to all wood species, as well as to the efficient chemical recovery systems that have been developed and implemented. But the chemistry of the Kraft process carries with it an inherent potential problem of malodorous compounds.

As a result of chemical reactions in the cooking stage, chromophoric groups of the residual lignin are formed thus causing the pulp to become darker in colour than the original wood. Because of the higher pH, the Kraft pulping process induces more chromophores than sulphite pulping and unbleached Kraft pulp has a considerably lower initial brightness than unbleached sulphite pulp.

2.1 Applied Processes and Techniques

Figure 2.1 gives an overview of the processes of a kraft pulp mill [SEPA-Report 4713-2, 1997].

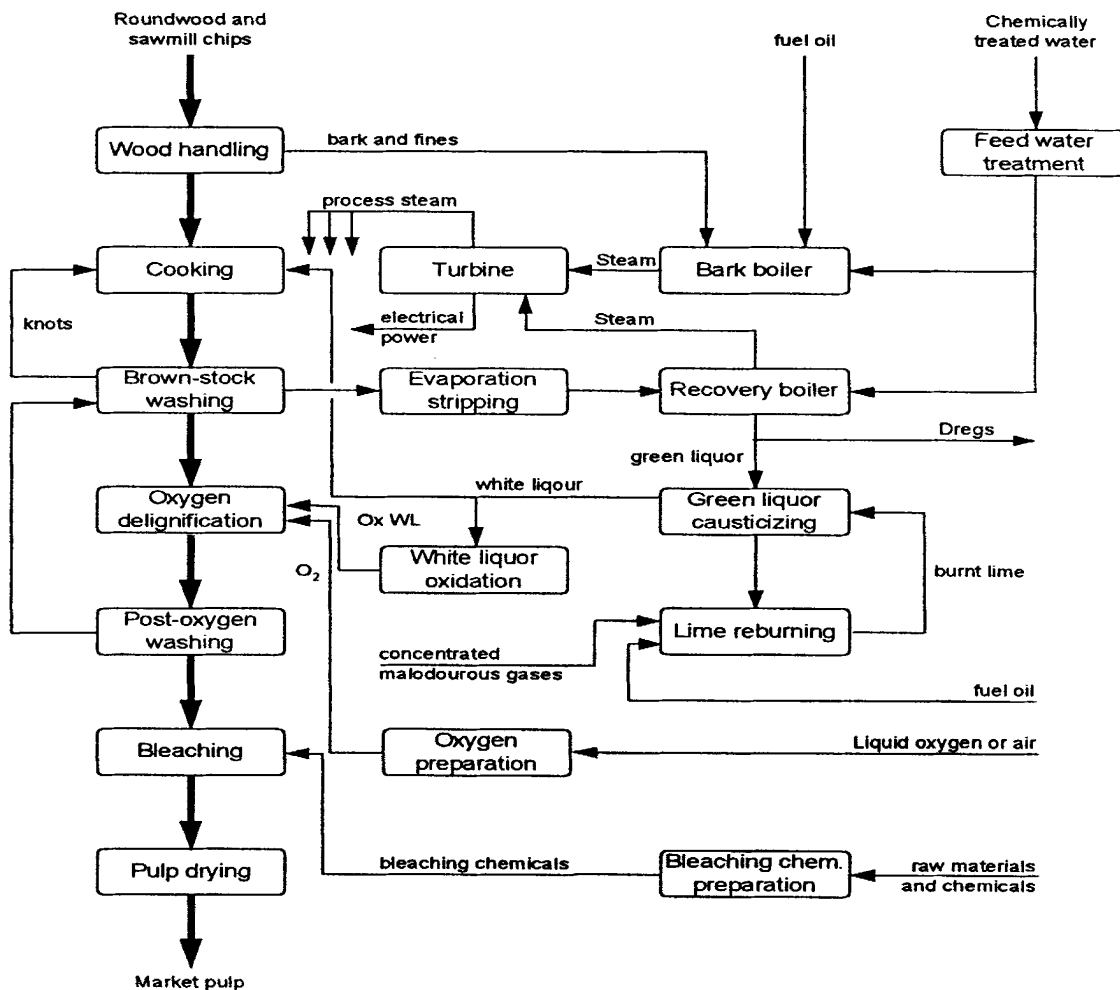


Figure 2.1 Overview of the processes of a kraft pulp mill [SEPA-Report 4713-2, 1997]. Often there is a screening after bleaching, too

A kraft pulp mill can be divided into four main parts: raw material handling, chemical defibration (delignification) with almost completely closed chemical and energy recovery system, bleaching with an open water system and the process external wastewater treatment system. Another more conventional division is the fibre line, recovery system and external wastewater treatment. Some auxiliary systems like reject handling, manufacturing of bleaching chemicals and auxiliary power generation are connected to the main departments.

2.1.1 Reception and storage of wood

Wood may be received as logs directly from the forest or as by-product chips from some other wood working industry like sawmills and plywood mills. Logs are mainly delivered with the bark on and have to be debarked before further processing. Chips are normally free of bark and can be used after screening and possibly washing. The wood is transported to the mills by ship, truck or rail but also to a limited extent by floating logs to the mill site. Where the latter is used, there will be some leaching of resin acids and nutrients while the wood is in contact with water.

Mechanical pulping techniques may use either logs or chips but chemical pulping techniques will always use chips. The objective in chipping is to form uniform sized chips, which will result in a better pulp product. Some chemical pulp mills store wood chips in piles for up to 40 days during which time there is some degradation of extractives within the wood by oxidative and enzymatic mechanisms. The pile of wood chips can become quite warm during this maturation period. Storage for greater than 40 days would be expected to reduce the subsequent fibre yield. Mechanical pulping on the other hand requires fresh wood and in all cases it is desirable to maintain the moisture content of the wood.

2.1.2 Debarking

The most common method for debarking is drum debarking. Bark is removed as the logs rub against each other when made to tumble by the rotating action of the debarking drum. Loose bark and wood sticks fall from the drum through special chutes. Debarked logs are showered with water before being delivered to the pulp mill.

The wet debarking process uses large volumes of water. In recent years “dry” debarking has been installed in many mills. Dry debarking give bark with lower water content, which will result in a better energy balance for the mill if the bark is burnt.

In Nordic Countries frozen logs and snow are thawed before debarking. This can be done in the debarking drum with hot water or steam or on special de-icing conveyors before the debarking drum.

Bark from the debarking unit is typically fed into a bark shredder and, if wet, pressed for burning. Some alternative uses for the bark exist and in some cases it is sold off site but the sheer volume involved in large installations favours on site disposal and energy recovery.

2.1.3 Wood Chipping and Screening

For chemical pulping processes the logs are reduced to chips in a chipper. A uniform chip-size distribution is necessary for the efficiency of the processes and for the quality of the pulp. The more uniform the chips are after the chipper, the lower the raw material consumption. After the chipper station the chips are screened in order to remove oversized chips and sawdust. However, sawdust can also be cooked together with chips or separately in a sawdust cooker, or it can be burnt or used for other purposes. Oversized chips may go for re-processing in a crusher or re-chipper. Chips are screened for thickness, as this is a critical parameter both in chemical and mechanical pulping. Often the overall optimum is reached by sacrificing some raw material to secure stable processing conditions, which, in turn, promote better pulp quality and less pollution. The material removed in the screening operation can be sold for other purposes or burnt in a solid fuel boiler with the heat recovery.

2.1.4 Cooking and delignification

In the Kraft process the fibres are liberated in the cooking plant by dissolving the lignin and part of the hemicellulose in the cooking chemical solution (white liquor), which contains sodium hydroxide and sodium sulphide as active chemicals. When the final product is unbleached pulp, the cooking is the only delignification stage.

The cooking process can be performed either in batch digesters or in a continuous digester. When using batch processes, in the cooking stage the wood chips and the liquors are charged into a batch digester where the cook is carried out in elevated temperature and pressure. When

the desired residual lignin content (measured as Kappa number) is reached, the contents are discharged to a blow tank and the cooking cycle is repeated. The amount of lignin that remains in the pulp can be determined approximately by multiplying the kappa number by the factor 0.165 [Uhlmann, 1991] i.e. a kappa number of 30 relates to about 4.95% residual lignin.

The cooking can also be carried out in a continuous digester (see Figure 2.2) where the wood/chemical charge and retention time as well as the temperature in the cooking zone defines the resulting lignin content. The chips are pre-heated by steam before entering the continuous digester in order to remove air, which interferes with the impregnation. After entering the digester, the chips are impregnated with cooking liquor and the temperature raised to 155 - 175°C. The cooking time at the maximum temperature is in the range of 1-2h. In conventional cooking the delignification of softwood (spruce or pine) can be brought down to a Kappa number of 30 - 35 whilst maintaining acceptable pulp strength properties. For hardwood (aspen, birch and eucalyptus) the Kappa number can be brought down to 14 - 22 [CEPI, 1997].

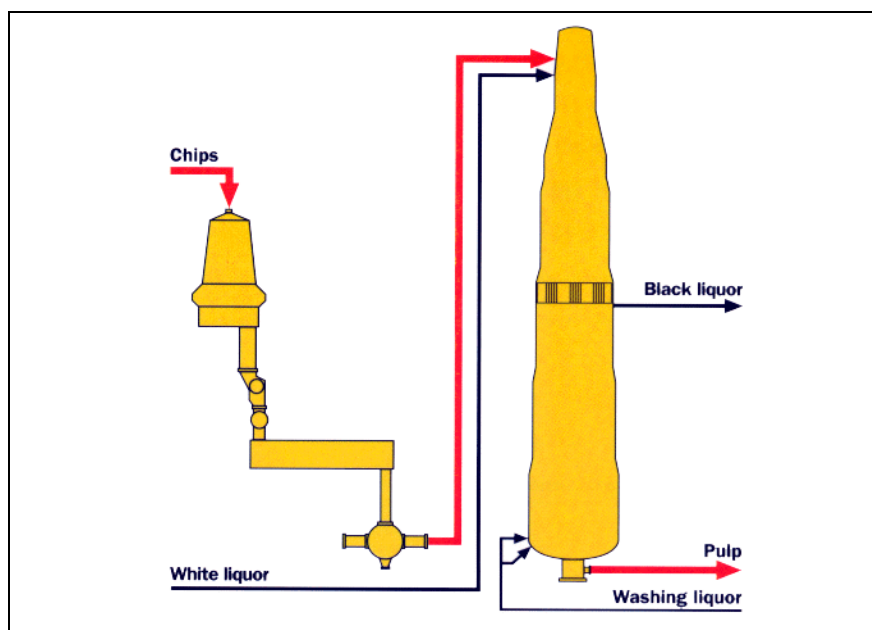


Figure 2.2: Continuous digester

As a result of the poor bleachability of kraft pulps and the pollution caused by pulp bleaching, several cooking modification methods have been developed with the aim of removing more lignin from the wood during cooking without reducing the yield. The Kappa number from the cooking of softwood can be reduced to a level of 15 - 25 through extended delignification [Finnish BAT report, 1996], while the yield and strength properties are still maintained. This means that 25 - 50% less lignin is left in the pulp compared with pulp that has a kappa of 32. The requirements for any subsequent bleaching chemicals are, therefore, reduced and the effluent discharges from the bleaching plant are decreased. Comparable kappa reductions can be achieved in the cooking of hardwood (see also 2.1.6).

2.1.5 Washing and screening

The pulp coming from the digester contains both fibres and spent cooking liquor (black liquor). About half of the wood is dissolved in the cooking. Consequently the black liquor contains inorganic chemicals and a large amount of organic substances. The black liquor is removed from the pulp in the subsequent washing and led to the chemical recovery system, where cooking chemicals and energy are recovered.

The dissolved organic substances together with the spent cooking chemicals are washed away from the cellulose fibres in the brown stock washing stages. Modern systems normally recover at least 99% of the chemicals applied in the digester. Washing the pulp coming from a conventional batch digester plant is normally carried out with drum washers, while a continuous digester plant utilises the Hi-heat wash zone in the digester with additional drum washers or diffuser washers. In today's batch as well as continuous cooking fibrelines, washing starts already in the digester by displacing hot black liquor with cold wash liquor. Subsequent washing is carried out in various types of washing equipment, e.g. vacuum drum washers, wash presses, diffusers or wire type washers.

Efficient washing reduces the carry-over of black liquor with the pulp resulting in a decreased consumption of chemicals in bleaching and reduced discharges from the bleaching plant. Efficient washing reduces chemical consumption also in oxygen delignification. The outcome of the washing is highly dependent on the efficiency of the equipment used, the outlet consistency of the pulp and the amount of wash water applied. However, if washing is improved by increasing the amount of wash water, the demand for steam will increase in the subsequent stage to evaporate and concentrate the black liquor.

Wash presses and diffuser washers are especially effective in the removal of dissolved organic substances, and this is one reason why wash presses have become more common, especially as the last washing stage before bleaching. Washing with the longest delay can be achieved in a diffuser type of equipment. Adding carbon dioxide to the wash water will improve the washing effect.

Before further processing, the pulp is screened with pressure screens and centricleaners. The objective of screening is to separate knots and fibre bundles from the main pulp stream with a series of vibrating equipment, filtration through pressure screens and centrifugal separation of fibres and other particles with different specific weights. Rejects from screening constitute a further waste stream to be dealt with.

2.1.6 Oxygen delignification

After cooking, delignification can be continued by oxygen in one-stage or in two stages with or without intermediate washing. Oxygen delignification can be combined with conventional and extended cooking.

Oxygen delignification takes place in alkaline conditions. In order to maintain the sodium balance of the mill, the oxygen stage normally uses the oxydised white liquor, where sodium hydroxide is the main alkaline chemical and sodium sulphide has been oxidised to thiosulphate. Due to relatively low solubility of oxygen to the alkaline liquor, the delignification reactor is pressurised and the temperature is elevated to about 100 °C. In oxygen delignification magnesium salt (MgSO_4) is added in order to preserve the strength of the pulp. The oxygen is mainly purchased but also some on-site plants are in operation. Because of better selectivity and lower investment costs the Medium Consistency (MC, 10-15%) system has dominated mill installations for the past ten years but high consistency installations (HC, 25-30%) are in use as well. Recently the industry has opted to install two-stage oxygen delignification systems to increase the selectivity of the treatment. Oxygen delignification is usually an intermediate stage in the pulp washing. The wash water is added onto the last washing stage after oxygen delignification and led counter-current to the pulp flow. Washing after oxygen delignification is usually done with one or two wash presses alone or in combination with some other type of washer. The organic material that is dissolved during oxygen delignification can be recovered and led to the chemical recovery system without major changes in the process. The recovery reduces the amount of organic material ending up in the wastewater and the amount of chemicals needed.

The degree of further delignification is 40-50% in a one-stage system and can be up to 70% in a two-stage system [Finnish BAT report, 96]. The Kappa number after conventional cooking and oxygen delignification is typically 18-22 for softwood and 13-15 for hardwood without extended delignification (CEPI, 1996). Depending on the wood species, oxygen delignification with extended cooking can achieve a reduction in Kappa number to around 8 - 12. The overall pulp yield might decrease by 1.5 - 2.5% and there is still lignin left that has to be removed by other means when high brightness pulp is demanded. The table below summarises kappa numbers currently achieved with different delignification technologies.

Delignification Technology	Hardwood	Softwood
Conventional Cooking	14 - 22	30 - 35
Conventional Cooking and Oxygen Delignification	13 - 15	18 - 22
Extended Cooking	14 - 16	18 - 22
Extended Cooking and Oxygen Delignification	8 - 10	8 - 12

Table 2.1: Kappa numbers currently achieved after different technologies used

The reduction of the Kappa of unbleached pulp (brown stock), whether it is achieved through extended digester delignification, oxygen delignification or some other method, will reduce the load of bleaching-plant pollutants that enter the external effluent treatment system. This is because dissolved substances are piped to the recovery system and then burned in the recovery boiler.

2.1.7 Bleaching

The purpose of bleaching chemical pulp is to obtain certain pulp quality criteria with respect to brightness, brightness stability, cleanness and strength. The brightness of unbleached Kraft pulp is rather low, below 30% ISO whereas fully bleached pulp has a brightness of 88% ISO or higher. Cooking and oxygen delignification cannot remove all the lignin and to achieve this brightness it is necessary to remove or oxidise the remaining lignin and impurities in the pulp. The Kappa number after bleaching is reduced below 1 unit [CEPI, 1996]).

Whereas delignification can be carried out within closed water systems bleach plants tend to discharge effluent to external treatment. These effluents from the bleach plant cannot easily be recirculated into the chemicals recovery mainly due to the fact, that these bleach plant effluents would increase built-up of chlorides and other unwanted inorganic elements to the chemical recovery system which can cause corrosion, scaling and other problems. Nevertheless, there are running projects on how to close up the bleach plant and some plants are operated with semi-closed water systems.

The bleaching of kraft pulp is carried out in several stages, usually four to five. The most commonly used chemicals are chlorine dioxide, oxygen, ozone and peroxide. Lately, peracetic acid has become commercially available as bleaching chemical. Chlorine and hypochlorite have largely been phased out as primary bleaching chemicals over recent years (e.g. PARCOM Decision on the Phasing-Out of the Use of Molecular Chlorine (Cl₂) in the Bleaching of Kraft and Sulphite Pulp). Small amounts of chlorine are formed as a by-product in most of the chlorine dioxide generation systems used, and a part of this chlorine will be present when chlorine dioxide is used in bleaching. Chlorine dioxide and ozone have to be produced on site (see Section 2.1.11). Peroxide, oxygen and alkali can be delivered to the mills.

Ozone is a very reactive bleaching agent whilst chlorine dioxide, oxygen and hydrogen peroxide are less reactive. Because of the different reaction mechanisms different types of bleaching chemicals are utilised in a bleaching sequence. Acid and alkaline stages are used to complement each other.

Peroxide bleaching is relatively slow and requires long reaction times and therefore large reactor volumes or increased pulp consistency. Increased pressure makes higher reaction temperatures possible, resulting in a reduced reaction time or improved bleaching outcome. It is necessary to remove metal ions to avoid degradation of the hydrogen peroxide by using metal chelating agents (i.e. EDTA or DTPA) or acid washing. An advantage with peroxide compared with the other oxygen bleaching chemicals is that peroxide bleaching at optimal conditions brightens the residual lignin.

Enzyme treatment before bleaching has been in use at some plants since 1991. It can be combined with different bleaching sequences to enhance the effectiveness of the chemicals used but typically results in a small loss of yield.

A bleach plant consists of a sequence of separate bleaching stages with different chemicals added. Each bleaching stage consists of:

- devices for mixing the chemicals and the pulp
- a bleaching reactor (upflow or downflow towers) designed with a suitable residence time for chemical reactions
- washing equipment for separation of used chemicals, removed lignin and other dissolved material from the pulp (drum washer or diffuser washer)

The bleaching stages are designed using symbolic shorthand according to the bleaching agent applied:

Q	Acid stage where chelating agent EDTA or DTPA has been used for removal of metals
Z	Ozone using gaseous ozone (O_3)
P	Alkaline stage with hydrogen peroxide (H_2O_2) as liquid
D	Chlorine dioxide stage using a water solution of chlorine dioxide (ClO_2)
E	Extraction stage using sodium hydroxide (NaOH)
E/O	Extraction stage using sodium hydroxide with subsequent addition of gaseous oxygen as a reinforcing agent
E/P	Extraction stage using sodium hydroxide with subsequent addition of hydrogen peroxide solution as a reinforcing agent

Nowadays an oxygen delignification has become more and more common delignification stage followed by bleaching sequence of D-E-D-E-D, D-E-D-D, D-EOP-D-E-D or QP-DQ-PO.

Some mills have responded to the market demands of Totally Chlorine Free (TCF) pulps by modifying the bleaching sequence. Nowadays, TCF is an established technology. A number of mills have the possibility of producing ECF- or TCF-pulps depending on the market situation. New sequences have been and are being developed, such as Q-E/P-E-P, Q-Z-P-E-P, OP-ZQ-PO or OP-Q-PO [CEPI, 1997].

The introduction of extended cooking and oxygen delignification have resulted to more efficient recovery of organic substances and allowed also development of use of other chemicals in bleaching and minimisation of use of chlorine chemicals. As a consequence, the total amount of organic compounds and total amount of chlorinated organic compounds have been reduced significantly.

The two main types of bleaching methods in use are so-called ECF (Elemental Chlorine Free i.e. when no molecular or gaseous chlorine is dosed in the bleaching) and TCF (Totally Chlorine Free) bleaching. ECF bleaching uses chlorine dioxide, alkali for the extraction of dissolved lignin, peroxide and oxygen for the reinforcement of the extraction stages. TCF bleaching uses oxygen, ozone or peracetic acid and peroxide with alkali for lignin extraction. Selectivity is important as far as the total yield and pulp quality is concerned because high selectivity means that the bleaching chemical is primarily reacting with the lignin. Chlorine dioxide and chlorine

are the most selective bleaching agents and selectivity is better in the bleaching stage than in cooking and oxygen delignification.

TCF bleaching requires a low incoming Kappa for the pulp (10 - 12) to attain full brightness and good strength properties because of the power of the bleaching chemicals and fibre degradation during bleaching although a final brightness of 89% ISO is achievable with TCF bleaching without yield loss. A larger amount of residual lignin remains in TCF bleached pulp than in ECF bleached pulp and this residue has to be stabilised to minimise yellowing after production. ECF bleaching can be done on a pulp with a higher Kappa.

The discussion about ECF vs. TCF bleaching

Over the last 10 years there were an intensive discussion and research on the environmental benefit of TCF compared to ECF. The evaluation of results of research and of syntheses of the great amount of laboratory and model ecosystem tests as well as field studies with whole mill effluents from bleached kraft mills (BKME) can be summarised as follows:

- The chemical composition of the effluent from modern kraft mills using low-kappa ECF or TCF bleaching of oxygen-delignified low-kappa pulp has largely changed in comparison with the situation 10-15 years ago, even if the operational standard of the individual mills is of major importance for the amount and quality of emissions [SEPA Report 4785, 1997]
- Modern mills with low-kappa ECF bleaching give very low emissions of chlorinated organic substances and high-chlorinated phenolic compounds generally cannot be detected in the effluent [ibid.]
- A comparison of toxic responses of bleach plant and whole mill effluents from mills using different schemes for non-chlorine bleaching, i.e. low-kappa ECF versus TCF bleaching, shows that neither technical concept invariably produces effluents with a lower toxic potency [FEI, 1996]. No clear difference in the effect pattern and effect intensity between effluent from mills using low-kappa ECF (chlorate reduced) and TCF bleaching has been detected.
- Relative merits of low-kappa ECF versus TCF (or vice versa) are not consistent due to different experimental strategies in test procedures and also to non-bleaching factors within the different mills as e.g. the operational standard of the mill [ibid.]
- Secondary treatment of effluents usually tends to decrease the toxicity of the effluents and according to model ecosystem studies effects on ecosystem level are mitigated after external treatment [ibid.]
- Recent model ecosystem studies have indicated a correlation between effluent COD and the effects observed. These findings suggest that it is not a question of whether to use ECF or TCF as the choice of bleaching, but rather to improve the pulping operation in itself [ibid.]. Thus, the amounts of fatty acids, resin acids and sterols in effluent from modern kraft mills are affected more by the fibre raw material or by contributions from the unbleached side rather than from the bleaching process [SEPA Report 4785, 1997]
- A TCF bleaching sequence is the more advantageous alternative for further system closure. However, the use of totally chlorine-free bleaching chemicals requires an extensive removal of the metals (such as manganese, iron, copper ions) out of the pulp due to their negative impact on the peroxide bleaching. This removal is usually effected by a chelating treatment or an acid wash of the pulps. There is a discussion about the environmental compatibility of chelating agents, because under normal conditions they are poorly biodegradable. There are developments to reduce the disposal of filtrates from chelating stages into the environment (see Section 2.5.3).

2.1.8 Bleached Stock Screening

After bleaching there is generally a final screening of pulp. Secondary screening takes place with the same type of equipment than the screening of unbleached pulp.

2.1.9 Drying

In an integrated pulp and paper mill, the pulp stock will be transferred forward to papermaking in a wet state (at about 4% consistency) and the accompanying water forms part of the overall water balance of the mill. For a non-integrated pulp mill where the pulp is not used for manufacturing of paper at the same mill site the pulp will be first pressed and then dried for transport. Drying machine consists of a wire part similar but simpler than wire part of a paper machine for initial dewatering of the pulp. After dewatering stage the pulp is dried with steam in a multi-stage drying part of the machine. After cutting into sheets bales for shipment are formed.

2.1.10 Chemical and Energy Recovery System

The recovery system in a kraft pulp mill has three functions:

- the recovery of the inorganic pulping chemicals
- the destruction of the dissolved organic material and recovery of the energy content as process steam and electrical power
- the recovery of valuable organic by-products (e.g. tall oil).

The fuel value of the recoverable black liquor is normally enough to make the kraft pulp mills more than self-sufficient in heat and electrical energy. Organic by-products play a limited economic role in most kraft pulp mills.

The main process units in the chemical recovery system are the evaporation of the black liquor (cooking liquor and counter current washing liquor, incineration of the evaporated liquors in a recovery boiler and causticizing, including lime regeneration.

An overview of the circuits of chemicals is presented in Figure 2.3 [BMU Austria, 1995] illustrating the main process steps and their functions.

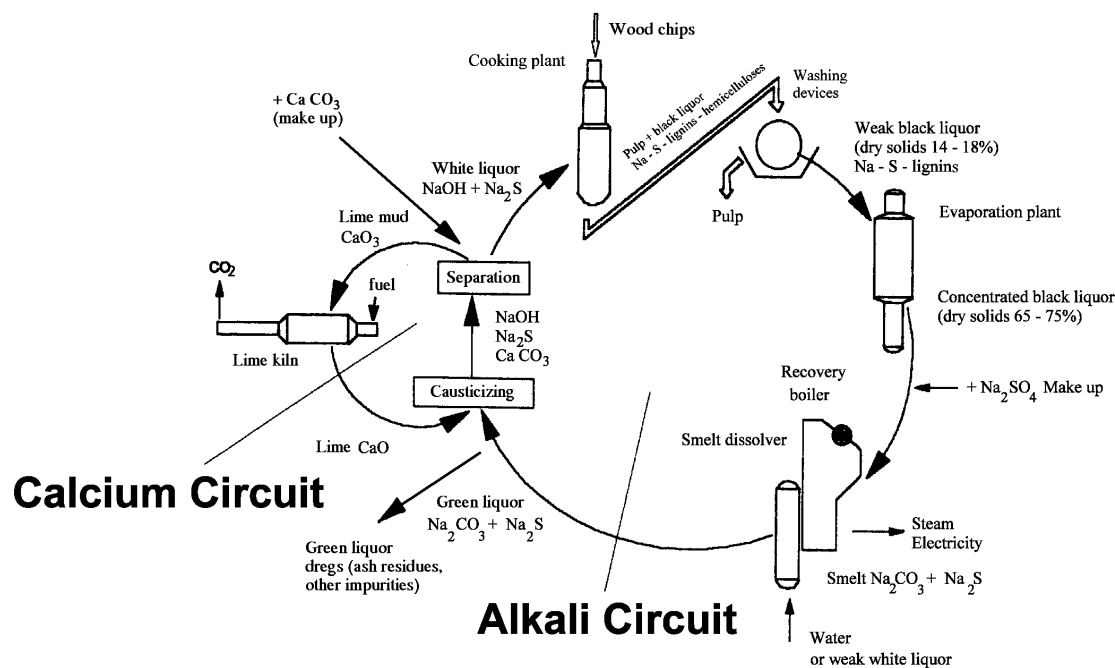


Figure 2.3 Recovery cycles of chemicals for a kraft mill

Black liquor from pulp washing normally has a dissolved solids content of 14 - 18% which has to be increased considerably before the liquor can be burnt. The liquor is concentrated in a multi-effect evaporation plant to a dry-solids content of 65 - 75% but as the dry-solids content increases, the viscosity of the black liquor increases and may become too high for pumping. At atmospheric pressure the upper limit is about 72 - 74% DS but two different principles are used to overcome the problem:

- pressurising the liquor, so that at a higher liquor temperature lowers the viscosity;
- changing the liquor rheology through a thermal depolymerization process.

The liquor can be concentrated to over 80% DS by using heat treatment on the strong black liquor and pressurised evaporation. In heat treatment some of the combustible material separates as non-condensable gases (NCG) which contain Total Reduced Sulphur (TRS). These gases are collected and burnt together with other malodorous gases.

Condensates from the black liquor evaporators and the cooking plant will vary in their degree of contamination according to origin but will typically contain TRS, methanol and some other volatile organic compounds. They are treated in a stripper column that is normally integrated with the black liquor evaporation by using secondary (or primary) steam. Stripping condensates makes it possible to reuse the condensate in washing unbleached pulp and in the causticizing plant.

The concentrated black liquor is burnt in the recovery boiler to recover the sodium and sulphur content in a suitable chemical form to regenerate the pulping chemicals and recover energy from the flue gases.

An increase in the dry-solids content of the black liquor from 65 - 70% to 80 - 85% changes the material and energy balances and the burning conditions in the recovery boiler. The flue gas flow decreases as less water enters the furnace. By increasing the dry-solids content to e.g. over 80% an increase in production or extended delignification with more efficient recovery of the

black liquor can be possible in a mill where the recovery boiler is the production capacity bottleneck. The combustion temperature increases with higher DS feedstock and causes more sodium (Na) to be vaporised which then reacts with sulphur and reduces sulphur emissions from the recovery boiler.

The smelt from the recovery boiler is dissolved in water or weak white liquor to produce “green liquor” which consists mainly of sodium sulphide and sodium carbonate. The green liquor is clarified and causticized with lime where sodium carbonate is converted to sodium hydroxide to produce white liquor for pulping. Ash residues and other impurities are removed from the process as green liquor dregs. The calcium carbonate lime mud from causticizing is separated from the white liquor, washed and calcined in a lime kiln resembling somewhat a standard rotary cement kiln to regenerate the lime. This calcination is a high-temperature, endothermic reaction, requiring external fuel.

The handling and burning of black liquor with a high sulphur content releases sulphur into the air as sulphur dioxide and malodorous gases containing reduced sulphur compounds such as hydrogen sulphide (H_2S), methyl mercaptan (CH_3SH), dimethylsulphide (CH_3SCH_3) and dimethyldisulphide (CH_3SSCH_3).

Strong malodorous gases are collected and generally burnt in a separate burner or in the lime kiln. The latter is less favoured because it might upset the operation of the lime kiln. Flue gases are in most cases treated through a scrubber, and the scrubber water is led back to the chemical recovery system. Some Kraft pulp mills also collect weak malodorous gases to a varying extent. Weak gases are emitted from chip pre-steaming, screening, pulp washing, the smelt dissolver and tank ventilations etc.

2.1.11 Preparation of Bleaching Chemicals on site

The most commonly used chemicals for bleaching of chemical pulps are chlorine dioxide, oxygen, ozone and peroxide. Chlorine dioxide and ozone have to be produced on site. Peroxide, oxygen and alkali can be delivered to the mills.

2.1.11.1 Chlorine dioxide

Chlorine dioxide must be generated on site because it is unstable as a gas and can only be stored as a solution of approximately 1% in water. The gas stable at typical process temperatures of 40 to 70°C and if the partial pressure of chlorine dioxide is kept below 100 mm Hg for at least five seconds. Once absorbed into solution chlorine dioxide can be stored for several months in the dark at -5°C without any gas space. Gaseous chlorine dioxide decomposes to chlorine and oxygen and this decomposition is explosive at =300 mm Hg partial pressure.

There are a number of possible reactions to produce chlorine dioxide and some techniques can produce up to 0.7 tonnes of by-product chlorine per tonne of chlorine dioxide whilst others produce very small amounts. In pulp and paper industry chlorine dioxide is formed by acidic reduction of the chlorate ion ClO_3^- .

Sodium chlorate is the common commercial source of the chlorate ion, but the choice of reducing agent has a great bearing on by-products and economics. Reducing agents, which have been used, include the chloride ion, hydrogen peroxide, sulphur dioxide and methanol.

Techniques have evolved over many years in order to maximise the yield of chlorine dioxide from the sodium chlorate, to minimise the formation of by-product chlorine and also to optimise the generation of waste acids. The two main techniques, which produce minimal by-product

chlorine, are the Matheson process that uses sodium chlorate, sulphuric acid and sulphur dioxide; and the more recent SOLVAY derived R8 process, which principally uses sodium chlorate, sulphuric acid, and methanol. Additionally some chloride ion is essential for the generation of chlorine dioxide in all these processes. Table 2.2 gives an overview about different chlorine dioxide generation methods.

	MATHIESON	R3	R3H	R5	R6	R7	R8	LURGI R6	
Input chemicals (t/t ClO ₂)									
NaClO ₂	1.75	1.6	1.68	1.75		1.68	1.65	1.08	
NaCl		8				0.35	0.03		
H ₂ SO ₄	1.30	1.1	0.80			0.40	1.10		
HCl		5	0.70	1.40					
SO ₂	0.75	1.7				0.40			
CH ₃ OH		3					0.15		
Cl ₂					0.80				
E1 power (MWh)					8.50				
By products (t/t ClO ₂)									
Na ₂ SO ₄	1.20	2.3	1.20			1.60		0.10	
H ₂ SO ₄	1.60	0					1.30		
Na ₃ H(SO ₄) ₂							0		
Cl ₂	0		0.70	0.80	0.30	0.20			
H ₂		0.7			0.05				
NaCl		0		0.95					
NaOH									0.70

Table 2.2: Chlorine dioxide generation methods in use in Finland
[Finnish BAT report, 1997]

It can be seen that only "Mathieson" and the so-called "R 8" technique does not produce chlorine as by-product.

Ideally any by-product sodium and sulphur from the generation of chlorine dioxide could be taken into the pulp mill as make-up chemicals and there would be very little or no effluent. However, if sodium or sulphur is produced in excess of the mill make-up requirements, they have to be removed from the process (see also Section 2.2.2.5).

A potential problem when ClO₂ is used is the formation of chlorate. About 10% of ClO₂ as active chlorine shows up as chlorate. This means that about 4-6 kg of chlorate is formed per t of pulp at ECF-bleaching at kappa 18. Chlorate is toxic to bacteria and plankton at levels of about 3-4 mg/l. In addition it inhibits growth of brown algae, e.g. bladder wrack, at concentrations from about 20 micrograms/l. The reason being that when N is the limiting factor for growth, algae take up chlorate, which is a known herbicide, instead of NO₃⁻.

2.1.11.2 Ozone

Ozone is produced from dry air or oxygen by the application of high voltages (10 - 20 kV) across two electrodes separated by the reactant gas. Ozone is not very stable and the yield of ozone is fairly low with a high level of unreacted oxygen expected in the product gas. A modern ozone generator fed with oxygen uses about 10 - 15 kWh/kg O₃ generated.

2.1.11.3 Other bleaching chemicals

Other bleaching chemicals are bought in ready for use - Hydrogen Peroxide as 50% solution; Dithionite as a solid. Oxygen is mainly purchased but there are a few mills in Europe, which generate oxygen on site. In a few pulp mills in TCF-bleaching sequences peracetic acid is used as bleaching chemical. For the production of peracetic acid about 3 kWh electricity /kg of product is required.

2.2 Present Consumption/Emission Level for Integrated and Non-Integrated Mills

2.2.1 Overview of input/output

An overview of the raw material and energy input as well as the output of products, by-products and the major releases (emissions, waste etc.) of the production of kraft pulp is presented in Figure 2.4.

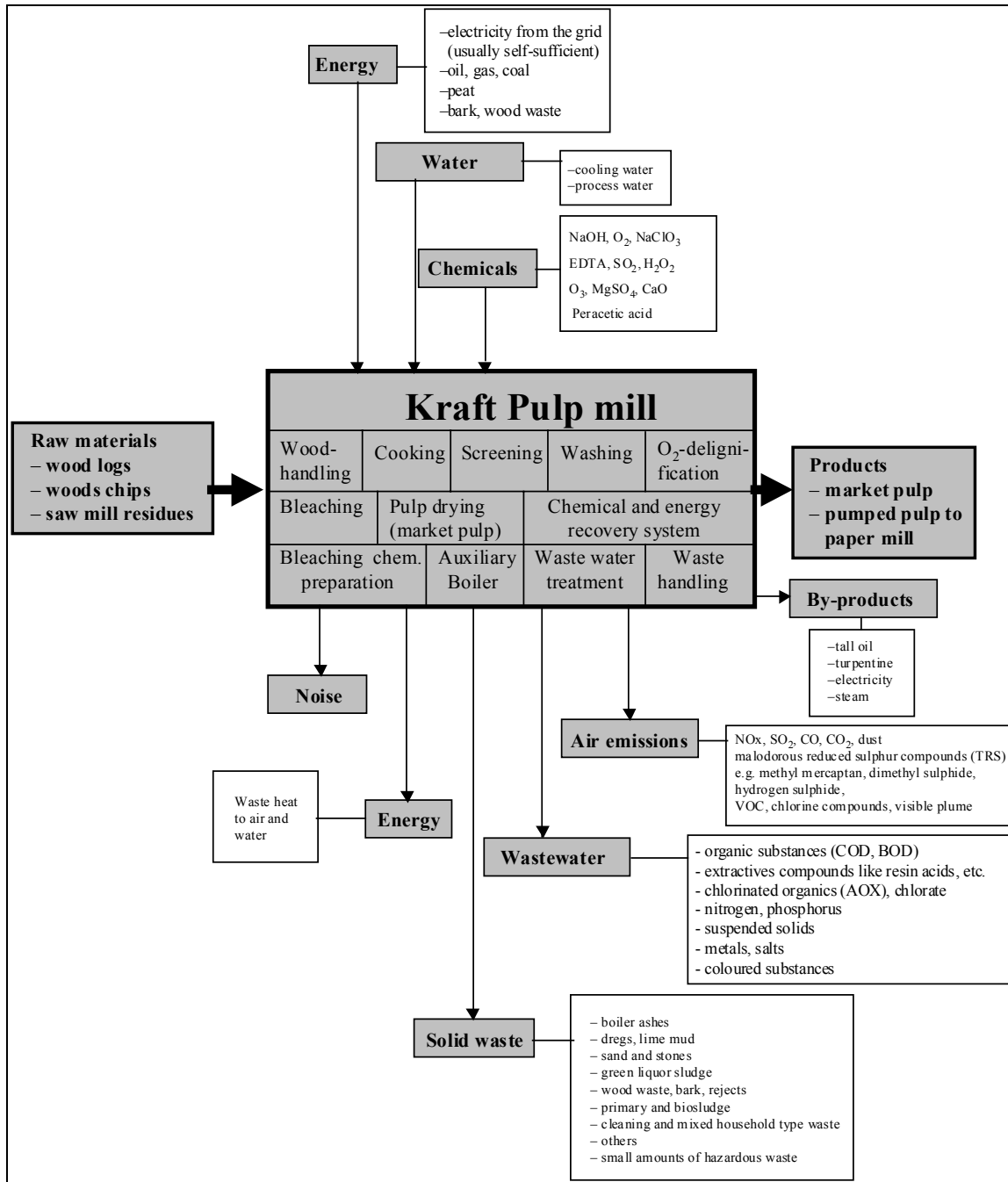


Figure 2.4: Mass stream overview of a kraft pulp mill.

The presence of some substances depend on the way of delignification and bleaching

The subsequent sections present specific consumption data, as well as specific emission data for individual operational steps associated with kraft pulp manufacturing.

2.2.2 Consumption and emission levels arising from process units

In kraft pulping the wastewater effluents and the emissions to air including malodorous gases are the centres of interest but in the next years it is also expected that waste will become an environmental issue of concern. The most relevant consumption of raw materials and emissions to water, air and soil (waste) as well as energy aspects are discussed below covering the following aspects:

- Wood consumption
- Water consumption and wastewater emissions from different process steps
 - Woodhandling
 - Condensates from evaporators
 - Spillages
 - Washing losses
 - Bleaching
 - Discharges of nutrients
 - Discharges of metals
- Emissions to the atmosphere
 - from the recovery boiler
 - from the lime kiln
 - from auxiliary boilers
 - Malodorous gases
 - Chlorine compounds from bleaching and bleaching chemical preparation
- Solid waste generation
- Consumption of chemicals
- Use of energy
- Noise

Where data are available emissions to water, air or soil (waste) are given before and after external treatment.

As for the reported emission and consumption figures, it should be borne in mind that, due to the use of some different measurement methods in the various Member States, data are not always strictly comparable from country to country. (See Annex III for more information on this issue but the different methods used do not alter the conclusions drawn in this document).

2.2.2.1 Wood consumption

All wood species can be used as raw material in the kraft pulp process. Logging and sawmill residues can also be pulped with the kraft pulp process. The use of wood and the yield for production of bleached pulp is dependent on the selectivity in delignification and bleaching. The wood required for manufacturing 1 tonne of chemical pulp is normally between 4 and 6.6 m³. In forestry the volume is measured as wood under bark. The density of wood varies with species but is between about 0.4 and 0.6 g/cm³. The amount of bark varies also, but is about 12 - 15% by weight.

2.2.2.2 Water consumption and waste from different process steps

As shown in Figure 2.5 emissions to water from a kraft pulp mill including a bleach plant originate from different process stages. They also include accidental spills.

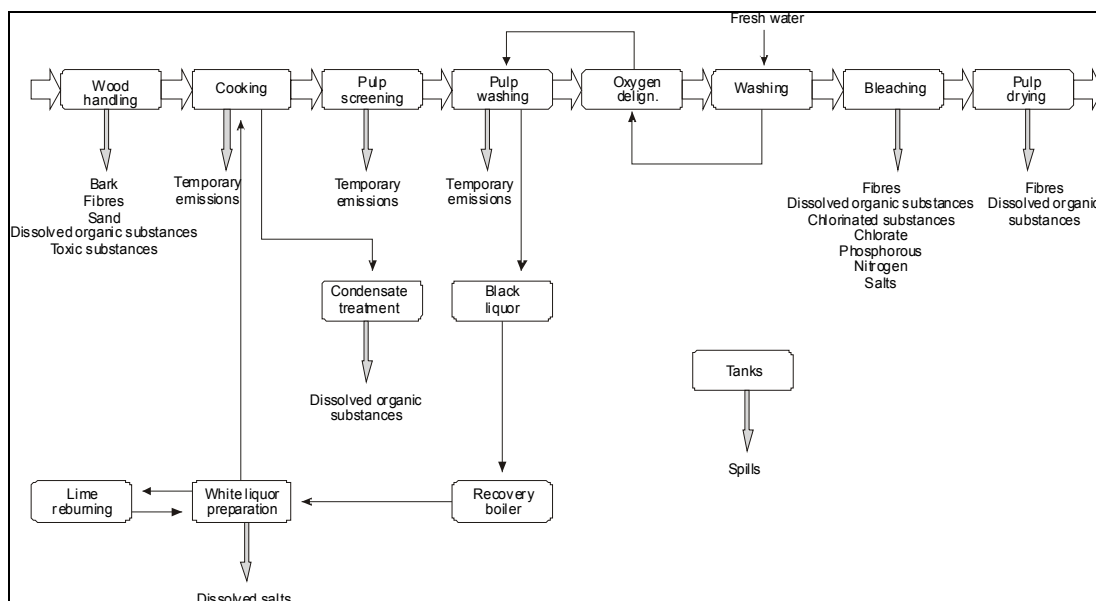


Figure 2.5: Emissions to water from a kraft pulp mill

Emissions to water are dominated by oxygen consuming organic substances, which are measured as COD and BOD. Effluent from bleach plant, where chlorine-containing bleaching chemicals are used, contains organically bound chlorine compounds, measured as AOX. Some compounds discharged from mills show toxic effects on aquatic organisms as some of the extractive components like resin acids that may be leached from bark in the wood handling. Emissions of coloured substances may affect the living species in the recipient negatively, since the water transparency is decreased. Emissions of nutrients (nitrogen and phosphorous) have a negative impact due to eutrophication. In lower concentration individual metals extracted from the wood can be determined in the effluents.

The water consumption varies considerably between different mills in EU or by more than a factor 10 or between 15 and 100 m³/t. Figures higher than about 50m³ are normally due to the fact that clean cooling water is included. Water consumption can be reduced in a pulp and paper mill by increasing internal water recirculation. In a kraft pulp mill, it can be realised e.g. by transferring wet debarking to dry debarking, by changing over to more efficient washing equipment, by recycling alkaline bleach filtrate, by using the condensates from evaporation and by closing the screen room with respect to water. There is a difference in water management between integrated and non-integrated pulp mills. In an integrated mill the pulp will come from the pulp process to the papermaking process at about 4% consistency and wastewater from pulping and from papermaking are usually treated in one single treatment plant. In non-integrated pulp mills the market pulp has to be de-watered and dried.

The volume of water used is closely linked to the wastewater load discharged from the mill. The pollution depends mainly on the design and operation of the processes that cause the major part of discharges and on the degree of closure of the mill. The main sources of wastewater and the corresponding load of pollutants are discussed in the following.

Wastewater from woodhandling

Stormwater run-off from the wood-yard might be polluted. The major source of pollution in woodhandling is however the debarking plant. It consumes water and creates an effluent containing nutrients, fibres and oxygen-consuming organic compounds like resin acids, fatty acids etc. that are toxic to aquatic life before treatment. Biological treatment has proven to be very efficient in eliminating toxicity. In a transfer from wet to dry debarking, water consumption and discharges are reduced. The dryness of the removed bark is however only marginally influenced. This is due to the fact that dry debarking means that water is recycled not that water is not used. In wet debarking 0.6 to 2 m³ of water is used per solid m³ of wood. Dry debarking still uses 0.1 to 0.5 m³ water per m³ of wood to wash the logs and some organics are dissolved but to a lesser extent compared to wet debarking.

Dryness of the bark can be increased by pressing or drying the bark. An increase in dryness will improve heat generation but result in an increased pollution load. Spans in pollution load in debarking effluents are given in Table 2.3 below.

Debarking technique	Effluent Volume m ³ /m ³ wood	BOD ₅ kg/ m ³ wood	COD kg/ m ³ wood	Tot-P g/ m ³ wood
Wet debarking and press	0.6 - 2	0.9 - 2.6	4 - 6	5 - 7
Dry debarking and press	0.1 - 0.5	0.1 - 0.4	0.2 - 2	2 - 4

Table 2.3: Pollution load of debarking effluent before biological treatment

[Finnish BAT Report, 1997]; BOD₇ has been converted into BOD₅ by use of the formula $BOD_7/1.16 = BOD_5$ proposed within the same report

Bark is normally 35 - 45 % solid contents (dryness) on the tree. After normal wet or “dry” debarking, the bark is about 30 - 35 % dryness. This can be increased to 40 - 45% in a press but then there is an additional press effluent to consider. Bark press effluent is toxic and high in COD (20 - 60 kg/m³). It could be dealt with at a chemical pulp mill by feeding it to the digester with the chips for subsequent evaporation and burning of the concentrate in the recovery boiler.

During the wintertime in northern countries frozen logs and snow must be melted before debarking. This can be done in the debarking drum with hot water or steam or on special de-icing conveyors before the debarking drum. At any given installation the water consumption and discharges from dry debarking will increase and will then be in the middle to upper range given in the above table.

Condensates from cooking and evaporation

Condensates originate from the process vapours from digesters and the evaporation plant. About 8 - 10 m³/ADt of total condensates are formed with a COD load of about 20 - 30 kg/t and 7-10 kg/ADt of BOD₅. The COD is mainly methanol (5-10 kg/Adt) with some ethanol and a number of organic sulphuric compounds (1-2 kg/Adt TRS), 1-2 kg turpentine and inorganic nitrous compounds. Foul condensate contains furthermore ketones, terpenes, phenolics, resin and fatty acids and various dissolved gases. A large proportion of nitrogen discharged from a Kraft pulp mill is contained in condensates.

About 1 m³ of condensate per tonne of pulp has a COD concentration of 10 - 20 kg/m³. The level is higher in condensates from hardwood pulp than from softwood. These strong condensates are normally treated in a stripper where the removal efficiency for most compounds is over 90% depending on the pH. Stripping systems usually remove malodorous gases (TRS) and COD contributing substances at the same time. Stripped condensates after treatment can be

1 - 1.5 kg COD/m³ of condensate. Normally about 0.2 tonnes of steam/tonne of condensate is fed to the stripper column. Energy saving techniques enable lowering steam consumption from 0,2 t steam/t of condensate down to 0.02-0.04 t steam/t of condensate. The stripped gases are either incinerated in a dedicated burner with subsequent SO₂ scrubbing or burnt in the lime kiln.

About 7 - 9 m³ of weaker condensates are formed with COD ranging from 0.5 to 2 kg/m³ containing a total of about 8 - 12 kg of COD/t of pulp. These condensates are free of metals and therefore particularly useful for washing in the bleach plant when aiming at closing up this part of the process. They can also be reused as scrubbing liquor for lime kilns or as white liquor make-up water. This means that some condensates will be used in closed parts of the process and not discharged to waste. Other condensates will be used in open parts, e.g. the bleach plant, and end up in the effluent together with those condensates, which are not reused but discharged directly to waste. Measured as COD, the total discharges of condensates to effluent are normally about 4 - 8 kg COD/t of pulp but this is mostly readily biodegradable.

Alternatively, moderately contaminated condensates can be stripped in a system linked to the evaporation plant thereby effecting treatment without any substantial additional use of energy. In this way the total COD load before any reuse is reduced to about 5 kg/t, a reduction of about 50% compared to only treating the most contaminated condensates.

Spills from different process departments

Spillage of fibres and black liquor occurs in the digestion plant, screening plant, and during washing. There are also spillage from the evaporation plant and from tanks. Spillage of white liquor, weak liquor, lime etc. occurs during causticizing. Most spills can be collected and recycled if adequate buffer volumes are used and appropriate procedures employed. Leakage from mechanical components such as pumps can be limited e.g. by choosing the right seals.

The conductivity or the fibre content of individual outflows of wastewater is normally checked in order to decide which liquids spilled are recycled in the process and which are directed to waste. Improved collection of spillage can be achieved if clean water, such as cooling and sealing water, is piped off separately. The remaining spillage water can then be more easily recycled in the appropriate part of the process.

Measured as COD, discharge of organic matters in spills is normally between 2 and 10 kg/t pulp. The lower figure is achieved using sufficiently large buffer volumes and proper supervision procedures. It should in principle be possible to reduce discharges of spills to zero if clean cooling and sealing waters are piped off separately, sufficient buffer volumes are in place and good house-keeping practised.

Improved collection of spillage not only reduces discharges to water but is also a reuse of valuable resources like chemicals, fibres and energy.

Black liquor residues (washing losses) from the handling of unbleached pulp

Pulp washing efficiency in chemical pulping relates initially to recovering as much as possible of the cooking chemicals and of dissolved organic substances. Press washing at the ultimate stage can reduce the amount of water from 6 - 10 m³/t of pulp to 2 - 3 m³/t thereby increasing the amount of chemicals and contaminants eventually burnt in the recovery boiler. The reduction of contaminants in the pulp is however less than the reduction of flow indicates. Washing is not 100% efficient so a certain amount of chemicals and pollutants is transported with the pulp to the bleaching stage where it consumes bleaching chemicals and enters the effluent.

Standardised methods exist for measuring this carry over which is often denoted "washing loss" and was originally measured as kg sodium sulphate per tonne of pulp. As this loss of make-up chemical has become less important for the process and environmental protection more, the washing loss is now normally measured as COD. Washing losses are currently typically 5 - 10 kg of COD/t for softwood and 7 - 12 kg of COD/t for hardwood.

Discharges from the bleach plant

The bleach plant is the most important point of discharge of pollutants to water in a pulp mill. If the bleachery can be wholly or partly closed, this would result in substantial further reductions in discharges to water of organic substances, nutrients and metals. Typical figures for wastewater quantities from a bleachery are 20 - 40 m³ water per tonne of pulp. Many mills have tried to increase the degree of closure of the bleach plant by reducing the water volume. Partial closure of the bleach plant is currently achieved at both ECF and TCF-plants. Compared to open bleacheries the reduction in COD-load has been 25-50 % and the reduction in flow even higher or down to 5-10 m³/t pulp compared to the more normal 25 m³/t pulp.

The emissions from the bleach plant depend on a number of factors: the degree of delignification achieved before the pulp enters the bleachery, the washing loss, the bleaching sequences chosen and bleaching chemicals used, the type of wood, the final brightness of the bleached pulp to be attained and the degree of closure of the bleach plant.

In Table 2.4 examples for the interrelation between wood-type, techniques and degree of delignification before the bleach plant, and COD generated during bleaching are compiled. The kappa numbers are based on values currently attained on a commercial scale using various delignification techniques. The calculation for the discharge of residual lignin in kg COD/t pulp assumes a discharge of approximately 2 kg COD per kappa unit and a pulp to be bleached to full brightness. However, where the kappa number is less than 10 the discharge of COD is closer to 1.5 kg per kappa unit [OSPAR, 1994].

Cooking Method	Oxygen Delignif./ Ozone Bleaching	Hardwood pulp		Softwood pulp	
		kappa	COD [kg/ADT]	kappa	COD [kg/ADT]
Conventional Cook.	---	18	38	30	63
Conventional Cook.	Oxyg. Delign.	13	27	15	32
Modified Cooking	---	16	34	20	42
Modified Cooking	Oxyg. Delign.	10	15	12	25
Further Modified C.	---	13	26	15	30
Further Modified C.	Oxyg. Delign.	10	15	10	15
Conventional Cook.	Ox. Delig.+Ozone	N.I.	3	N.I.	6
Explanatory note: N.I. = No information available					

Table 2.4: Expected discharge of residual lignin measured as COD from bleach plants for different delignification techniques [OSPAR, 1994]

Chlorinated organic substances (AOX)

Since many years the public debate on the pulp and paper industry has focussed on discharges of chlorinated organic substances. A different perception of the impact of chlorinated compounds in the public enhanced the environmental pressure on pulp mills in Western Europe and thus, a change in the marketing concepts of the mills virtually stopped the use of molecular chlorine for bleaching of pulp. This means that the formation of chlorinated dioxins and dibenzofurans has virtually ceased and the degree of chlorination of the remaining chlorinated substances has declined. At the same time, the composition of AOX formed has undergone a change parallel with the reduction of AOX discharges from pulp mills. For example, phenolic compounds with 3-5 chlorine atoms in the atomic ring, i.e. the phenolic compounds that degrade most slowly and are most toxic, have decreased significantly below 1 g/t ADP. In recent years, following market demands, some mills have completely eliminated the use of bleaching

chemicals containing chlorine by combining oxygen delignification with an ozone stage and/or a peroxide stages.

For both, softwood and hardwood pulp, the following tables give examples for different bleaching sequences used in European pulp mills and the corresponding discharge of chlorinated organic substances, measured as AOX. The tables include delignification techniques, bleaching sequences, kappa numbers, use of chlorinated bleaching chemicals and discharges of chlorinated organic substances before treatment.

Cooking techniques	Bleaching sequences	kappa	ClO ₂ [kg/t]	AOX [kg/t]
Conventional Cooking	D(EOP)DED	30	95	2
Conv. Cooking + Oxy. Delign.	D(EOP)DED	16	60	0.8
Modified Cook. +Oxy. Delign.	D(EOP)D(EP)D	10	30	0.3
Conv. Cooking + Oxy. Delign.	ZD	No inf.	10	0.1
Modified Cook. +Oxy. Delign.	ZP	No inf.	0	0
Notes: "D" means Chlorine Dioxide; "E" means Extraction; "O" means Oxygen; "P" means Peroxide; "Z" means Ozone				

Table 2.5: Examples for different sequences for bleaching of softwood pulp used in European pulp mills and the corresponding discharge of chlorinated organic substances measured as AOX [OSPAR, 1994]

Cooking techniques	Bleaching sequences	kappa	ClO ₂ [kg/t]	AOX [kg/t]
Conv. Cooking + Oxy. Delign.	D(EO)DED	13	40	0.5
Modified Cook. +Oxy. Delign.	D(EOP)DED	10	30	0.3
Conv. Cooking + Oxy. Delign.	ZD	No inf.	5	0.1
Modified Cook. +Oxy. Delign.	ZP	No inf.	0	0
Notes: "D" means Chlorine Dioxide; "E" means Extraction; "O" means Oxygen; "P" means Peroxide; "Z" means Ozone				

Table 2.6: Examples for different sequences for bleaching of hardwood pulp used in European pulp mills and the corresponding discharge of chlorinated organic substances measured as AOX [OSPAR, 1994]

Pulps entering the bleach plant with low kappa numbers require less bleaching chemicals. For example, if the kappa number is below 10, the need of chlorine dioxide as active chlorine can be limited to about 30 kg/t for softwood pulp, equivalent to about 6 kg chlorides. Another 1 kg chlorides/t comes with the wood. The amount of chloride resulting from bleaching stages with chlorine containing chemicals is of concern because one reason why it is not been possible to recycle bleachery wastewater to the closed system is its content of chlorides. These chlorides cause corrosion in the process equipment if they cannot be expelled in the effluent.

Summary of discharge before treatment

Discharges of organic substances

The volume and total load of organic substances of effluents discharged from different process steps after primary treatment are summarised in Table 2.7.

Process stage	COD kg/ADt
Wood handling	1 - 10
Condensates	2 - 8
Spillage	2 - 10
Washing loss	6 - 12
Bleaching	15 - 65
Total from mills	31 - 105

Table 2.7: Discharges of organic substances before external treatment from kraft pulp mills
The differences between softwood and hardwood are quite small and the following figures for subprocesses are not monitored on a continuous basis while the total figure is based on available data on annual averages and on continuous and flow-proportional sampling [OSPAR, 1994], [Finnish BAT report 1996], [CEPI 97]

At present the lowest total discharges after primary treatment in bleached kraft pulp mills are 25-30 kg COD/t of pulp for softwood. One Portuguese eucalyptus pulp mill (hardwood) reported 17.3 COD/t pulp as a yearly average in 1997 and 21.7 COD/t pulp in 1998 after primary treatment only.

Discharges of nutrients

Nutrients originate mainly from the wood itself although biological effluent treatment may require the addition of nutrients if deficient. Studies at kraft pulp mills have shown that nitrogen discharges principally derive from the unbleached part of the process, whereas phosphorus discharges come from the bleachery.

The prospects of reducing nutrient discharges from the process are mainly dependent on the possibilities of further processing of the condensate and further delignifying the pulp in the closed part of the process. Data below gives an indication of specific figures for phosphorus and nitrogen discharges in kg/t of kraft pulp **before** treatment.

Process	Phosphorous kg/ADt	Nitrogen kg/ADt
Unbleached	0.01-0.04	0.2-0.4
Bleachery	0.04 -0.06	<0.1*
Total from mill	0.05 -0.10	0.2-0.4*
Note: * Use of chelating agents can increase this figure of nitrogen by about 0.1 - 0.2 kg/t. Chelating agents will normally end up in the white water. Some mills add the chelating agents (also) in the closed part of the process. In this case the complexing agents end up in the recovery boiler i.e. are incinerated.		

Table 2.8: Discharges before treatment of phosphorus and nitrogen in kg/t of kraft pulp [OSPAR, 1994]

Discharges of metals

The wood used contains metals, which are discharged with the wastewater. As is the case for phosphorus a reduction in discharges of metals is probably possible by increasing the degree of process closure but options for external treatment to reduce metals are very limited.

	Cd	Pb	Cu	Cr	Ni	Zn
Unbleached pulp	0.03	0.3	0.5	0.2	0.4	5
Bleached pulp	0.1	0.4	1	0.7	0.9	15

Table 2.9: Discharges of metals from Kraft pulp mills in g/Adt [OSPAR, 1994]

Summary of discharge after external treatment

Minimum current external treatment is sedimentation and for pulp mill effluents secondary biological treatment is commonly also applied. Data below show variations in total treatment effects of sedimentation and biological treatment of kraft pulp mill effluents as % reductions. The more recent plants have reduction figures in the upper part of the ranges given. Aerated lagoon can be modified to incorporate sludge recycling. In that case, the treatment efficiency approaches that of an activated sludge plant.

Reduction rate of	BOD₅ [%]	COD [%]	AOX [%]	P [%]	N [%]
Aerated lagoon	40 - 85	30 - 60	20 - 45	0 - 15	0
Activated sludge	85 - 98	40 - 70	40 - 65	40 - 85	20 - 50

Table 2.10: Percentage reduction at wastewater treatment plants at chemical pulp mill [OSPAR, 1994], [Finnish BAT report, 1996]

Alternatives to activated sludge exist which are more compact and less expensive. The experience from such installations is more limited but they are claimed to have equivalent reduction levels to activated sludge.

Data on current discharges to water expressed as loads based on available data from kraft pulp mills within EU are given in Table 2.11.

	Flow [m³/t]	BOD₅ [kg/t]	COD [kg/t]	AOX [kg/t]	TSS [kg/t]	Tot-N [kg/t]	Tot-P [g/t]
Unbleached pulp	20 -80	1- 20	7 - 50	---	0.2 - 15	0.1 – 1	3 - 40
Bleached pulp	30 – 110 ¹⁾	0.2 - 40	4 - 90 ²⁾	0 - 2	0.2 - 10	0.1 - 0.8	5 - 90
Explanatory notes: 1) Figures above 50 m ³ /t is normally due to that cooling water is included 2) A green-field mill starting to operate in 1996 reports 4 kg COD/t as annual average for 1998.							

Table 2.11: Reported annual average discharges from kraft pulp mills within EU [Finnish BAT report, 1996], [SEPA Report 4869], [Finnish Forestry Industries Federation, 98], [CEPI 97]. The figures have been derived from the different analytical methods that are described in ANNEX III. All of these methods are considered to yield equivalent results. Water samples analysed have been homogenised and are unfiltered and undecanted. Figures given are long time averages, normally annual values.

2.2.2.3 Emissions to the atmosphere

An overview of the emissions to the atmosphere from a kraft pulp mill is shown in Figure 2.6.

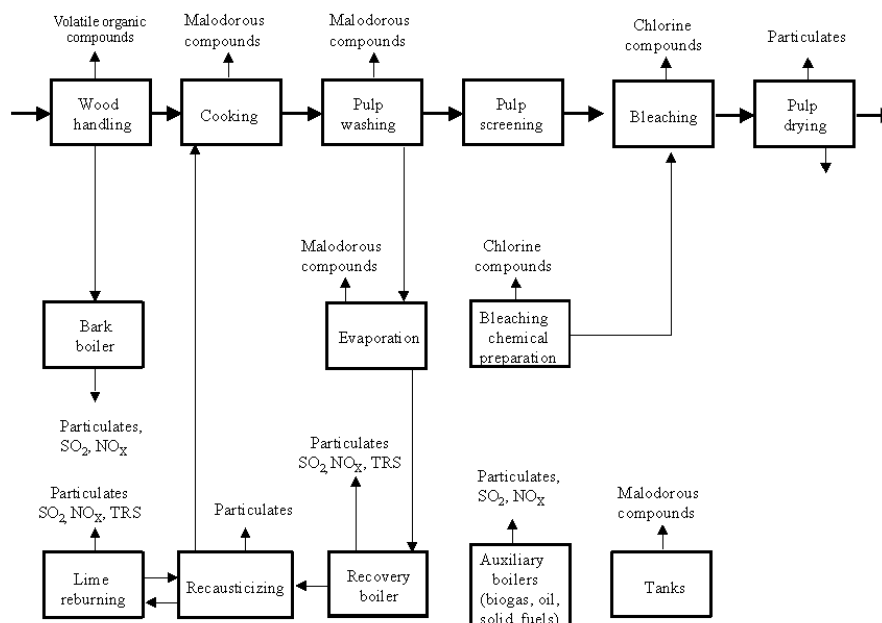


Figure 2.6: Emissions to the atmosphere from kraft pulp mills

Emissions to the atmosphere from a kraft pulp mill originate from chip storage, cooking digester, pulp washing, bleaching plant, bleaching chemical preparation, chemicals recovery, evaporation, bark furnace, recovery boiler, white liquor preparation, lime kiln, tanks and pulp drying (only for market pulp). They consist mainly of sulphur-containing compounds such as sulphur dioxide and malodorous reduced sulphur compounds like methyl mercaptan, dimethyl sulphide, and hydrogen sulphide. The latter compounds are commonly referred to as total reduced sulphur (TRS). From furnaces nitrogen oxides are also emitted and furthermore small amounts of dust (solid particulates) as fly ash. From bleach plants and from bleaching chemical preparation chlorine compounds may leak to the atmosphere. Volatile Organic Compounds (VOCs) mainly turpenes, are emitted to the atmosphere from wood chips stored in heaps outdoors the process. The VOC emission from chip piles vary among other things with the time chips are stored, temperature and the wood species. In the following the major sources of air emissions are discussed in more detail.

2.2.2.3.1 Air emissions from the recovery boiler

The recovery boiler is a major source of atmospheric emissions in a kraft pulp mill. Emissions are mainly represented by sulphur dioxide. In addition there are emissions of particulates (primarily sodium sulphate and sodium carbonate), nitrogen oxides and malodorous compounds (hydrogen sulphide).

The recovery boiler is fed with the evaporated black liquor. Approximately one third of the dry substance in the evaporated liquor consists of inorganic chemicals and two thirds are dissolved organic substance. After a conventional evaporation the black liquor (strong liquor) has a dry solids content of about 65%. The aim of evaporation is to achieve a high dry solids (DS) content in the thick black liquor fed to the recovery boiler in order to generate more steam. By installing

further equipment a dry solids content of 75 - 80+ % can be achieved. The sulphur emissions from the boiler will typically be reduced by about 80% when the DS content is increased from 65 - 67 to 74 - 76 % due to higher temperature in the recovery boiler and the more favourable incineration conditions. Some examples exist however where emissions of S have not reduced beyond DS of 72 - 73%. A drawback to the higher temperature is that emission of NO_x can increase. The recovery boiler is equipped with an electrostatic precipitator in order to remove the large amount of particulates (mainly Na₂SO₄) from the flue gases. The dust is fed back into the furnace by mixing into the strong black liquor. Additionally, recovery boilers are often equipped with a scrubber in order to decrease the emission of SO₂.

Typical emissions to air from recovery boilers are given in Table 2.12. The gas flow is normally about 6000 - 9000 m³ ndg/t of pulp while process steam production is between about 13 and 18 GJ/t of pulp. Due to the lower yield for softwood pulping this figure is higher for softwood than for hardwood. An increased closure of the process also has a higher energy production as a consequence.

Sulphur dioxide		
- without scrubber and 63-65 % DS of black liquor	100-800 60-250 1-4	mg/m ³ n mg/MJ kg/ADt
- with scrubber and 63-65% DS of black liquor	20-80 10-25 0.1-0.4	mg/m ³ n mg/MJ kg/ADt
- without scrubber and 72-80 % DS of black liquor	10-100 12-30 0.2-0.5	mg/m ³ n mg/MJ kg/ADt
Hydrogen sulphide ¹⁾		
- over 90% of the time (90 percentile)	< 10 < 0.05	mg/m ³ n kg/ADt
- temporarily	higher	
Nitrogen oxides (as NO ₂)	100-260 50-80 0.6-1.8	mg/m ³ n mg/MJ kg/ADt
Particulates		
- after electrostatic precipitator	10-200 0.1-1.8	mg/m ³ n kg/ADt
Notes:		
1) Level corresponding to Swedish emission limitation		

Table 2.12: Emissions from Kraft pulp recovery boilers in kg/ADt at a gas flow of about 6000 - 9000 m³/t
[Mainly from SEPA report 4008, 1992]

In the following the main principles and operating variables that influence the emissions from the recovery boiler are discussed to explain the complexity of pollution prevention at this installation.

Figure 2.7 below shows some principal inorganic reactions in a recovery boiler and also where in the furnace the reactions take place. In a conventional recovery boiler there is an oxidising zone in the upper part and a reducing zone in the lower part. The strong liquor is introduced through one or several nozzles into the reducing zone. Combustion air is mostly supplied at three different levels as primary, secondary and tertiary air (from the bottom up).

A smelt consisting mainly of sodium sulphide (Na_2S) and sodium carbonate (Na_2CO_3) is formed at the bottom of the furnace. When the sulphur is reduced to sulphide in the smelt also some hydrogen sulphide is formed. Small amounts of hydrogen sulphide may leave with the flue gases if the air supply is not sufficient or if the mixing of air into the furnace is incomplete. Temporary high emissions of hydrogen sulphide from the smelt may occur as a consequence of disturbances caused by deposits of dry substances on the furnace walls falling into the smelt. In the oxidising part of the furnace, the sulphur is oxidised to sulphur dioxide and sodium in the gas phase reacts with the sulphur dioxide to form sodium sulphate. A higher dry solids content leads to a high temperature in the furnace and thus a lower emission of hydrogen sulphide and a higher emission of sodium. The higher sodium emission means that more sulphur is bound as sodium sulphate and thus the emission of sulphur dioxide is decreased.

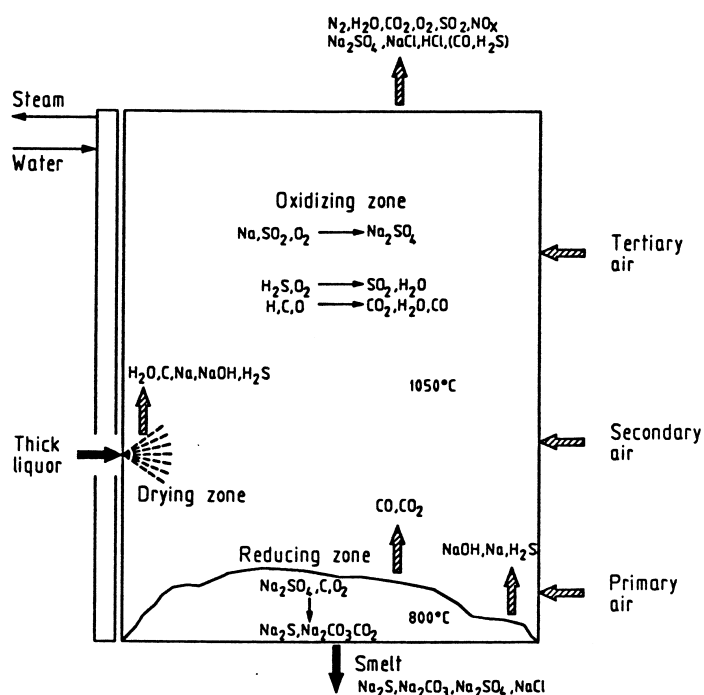


Figure 2.7: Some conceptual chemical reactions in a recovery boiler [SEPA report 4008, 1992]

In general, the emission of sulphur from the recovery boiler is influenced by the following operating variables:

- temperature in the different zones which on the other hand is influenced by the heating value and dry solids content of the strong black liquor and the amount of combustion air
- the sulphur-to-sodium ratio (S/Na_2) in the liquor (sulphidity). A high S/Na_2 -ratio means that the release of sodium in the furnace in relation to the sulphur amount is not sufficient to bind the sulphur and thus a larger share of the sulphur leaves the furnace as sulphur dioxide instead of sodium sulphate. High dry solid contents of the black liquor may compensate this effect.
- supply (amount of air excess and primary air temperature) and distribution of combustion air
- distribution of the black liquor across the boiler area
- the load on the furnace. Operating a recovery boiler in an overloaded mode has an adverse effect on the emissions characteristics, especially on the quantity of hydrogen sulphide produced.

A general observation is that even if general indications of emission levels can be given, each recovery boiler is an individual and optimum conditions have to be carefully sought.

In order to decrease the SO₂ emissions from the recovery boiler it is often equipped with a flue gas scrubber operating at pH 6-7. pH is controlled by adding sodium hydroxide (NaOH), weak liquor or oxidised white liquor. A higher pH would remove hydrogen sulphide but carbon dioxide would be absorbed which would quickly neutralise the alkali. Surplus liquor from a scrubber is recycled to the process, normally to the white liquor preparation.

The formation of NO_x in a recovery boiler is mainly influenced by the nitrogen content in the black liquor and excess O₂ during combustion. The NO_x formation per MJ input is generally low due to the relatively low oxygen concentration needed for an efficient recovery of chemicals and the emission of NO_x normally varies between 1 and 2 kg/t of pulp.

An increase in excess O₂ from 1.5 to 2.5% may increase NO_x by about 20% and increased DS content from 65 to 75% may increase NO_x by up to 20%. The nitrogen content is higher in hardwood liquors than in softwood which can also result in about 10% higher NO_x.

Reduced NO_x can normally be achieved by modifications to the air feed system and optimising combustion conditions. Emissions are normally between 50 and 80 mg/MJ but new recovery boilers can achieve levels down to about 40 mg/MJ or well under 1 kg NO_x/t (e.g. Moensteras mill, Sweden).

2.2.2.3.2 Air emissions from the lime kiln

In the lime reburning process the calcium carbonate formed during the recausticising process (see Figure 2.3) is thermally converted back to calcium oxide according to the reaction equation $\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$. The reaction takes place in a rotary kiln where wet lime mud is dried, heated up to the reaction temperature, calcinated and cooled again. The calcination reaction starts at 800°C and to complete the reaction temperatures up to 1000-1100°C are required in the hot end of the kiln. The cooling is done by air in heat exchangers. The gas flow in a lime kiln is about 1000 Nm³/t (dry gas) of pulp and the energy used is about 1.5 - 1.8 GJ/t of pulp.

The major air emissions from the lime kiln are sulphur dioxide, nitrogen oxides, reduced sulphur compounds (TRS) and particulate matter. Typical emissions to air from a lime kiln are shown in Table 2.13.

Sulphur dioxide - oil firing without non-condensable gases	5-30	mg/m ³ n	
	2.5-16	mg/MJ	
	0.003-0.002	kg/ADt	
- oil firing with non-condensable gases	150-900	mg/m ³ n	
	80-740	mg/MJ	
	0.1-0.6	kg/ADt	
Hydrogen sulphide - normally	< 50	mg/m ³ n	
	< 0.03	kg/ADt	
	- temporarily higher		
Nitrogen oxides (as NO ₂) - oil firing	240-380	mg/m ³ n	
	130-200	mg/MJ	
	0.2-0.3	kg/ADt	
	- gas firing	380-600	mg/m ³ n
	200-320	mg/MJ	
	0.3-0.4	kg/ADt	
Particulates - after electrostatic precipitator	20-150	mg/m ³ n	
	0.01-0.1	kg/ADt	
	- after wet scrubber only	200-600	mg/m ³ n
	0.1-0.4	kg/ADt	

Table 2.13: Typical emissions to air from a lime kiln

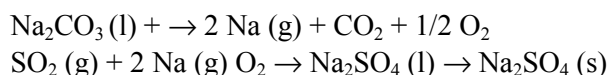
[SEPA report 4008, 1992]; The higher SO₂ values when firing with non-condensable gases are caused by the fact that the capacity of the lime kiln to trap sulphur is often not sufficient if all TRS containing air is treated in the lime kiln.

The emissions from the lime kiln in a kraft mill are mainly affected by solids retention time, gas contact area, type of fuel and temperature.

SO₂ emissions

Sulphur emissions from the lime kiln are due to sulphur in the fuel and malodorous gases if such are burnt. The role of sulphur entering the sulphur with lime mud is in this respect marginal.

A limited amount of sulphur can be absorbed in the lime kiln by gaseous Na forming sodium sulphate according to the reaction equations



The main sulphur absorbing compound is thus the sodium carbonate (Na₂CO₃) in the lime mud. When this capacity is exhausted, SO₂ is released. This effect is enhanced when malodorous non-condensable gases are incinerated in a kiln. Therefore, SO₂ emissions are usually a clear function of the amount of malodorous gas flow.

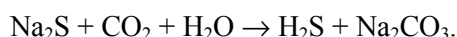
To minimise the formation of SO₂ either the sulphur content in the fuel can be reduced or if malodorous non-condensable gases (NCGs) are to be burnt in the lime kiln, sulphur compounds can be scrubbed out of these gases prior to burning in the lime kiln. A small internal NaOH scrubber for the malodorous gas flow (i.e. not for the total flue gas flow) will reduce H₂S almost completely while the methylsulphides are reduced by about 50 - 70 % and methylmercaptane by

less than 20%. Typical total S emissions from lime kilns are ten up to several hundred mg/m³ if NCGs are burnt and 10 - 30 if they are not.

Total Reduced Sulphur emissions (TRS)

The TRS emissions from a lime kiln consist mainly of hydrogen sulphide. Observed H₂S concentrations are normally less than 50 mg/m³ (90 percentile) resulting in a total emission of <0.03 kg/t.

H₂S formation in the lime kiln depends on oxygen levels and the amount of sodium sulphide in the mud burnt in the kiln. The presence of sufficient excess air can be ensured by a residual oxygen control system. The sodium sulphide content can be controlled by properly operated lime mud washing and filtering so that sodium sulphide (Na₂S) is prevented from entering the lime kiln. If Na₂S enters the cold drying and heating section of the lime kiln in the presence of CO₂ and water H₂S is formed according the reaction equation



With a proper capacity of the lime mud filter a small amount of air is sucked through the lime mud cake and the residual Na₂S left on the surface of lime mud particles is then oxidised to sodium thiosulphate that does not cause any H₂S formation in the kiln. If H₂S problems arise, the reason is in many cases poor lime mud quality in terms of lime mud dry solids content (normally over 80%) and purity (low free alkali concentration is required). Technical options are improvement of green liquor clarification and the lime mud washing or replacing a part of the lime with make-up lime.

Particulate matter

Particulate matter is made up of lime dust and sodium condensed out of the vapour phase. The emissions can be controlled internally by design and proper running of the kiln and externally by adding an electrostatic precipitator or a scrubber. An electrostatic precipitator is capable of reducing the concentration of particulates down to about 20 - 100 mg/m³ and a water scrubber to about 200 - 600 mg/m³.

Nitrogen oxides (NO_x)

NO_x emissions are mainly correlated to burner design and for a particular burner, to nitrogen content of the fuel and combustion temperature. An increase in emissions would result from the use of fuel with a higher content of nitrogen. Both incineration of NCGs and use of biogas and methanol as fuel, increase NO_x formation.

NO_x concentrations are from about 100 mg/m³ when only tall oil is used, up to about 900 mg/m³ with NCGs and methanol together with bark powder, pyrolysis gases or fossil oil.

2.2.2.3.3 Air emissions from auxiliary boilers

Bark boilers

Bark will burn autothermically at about 20% dryness. Before incineration the loose bark and wood sticks removed from the logs in the debarking drum is fed into a bark shredder and is finally pressed to a dryness of 38-45%. The consumption of energy in a press is about 5 kWh/t of bark having an initial dryness of about 35% and the increase in heat generation is about 2 GJ/t_{45%} if the dryness increases from about 35 to 45%. At 45% dryness, bark represents a heat value of about 7 - 8 GJ/t and it can be used as a source of energy within the plant or sold as a by-product, e.g. as pellets. At the plant it is normally used in an auxiliary boiler. If it is to be used as fuel within the process or sold as pellets it must first be dried to up to about 90% dryness. It can then, after either been gasified or pulverised, be used e.g. in the lime kiln.

Bark is used as power plant fuel in pulp mills to a large extent. As bark contains only small amounts of sulphur, there will be only low sulphur dioxide emissions depending if other sulphur-containing fuels are added. When bark is being burnt together with fuels that contain sulphur (e.g. fossil fuels), the alkaline bark ash binds some of the sulphur and thus reduces the emissions.

In bark boilers the emission of nitrogen oxides will also be lower than in the burning of other kinds of fuel due to the low combustion temperature. Emissions are typically 70 - 100 mg/MJ when only bark is fired but at times when oil is used in the boiler an increase to about 100 - 150 mg/MJ will be the case. Excessive oxygen increases NO_x formation but lower excess oxygen levels increase CO and VOC. The total NO_x-reduction achievable in a bark boiler is about 30-50% by making changes in combustion techniques and/or applying an SNCR-process (Selective Non-Catalytic Reduction). Examples for the application of the SNCR process on bark boilers can be found for instance in some Swedish mills (Nymölla, Husum).

Given a heat production from bark of about 7 GJ/t of bark the range of NO_x emissions is about 0.3 - 0.7 kg/t bark. The lower figure represents optimised combustion conditions and/or the use of SNCR where urea is used to reduce NO to nitrogen, carbon dioxide and water. The NO_x emissions would then be about 40 - 60 mg/MJ or 100 - 200 mg/m³ (NTP, dry gas).

Dust emissions are normally reduced to about 20 - 40 mg/Nm³ (dry gas) at 11% O₂ when electrostatic precipitators (ESPs) are used and about 200 mg/m³ with cyclones. Emissions of gaseous sulphur are small at about 5 - 20 mg/MJ when burning bark. Some reported figures on sulphur emissions from bark boilers from Swedish mills are Stora Fors 7, Mörrum 19, Norrsundet 20, Ortviken 15, Skoghall 13, Dynäs 10 mg S/MJ fuel input to the boilers. Probably some of the S in the bark is removed with the ashes.

Unit	S	NO _x	Particulates
kg/t	0.04-0.1 kg/t	0.3 - 0.7 kg/t	0.1 - 1 kg/t
mg/MJ	5 - 15 mg/MJ	40 - 100 mg/MJ	20 - 200 mg/m ³

Table 2.14: Emissions to air from bark boilers

Data as kg/t bark and mg/MJ respectively. Normal figures of gas flow are about 1600 - 1700 m³/t of pulp

Other steam boilers

In integrated pulp and paper mills the excess heat produced by the pulp mill is not quite enough to cover the energy consumption of the paper production. The additional demand for heat has to be produced in auxiliary steam boilers. Fossil fuel is used as support fuel in bark and sludge boilers and as the main fuel in auxiliary boilers as well. The fuels used in the boilers are coal, fuel oil, natural gas, peat, wood waste and fibrous sludge from effluent treatment. The emissions from power production are dependent on the fuel, the fuel mixture and the impurities content. For instance oil and coal contain sulphur but natural gas does not. Most of the boilers for solid fuels are circulating and fluidised boilers especially when difficult mixed fuels with varying properties are incinerated. These boilers offer the opportunity to use a wider range of fuels and generate lower emissions than grate boilers. The combustion efficiency is high due to the effective mixing of the materials and heat transfer between the solid material and the flue gas. NO_x emissions are relatively low due to the low combustion temperature (800°C -950°C). If the fuel contains sulphur, sulphur emissions can be prevented by the addition of lime to the bed. At temperatures below 900°C sulphur reacts with lime or calcium in the bark and the sulphur dioxide emissions are reduced considerably.

Type of fuel	mg NO _x /MJ	mg S/MJ	Particulates [mg/m ³]
oil	60 - 150	25 - 100 ¹⁾	20 - 200
No data for other fuels			
Notes:			
¹⁾ Sulphur content of the fuel oil: 0.1 - 0.4 %			

Table 2.15: Examples for currently observed emissions from different types of auxiliary boilers [SEPA Report 4008, 1992], [annual reports by Swedish mills to SEPA]

2.2.2.3.4 Malodorous gases

Malodorous gases in kraft pulping are normally H₂S, methyl mercaptane, dimethyl-sulphide and dimethyl-disulphide. Sometimes malodorous gases are referred to as Total Reduced Sulphur, TRS. The malodorous gas streams are generally divided into strong (concentrated) and weak (diluted) gases. The latter normally refers to a concentration of < 0.5 g of S/m³, while the more concentrated or strong gases are normally above 5 g/m³.

Concentrated gases come from digester, evaporation plant and condensate stripper. In total they add up to about 25 m³/t of pulp. The non-condensable gases from the cooking plant and the stripper gases from the steam stripping of foul condensates from the evaporation plant usually contain 1-2.5 kg S/Adt. [Finnish BAT Report, 1997] and are normally higher at hardwood pulping than at softwood due to different lignin structure.

Concentrated gases are collected and burnt either in the lime kiln, the recovery boiler or in a separate burner. If a dedicated burner is used a scrubber is normally added to control emission of the SO₂ formed.

The heat energy can be used but NO_x formation is high, up to 1 g/MJ of fuel. This level can be reduced by about 70% by optimising combustion conditions.

The advantage of burning the malodorous gases in the lime kiln is that no extra furnace is needed. In addition, the sulphur in the gas can be absorbed which reduces the emission of sulphur dioxide. However, as said above, the S-content in malodorous gases can overload the absorption capacity in the lime kiln.

On average, 15 % of the fuel used in a lime kiln can be replaced by malodorous gas. However, the variation of the amount of energy of the gas may make it difficult to produce lime of good and uniform quality. Separating off methanol from the gases minimises the problem with varying gas quality. The separated methanol can then be fed in liquid phase to the lime kiln or to a dedicated burner for malodorous gases.

Diluted gases come from e.g. from chip-pre-steaming, screening, pulp washing, smelt dissolver and ventilation of various tanks that contain black liquor etc. They add up in total to about 2000 - 3000 m³/t of pulp with 0.2 - 0.5 kg S/ADt [Finnish BAT Report, 1997].

Diluted gases at some mills are collected and burnt in the recovery boiler, in the lime kiln, or scrubbed. Scrubbing is mainly effective on H₂S. Burning the weak gases in the recovery boiler may influence the operation of the boiler and would require modification of the boiler. At some mills both weak and strong malodorous gases are burnt in the recovery boiler. Information from this practice is however limited.

In cooking and evaporation, a part of the malodorous compounds are transferred to the condensates. In addition to reduced sulphur compounds, the condensates contain methanol and some other oxygen consuming compounds (BOD load). The foul condensates are collected and treated separately as described above (see: wastewater discharges from different process steps).

2.2.2.3.5 Chlorine compounds from bleaching and bleaching chemical preparation

In bleached kraft pulp mills using chlorine dioxide as bleaching chemical chlorine compounds from the bleach plant and the ClO₂-production are released to the atmosphere. In Table 2.16 some examples of measured values are presented and compared with values set under normal conditions in permits in Sweden.

Name of the mill (reference year)	Condition in the permit [kg active chlorine/t of bleached pulp]	Measured values [kg active chlorine/t of bleached pulp]
Husum (1995,96)	0.2 annual	0.0-0.04 kg Cl ₂ and ClO ₂ as chlorine/ t of pulp; monthly grab (one 0.4)
Skärblacka (1996)	0.3 monthly	0.08 annual average
Mönsterås (1997)	0.05 annual	0 (TCF)
Gruvön (1997)	0.2 monthly	0.02 (one week average)
Skoghall (1997)	0.2 monthly	0.05 (one week average)
Skutskär (1997)		0.0004 bleachery 0.006 ClO ₂ -production

Table 2.16: Examples of measured values of chlorine emissions to air from the bleach plant and ClO₂-production from some Swedish pulp mills

Data from mills' obligatory annual reporting and from permits. The figures cover all emissions from the plant, normally measured in ventilations from the bleach plant and from chlorine dioxide production after scrubbers

Summary of emissions to the atmosphere after external treatment

Available data on annual average emissions in kg/t of kraft pulp are summarised in Table 2.17 below. To facilitate the comparison of all emissions of gaseous sulphuric compounds including SO₂ have been given as gaseous S. Emission data for the recovery boiler are normally based on continuous monitoring while the other sources are less frequently monitored. It should be pointed out, however, that not all mills report diffuse emissions and the methods for calculating and reporting the total emissions vary between mills and between the Member States.

Source of emission	Total gaseous S [kg/t ADt]	NO _x [kg/t ADt]	Particulates [kg/t ADt]
Recovery boiler	0.01 - 2	0.8 - 1.8	0.2 - 1.8
Lime kiln	<0.01 - 0.7	0.02 - 0.6	0.02 - 0.9
Bark boiler	0.02 - 0.06 ¹⁾	0.03 - 0.2	0.03 - 0.3 ¹⁾
Malodorous gases	0.01 - 2 ²⁾		---
Total emissions from mills	0.04 - 4	0.85 - 2.6	0.25 - 3
Explanatory notes:			
1) For the bark boiler estimated figure. Any use of fossil fuel in the bark boiler is not included			
2) Concentrated gases are assumed to be burnt in the lime kiln			

Table 2.17: Long time (annual) average emissions to the atmosphere from kraft pulp mills within EU

The figures are based on the different analytical methods that are discussed in ANNEX III or methods yielding equivalent results. NO_x is the sum of NO- and NO₂ emissions calculated as NO₂ [SEPA report 4869], [Finnish Forestry Industry Federation, 1998], [Finnish BAT Report, 1996], [data from personal communication with mills]

Emissions of Volatile Organic Compounds (VOC) from the process are reported to be about 0.4 kg/t of softwood kraft and less than 0.1 kg/t for hardwood kraft. As mentioned above there are also some emissions of VOCs from the chip-heaps. As an example VOC emissions from the chips are about 0.2 - 0.3 kg/m³ of wood at kraft pulping.

2.2.2.4 Solid waste generation

The production of kraft pulp generates various fractions of solid waste: inorganic sludge (dregs and lime mud) from the chemical recovery; bark and wood residues from woodhandling; sludge from effluent treatment (inorganic material, fibres and biological sludge); dust from boilers and furnaces; rejects (mainly sand) from the wood handling; ashes and miscellaneous material (like building material). Many organic substances, which might be considered waste products, are burnt for energy recovery. This normally includes bark and wood residues and could include water treatment sludge.

Dregs and lime mud are separated from the chemical recovery cycle in order to keep the amount of inert material and non-process chemicals in the cycle at an acceptable level and thus secure high reaction rates in the chemical recovery system.

Bark and wood residues from woodhandling is normally burnt for energy recovery and should thus be considered as waste only if they can not be burnt and have to go to permanent landfilling. Wood ash from bark boilers contains nutrients taken from the forest with the wood raw material and this ash can be suitable as a fertiliser as long as it is not contaminated by e.g. metals like Hg, Cd and Pb although these come from the wood itself. A leaching of heavy metals from the recycled ashes spread to forest or agricultural land might be a drawback of these measures.

Sludge from wastewater treatment is one of the main groups of potential waste. A large amount of sludge is generated in primary treatment and in biological treatment with the activated sludge method. Aerated lagoons generate only small amounts of excess sludge and the generation of sludge in anaerobic treatment is also moderate. Chemical flocculation produces a considerable amount of sludge. Biological and chemical sludge has poor de-watering properties.

The sludge is usually thickened before being de-watered in a filter press, screw press or on a vacuum filter. Often excess sludge from biological wastewater treatment is mixed with primary sludge and bark sludge before de-watering. Inorganic and/or organic chemicals are used to improve the de-watering of sludge by forming larger flocs. Mixed sludge can be de-watered to 25-35% dryness with filter presses and to 40-50% with a screw press using steam in the pre-treatment stage.

In sludge burning the net energy production is about zero or negative if the dry-solids content in the sludge is below 40% and if the sludge contains a high amount of inorganic material. To maintain good burning conditions the use of auxiliary fuel is necessary unless the sludge is mixed with bark and other wood waste material. Burning reduces the volume of waste and the inorganic content remains as ash, which is normally transported to a landfill site.

Sludge from chemical precipitation cannot be burned alone without the use of auxiliary fuel because of the high content of inorganic matter and water. The sludge is therefore often transported to a landfill site. Sludge from flocculation with only synthetic organic polyelectrolytes is suitable for incineration.

Data on waste generation is limited. Therefore in Table 2.18 available data for various types of wastes generated in a kraft pulp mill from one Member State is given.

Type of waste	kg dry solids per tonne of pulp
Wastewater treatment sludge	10
Wood ash	9
Other ashes	14
Fibre and coating waste	5
Wood waste	6
Hazardous waste	0.2
Total	43
Explanatory notes: "wood ash" is fly ash and dust from incineration of wood material (e.g. from the bark boiler) "other ashes" are ashes from fuels used in energy production other than wood and black liquor "wood waste" is bark, chips, sawdust, wooden packages etc. Wood waste is landfilled only if it can't be burned (containing sand or if it is in some other way too dirty)	

Table 2.18: Average waste generation in kraft pulp mills in kg dry solids/t pulp [Finnish BAT Report, 1996]. The absolute figures has been transferred to specific data per tonne of pulp by dividing the given total values by the yearly production of bleached and unbleached kraft pulp in Finland (5.7 Mt/a). The figures include both integrated and non-integrated mills

Other reports [CEPI, 97] describe little higher amounts of solids wastes as typically for kraft mills. There, unbleached kraft pulping is held to produce 20 - 60 kg dry solids organic waste/ADt (kraft) and 30-60 kg dry solids inorganic waste/ADt. For bleached kraft pulping 30-60 kg organic wastes (dry basis) per tonne of pulp and 40-70 kg inorganic wastes (dry basis) per tonne of pulp are reported.

Data on solid waste in Swedish mills (expressed as dry solids, DS) are reported as the following¹:

Green liquor sludge, dredges and lime mud

These wastes are often mixed and it is very difficult to give separate figures. In total the amount varies roughly between 10 and 60 kg/t of pulp with an average of about 30 (SEPA 4869). The composition in such a mixed waste varies as well. In Report 4 from the project "Miljö 95/96" data for a number of samples are given. The following averaged data is calculated for green liquor sludge with different amount of lime mud.

Lime mud [%]	Dry solids, [DS %]	Ash [%]	Organic content [%]	tot-Ng/kg DS	tot-P g/kg DS	tot S g/kg DS
<2	45	62	20	0.4	0.6	23
75	59	62	6.5	<0.4	2.8	6.3

Table 2.19: Average composition of green liquor sludge with different amounts of lime mud
The figures are divided into two groups: one with almost no lime mud (< 2%) and the other with much lime mud (about 75% as an average)

Metal concentrations are also reported for the same samples. In Table 2.20 averaged values are shown.

¹ Data mainly taken from SEPA report 4869 "Skogsindustrins utsläpp till vatten och luft samt avfallsmängder och energiförbrukning 1996" (The Forest Industry's emissions to the atmosphere and water, amounts of waste and consumption of energy 1996) and Report 4 ("Avfall från skogsindustrin- Mängder, sammansättning och omhändertagande" = Waste from the Forest Industry- Amounts, Composition and Disposal) from the project "Miljö 95/96" (Environment 95/96) run by the The Swedish Forest Industries Water and Air Pollution Research Foundation (the SSVL).

Lime mud [%]	Ba	Cd	Co	Cr	Cu	Hg	Ni	Pb	Sr	Zn
<2	430	16	9.2	75	90	0.07	60	18	330	2300
75	310	11	5.3	85	96	<0.10	29	11	290	1000
Notes: All values expressed as [mg/kg dry substances]										

Table 2.20: Average metal concentrations in green liquor sludge with different amounts of lime mud

Green liquor sludge is in Sweden normally dried on drum filters with a precoat layer of lime mud given a DS of 30-70%. If centrifuges are used the DS is about 8-20%. (Report 4 of Miljö 95/96). The sludge is normally landfilled.

Ashes, slags, particulate matter (e.g. from electro static precipitators)

According to SEPA 4869 the amounts are for kraft pulp mills between about 5 and 45 kg/t of pulp.

Wood yard waste to landfill

The amounts vary between 1 and 20 kg/t of pulp. This waste mainly consists of bark, sand and stones (SEPA 4869).

Rejects from screening/fibre rejects

Limited amount of data in SEPA 4869 shows figures between about 2 and 20 kg/t of pulp

Sludge from biological treatment

With aerated lagoons at kraft pulp mills the amount of sludge is very small usually < 1 kg of DS/t of pulp (from report 4). Biological treatment in activated sludge plant generates higher amounts of sludge.

2.2.2.5 Consumption of chemicals

The consumption of chemicals varies from mill to mill and is to a certain extent regarded as confidential. However, the consumption of main chemicals is reported as typically being as follows in kg/t of pulp.

Substance	Consumption for unbleached kraft pulp [kg/t]	Consumption for bleached kraft pulp [kg/t]
NaOH	10-20	25-50
O ₂	-	5-25
NaClO ₃	-	20-50
EDTA	-	0-4
S	-	
SO ₂	-	2-10
H ₂ O ₂	-	2-30
O ₃	-	0-5
MgSO ₄	-	0-3
CaO	5-10	5-10

Table 2.21: Consumption of main chemicals in kg/t ADP for kraft pulp production [CEPI 1997]; All chemical consumption are expressed as 100% effective chemicals and not as commercial solutions containing various amounts of water

The main purpose of the chemicals mentioned above is:

- Magnesium sulphate is added at the rate of 0 - 2 kg MgSO₄/ADt for hardwood or 2 - 3 kg MgSO₄/ADt for softwood in order to preserve the strength of the pulp in oxygen delignification.
- The consumption of oxygen for delignification is 12 - 15 kg/ADt for hardwood pulp and 20 - 25 kg O₂/ADt for softwood pulp.
- The alkali consumption is 12 - 15 kg NaOH/ADt for hardwood and 20 - 25 kg NaOH/ADt for softwood [Finnish BAT Report, 1997]
- Chelating agents like EDTA and DTPA are used to remove the metals in hydrogen peroxide bleaching sequences in order to prevent the decomposition of the hydrogen peroxide. Emissions of chelating agents might effect the distribution of the metals in the receiving water body and in the organisms living there. Moreover, the use of chelating agents cause emission of nitrogen the amount of which depends on the amount used.

At steady state running conditions, it is a fundamental that any substance entering a mill also must exit the mill. In kraft pulp mills using NaOH and Na₂S as main cooking chemicals the input and output of sodium and sulphur have to be controlled and balanced. The requirement for reduced emissions of sulphur dioxide from mills implies that preferably less sulphur should enter the mill or that sulphur has to be discharged as less harmful substances (as for example sulphate). The main sources of sulphur are listed in Table 2.22.

Source	Amount of sulphur [kg S/ADt]
Wood, water, chemicals	0.3 - 0.5
Fuel oil to lime kiln and recovery boiler	1.0 - 2.0
Tall oil production	2.0 - 3.0 ¹⁾
Chlorine dioxide generation	0 - 15 ²⁾
Magnesium sulphate for oxygen stage	0 - 0.8
Total	3.5 - 25.5
¹⁾ Often spent acid from chlorine dioxide production can be used	
²⁾ Depending on type of process and valid for a mill using up to 40 kg/ADt of chlorine dioxide expressed as active chlorine	

Table 2.22: Typical sulphur intakes to a bleached kraft pulp mill
[SEPA report 4008, 1992]

At present, the emissions of sulphur dioxide from kraft mills vary down to levels as low as 0.3 kg S/ADt (see Table 2.17). Non-gaseous losses of sulphur in effluents can be estimated to correspond to 2 kg/ADt [SEPA report 4008, 1992]. Thus, the total losses of sulphur from a pulp mill would be as low as about 2.3 kg S/ADt in some cases. A comparison with the intake of sulphur when operating with a high proportion of chlorine dioxide in bleaching shows that a high amount of sulphur may have to be discharged or disposed as neutral salts (e.g. Na₂SO₄). However, this will simultaneously cause sodium losses that need to be compensated by more expensive sulphur-free sodium make-up chemicals. To determine correct numbers, the chemical balances have to be worked out on a case-by-case basis for each mill and each process.

2.2.2.6 Use of Energy

The major part of heat energy is consumed for heating different fluids and for evaporating water. Heat energy is also used to accelerate or control chemical reactions. Electrical energy is mostly consumed for the transportation of materials (pumping) and for the operation of the paper machine (only in integrated pulp- mills).

The manufacturing of bleached kraft pulp consumes about 10-14 GJ/ADt of heat energy (steam for the production of electrical power not included). The consumption of electrical energy is 600-800 kWh/ADt, including the drying of pulp. The energy consumption for pulp drying is about 25% of the heat energy and 15-20% of the electrical energy. Over 50% of the electrical energy consumption are used for pumping.

The energy consumption depends on the process configuration, process equipment and process control efficiency.

Table 2.23 below summarises reported average energy consumption as heat (excluding that for back-pressure power generation) and electric power for some non-integrated and integrated pulp mills.

Pulp and paper grade	Process heat [GJ/t]	Electric power [kWh/t]
Non-integrated production of bleached kraft pulp - whereof external supply	14.4 1.2	760 0
Unbleached kraft pulp production with integrated production of paperboard - whereof external supply	16.4 1.5	959 388
Bleached kraft pulp with integrated production of uncoated fine paper - whereof external supply	17.5 3.5	1218 706

Table 2.23: Average energy consumption in Swedish pulp and paper mills in 1995
[SEPA report 4712]

From available data for Swedish mills in Table 2.23 to Table 2.29 [SEPA report 4712] energy consumption and energy balances for a number of different mills are summarised per sub-process. Thus, the main energy consuming process stages can be identified. The figures in Report 472 represent a modernised mill like a mill built in the 1970s and since then modernised. A newly built or recently modernised existing mill, would most probably have lower values.

Department	Process heat [MJ/t]	Electric power [kWh/t]
Wood handling	200	45
Cooking	1700	64
Washing and screening	0	45
Evaporation	4000	21
Recovery boiler	600	48
Auxiliary boiler	0	23
Causticizing	0	14
Lime kiln	1500	7
Miscellaneous, pulp mill	2600	133
Total pulp mill	10600	400
Stock preparation	0	200
Paper machine	5800	350
Total paper mill	5800	550
Effluent treatment	0	9
Total per tonne of paper	16400	959

Table 2.24: Average energy consumption for the production of 243000 ADt/a unbleached Kraft pulp, and integrated production of 250000 t/a paperboard

Department	Process heat [MJ/t]	Electricity [kWh/t]
Pulp mill		
Recovery boiler, process steam	+14500	
Auxiliary boiler, process steam (only own bark)	+2050	
Turbine generator	-2050	+571
External supply (heat for lime kiln)	+1500	0
Consumption (including lime kiln)	-10600	-400
Effluent treatment	0	-9
Excess energy from pulp mill	+5400	+162
Paper mill		
Consumption	-5400	-550
External supply	0	+388
Total external supply	1500	388

Table 2.25: Energy balance for the production of 243000 ADt/a unbleached Kraft pulp, and integrated production of 250000 t/a paperboard

Department	Process heat [MJ/ADt]	Electric power [kWh/ADt]
Wood handling	150	55
Cooking	2050	65
Washing and screening	0	55
Oxygen delignification	400	45
Bleaching	500	83
Bleach chemical preparation	70	6
Bleached stock screening	0	40
Pulp drying	2850	105
Evaporation	4100	30
Recovery boiler	610	60
Power boiler	0	30
Causticizing	0	20
Lime kiln (direct heat)	1500	10
Miscellaneous, pulp mill	2170	136
Total pulp mill	14400	740
Effluent treatment	0	20
Total per ADt of pulp	14400	760

Table 2.26: Energy consumption for non-integrated 250000 ADt/a bleached Kraft pulp

Department	Process heat [MJ/ADt]	Electric power, [kWh/ADt]
Recovery boiler, process steam	+17500	
Power boiler, process steam (only own bark)	+3000	
Turbine generators	-2600	+650
External supply	+1200	0
Consumption (including lime kiln)	-14400	-630
Effluent treatment	0	-20
Excess energy from pulp mill (including waste heat)	+4700	0
Total external supply	1200	0

Table 2.27: Energy balance for non-integrated 250000 ADt/a bleached Kraft pulp

Department	Process heat [MJ/t]	Electric power [kWh/t]
Wood handling	230	46
Cooking	1800	55
Washing and screening	0	46
Oxygen delignification	400	38
Bleaching	500	70
Bleach chemical preparation	70	5
Bleached stock screening	0	34
Pulp drying	0	0
Evaporation	3600	25
Recovery boiler	600	51
Power boiler	0	25
Causticizing	0	17
Lime kiln	1300	8
Miscellaneous. pulp mill	1900	115
Total pulp mill	10400	535
Stock preparation	0	250
Paper machine	7100	420
Total paper mill	7100	670
Effluent treatment	0	13
Total per tonne of paper	17500	1218

Table 2.28: Energy consumption for an integrated bleached Kraft mill with 250000 t/a of surface-sized uncoated fine paper.

Department	Process heat [MJ/t]	Electric power [kWh/t]
Pulp mill		
Recovery boiler, process steam	+13800	
Power boiler, process steam (Only own bark)	+2300	
Turbine generator	-2100	+512
External supply (incl. lime kiln)	+1300	+36
Consumption	-10400	-535
Effluent treatment	0	-13
Excess energy from pulp mill	+4900	0
Paper mill		
Consumption	-7100	-670
External supply	+2200	+670
Total external supply	3500	706

Table 2.29: Energy balance for an integrated bleached Kraft mill with 250000 t/a of surface-sized uncoated fine paper

As shown in the tables above chemical pulping plants are energy-intensive installations that consume high amounts of energy but at the same time produce steam and electrical power on site by use of regenerative fuels. Thus, modern non-integrated kraft pulp mills are energy self-sufficient mainly because of efficient energy recovery by burning 50% of the incoming wood in the recovery boiler (strong black liquor) and the use of bark as auxiliary boiler fuel. Furthermore, secondary energy from different process steps can be recovered as warm and hot water (40-80° C). Fossil fuels are mainly used as support fuel (e.g. oil in the lime kiln).

The conventional power plant configuration in a non-integrated kraft pulp mill is a recovery boiler and a bark boiler feeding a back-pressure turbine with intermediate steam tapping and, possibly, condensing. The recovery boiler acts as a power station where the strong black liquor is burnt and generated heat is utilised for the generation of high-pressure, superheated steam. Part of the energy content in the high-pressure steam is utilised for generating power in a back-pressure turbine. Medium-pressure steam extracted from the turbine and low-pressure exit steam are utilised for covering the heat energy demand in the kraft pulp process. The ratio of electrical effect/heat effect is, usually, 0.2 - 0.3 [Finnish BAT report, 1997].

Malodorous gases are collected and burnt, mainly for environmental protection reasons, as there is no/little net energy generation.

In an integrated pulp and paper mill the excess heat produced by the pulp mill is not quite enough to cover the energy consumption of the paper production. The additional demand for heat has to be produced in wood/bark boilers and auxiliary boilers. Fossil fuel is used as support fuel in bark and sludge boilers and as the main fuel in auxiliary boilers as well.

Peaks in energy consumption are often satisfied by using a small boiler for fossil fuel. Combined heat power plants (CHP) based on gas turbine in combination with a steam boiler and steam turbine are very efficient and a few installations have been made in Europe. CHP plants are used when the need for electrical energy at a paper mill is high because the electrical effect/heat effect ratio is usually 0.8 - 0.9 [Finnish BAT report, 1997].

In the following some additional figures of energy consumption of single process stages of pulp mills are compiled:

- De-icing will consume about 30 MJ of heat as hot water or steam per m³ of wood processed.
- The total energy consumption in debarking is 7-10 kWh/m³ of wood [Finnish report]
- The energy for pulp drying (only market pulp) can be of the order of 3 GJ/tonne of pulp or some 25% of the total heat requirement for a kraft pulp mill and 15-20% of the electrical energy.
- The average electrical energy consumption in the manufacture of bleaching chemicals is presented in Table 2.30.

Chemical and (bleaching stage code)	Electrical energy consumption [kWh/kg chemical]
Chlorine dioxide (D)	10
Oxygen (O)	0.4
Ozone (Z)	10
Peroxide (P)	3.5
Alkali (E)	1.6

Table 2.30: Average electrical energy consumption in the manufacture of bleaching chemicals, [Finnish report, 1997]

- External treatment of wastewater normally consumes energy [the following figures are compiled from Finnish report, 1997]. Anaerobic treatment is an exception if the energy content in the generated biogas is recovered by burning. The consumption of electrical energy in activated sludge treatment is in the range of 1.2-2 kWh/kg of reduced BOD (aeration and pumping), which is the equivalent of 1 -1.5 kWh/ m³. The energy consumed in filtration is dependent on the drop in pressure across the medium. For example, the ultrafiltration of coating wastewater consumes 3 - 5 kWh/m³. Evaporation at low pressure using mechanised vapour recompression consumes 5 - 15 kWh/m³. Typical specific energy consumption per tonne of bleached kraft pulp is reported as to 3 kWh/t for mechanical treatment and 46 kWh/t for activated sludge treatment of the effluents from mills.

2.2.2.7 Noise (local)

The debarking plant generates noise that can be controlled by carefully insulating the debarking house. There are several other sources of noise like chipping, fans, engines, stacks and steam vents. Trucks and other vehicles used at the plant can cause noise in the vicinity of the mill. From two examples of Swedish pulp mills it can be assumed that the noise level about 500 m from the middle of the pulp plant can be about 50 dB (A) over night and at about 2 km away it can be about 45 dB (A). The guidelines for all existing industries in Sweden is < 45 dB (A) over night at the closest house where people live. This may be difficult to achieve if houses are located very close to the mill as for example within a radius of < 500 meter.

2.2.2.8 Emission to soil and groundwater

If preventive control measures for storage and handling of chemicals are in place, well maintained and controlled operation of pulp and paper mills usually should not give raise to hazardous emissions to soil and groundwater.

A general policy for prevention of, preparations for and response to industrial accidents is usually based on the prevention principle (e.g. Annex IV IPPC-D). That means that the plant is constructed and operated in such a way as to prevent an uncontrolled development of normal operation and as to reducing the consequences of accidents. The best safety techniques are applied.

To prevent hazardous emissions to soil and groundwater from storage and handling of chemicals the safety of industrial installations should be ensured by the following means:

- Design and operation of facilities in such a way that potential pollutant cannot escape
- Possibility of quick and reliable detection of leakage from all parts of the facility which come into contact with the hazardous pollutants.
- Single-walled underground containers are not sufficient for this purpose.
- Quick and reliable detection of leaks of substances and their prevention from escaping and properly disposal. When not double-walled and provided with a leak indicator, the facilities are, as a rule, equipped with a collection system/device of a tight and durable design. As a matter of principle, collection chambers may not have any discharge openings.
- Operating instructions including a monitoring, maintenance and an alarm plan are drawn up and observed.

The technical and environmental aspects of storage and handling of chemicals do not specifically relate to the pulp and paper industry and are therefore only briefly treated. They will be covered by another horizontal BREF on emissions from storage of chemicals (of dangerous substances and bulk material)

With regard to the cessation of activities and in order to avoid any pollution risk and to return the site of operation to a satisfactory state, soil protection is of major importance. An integrated approach requires making sure that at least the following measures are taken:

- Minimisation of the amount of soil that needs to be excavated or replaced due to construction measures
- Minimisation of the additional input of substances into soil during the operation phase of a facility (e.g. additional input due to spillage or due to deposition of airborne substances should not lead to exceeding of precautionary soil levels. Ensuring a clean closure when a facility will be shut down, e.g. cleaning up of contaminated soil, hazardous landfills

2.3 Techniques to consider in the determination of BAT

In this paragraph all **relevant** techniques currently commercially available for prevention or reduction of emissions/waste and reducing consumption of energy and raw materials, both for new and existing installations are given. This list of techniques to consider in the determination of BAT is not exhaustive and may be continued when reviewing this document. These techniques cover in-process measures and end-of-pipe technology as well and stands for possibilities for improvement to achieve integrated prevention and control of pollution.

In Table 2.31 an overview of techniques for reduction of emissions from kraft pulping are given. In the rows the single available techniques are compiled. It was tried to give possible cross-media effects of every technique in the same table. It can be concluded that it is not an easy task to describe cross-media effects in a way that would not cause any dispute. There are a lot of "grey-zones" in the assessment of cross-media effects. Furthermore, they may depend on other techniques, which may be linked to a given measure, the reference to which a technique is compared with and the system boundary taken into account as well. Therefore, the qualitative assessment of cross-media effects should only be taken as help for operators or inspectors which side-effects a measure may possibly occur and is not much more than a starting-point when considering possible shifts of pollution. The results of the assessment should not be considered as imperative. Furthermore, prevention and control measures can avoid some of them. Besides other things, the cross-media effect will also depend on the specific conditions of every mill. Therefore, a general statement can hardly be given. However, the table may indicate at which environmental media (water, air, waste, and energy) a measure is aiming at. The corresponding paragraphs under the detailed discussion of every technique give further explanations.

In the columns the tendency of effects caused by different techniques on emissions, raw material consumption and the mill performance are indicated qualitatively by using arrows up "↑" and down "↓". The arrows down "↓" indicate savings of raw materials or energy and a reduction of emissions into the different media water, air and soil. Arrows up "↑" indicate an increase of emissions, consumption and impacts on the production process. Some of the measures for pollution prevention and control presented in this section concern more than one environmental medium (as water, air or soil) at a time. Some techniques may have a positive and/or negative impact on other environmental media or on raw material and energy consumption (cross-media-effects). The given effects will be noted by using the arrows. An arrow in brackets "(↑)" means only a slight - often negligible - increase of energy consumption, raw material use or emission to environment when implementing a certain measure. The economic aspects (investments, operational costs) are not included in the table but are explained in the text. Data on economics can only give a rough picture and indicate the levels of costs. They will vary with the design of the whole plant and depend among others on the size of the mill and how a measure fits together with other mill equipment.

Each technique is provided with a reference mark, which helps to identify the according section in the text where each single technique is discussed in detail. In the following the use of Table 2.31 is explained by means of the brief discussion of one technique (see Section 2.3.1 "dry debarking"):

In a transfer from wet debarking to dry debarking there is no effect on chemical consumption. Energy consumption in debarking increases due to the operation of the debarking drum in dry debarking mode. On the other hand, substantial amount of energy may be gained, if the bark is used as an auxiliary fuel at lower water content. Dry debarking results in a significant decrease of emissions to water, e.g. flow reduction in the range of 5 - 10 m³/t, TSS reduction in the range of 2 - 10 kg/t and total COD loading can be reduced up to 10%. There are no effects on air emissions and on solid waste generation.

In this Chapter the main technical options with the best environmental and economical performance are highlighted. It has been tried to discuss the single measures following a uniform structure to have a similar presentation of all techniques to consider in the determination of BAT. Of each technique a description, discussion of applicability, main achieved environmental performance, monitoring of emissions, cross-media effects, operational experiences, data on economics, driving force for implementing this technique, reference plants and literature are given. Most of the techniques can be found in numerous plants in Europe whereas a few of them are only implemented in some mills.

The right combination out of this list of techniques offers the opportunity to the mills to achieve both good environmental and economic performance at the same time. However, it is up to the mill, which of the possible techniques is applied to achieve the resulting consumption and emission levels given in the next chapter "Best Available Techniques". The description of each technique includes an outline of advantages, drawbacks and consequences of the implementation of a certain technique.

Pulp and paper mills are characterised by a relatively high degree of integration so that most of the opportunities for improvement are process-integrated measures. But a few end-of-pipe techniques that are considered as BAT are described as well. One has to bear in mind, that there is a certain overlapping between the further down described process-internal solutions and external control measures.

Techniques to consider in the determination of BAT	Effects on the consumption and emission level (cross-media effects)					Impact on the production process E.g. energy balance, yield, mill performance
	Chemical consumption	Energy consumption	Emission to water	Emission to air	Solid waste	
3.3.1 Dry debarking	n.e.	↑ in debarking	↓ COD, ↓ TSS, ↓ flow	n.e.	n.e.	↑ energy generation in bark boilers
3.3.2 Extended modified cooking to a low kappa Continuous (c) or batch (b)	↑ in cooking ↑ lime demand ↓ in bleaching	(↑) cooking (c), ↓ cooking (b) (↑) evaporation, (↑) lime kiln	↓ COD ↓ AOX	↑ odour	n.e.	↑ energy generation, (↑/↓) final pulp yield
3.3.3 Closed screening	n.e.	n.e.	↓	n.e.	n.e.	n.e.
3.3.4 Oxygen delignification	↑ in O ₂ -stage ↓ in bleaching	↑ O ₂ -stage, ↑ white liquor oxidation, ↑ caustic.&lime kiln	↓	n.e.	(↑) dregs	(↑ energy generation)
3.3.5 Ozone bleaching	↑ in O ₃ -stage ↓ in bleaching	↑ O ₃ -stage, ↑ O ₃ generation, ↓ in bleaching	↓	n.e.	n.e.	n.e.
3.3.6 ECF bleaching technique (vs. TCF) ¹⁾ (at same incoming low Kappa)	(↑/↓)	(↑/↓)	↑ AOX, ↑ ClO ₃	↑ Cl ₂	n.e.	n.e.
3.3.7 TCF bleaching technique (vs. ECF) ¹⁾ (at same incoming low Kappa)	(↑/↓)	(↑/↓)	(↓ COD), ↓ AOX, ↑ N chelat. agent)	n.e.	n.e.	n.e.
3.3.8 Partly closure of the bleach plant + increased evaporation	↑ bleaching	↑ evaporation	↓	(↑)	(↑ dregs)	(↓ water consumption)
3.3.9 Collection of almost all spillage	n.e.	(↑ evaporation)	↓	n.e.	n.e.	n.e.
3.3.10 Efficient washing and process control	↓ bleaching ↓ cooking	↑ washing (electr.)	↓	n.e.	n.e.	
3.3.11 Stripping and re-use of condensates	↓ in bleaching	↑ steam	↓ COD, N	↓ odour	n.e.	n.e.
3.3.12 Buffer tanks for concentrated liquids	n.e.	n.e.	↓	n.e.	n.e.	n.e.
3.3.13 Biological wastewater treatment	↑	↑	↓	(↑ odour)	↑	Sludge burning ?
3.3.14 Tertiary treatment (precipitation)	↑	↑	↓	n.e.	↑	Sludge burning ?
3.3.15 Increase of DS of black liquor	n.e.	↑ evaporation	n.e.	↓ SO ₂ , (↑ NOx)	n.e.	↑ evaporation capac. needed ↑ energy generation in the rec. boiler, ↑ prod. capacity
3.3.16 Installation of scrubbers on the recovery boiler	n.e.	(↑)	n.e.	↓	n.e.	(↑/↓) energy balance
3.3.17 Incineration of odorous gases in the recovery boiler	↓ S make-up demand/ ↑ S excess	↑ handling system	n.e.	↓ TRS	n.e.	↑ energy generation (burning with heat recovery)
3.3.18 Incineration of odorous gases in the lime kiln	↓ S make-up demand/ ↑ S excess	↑ handling system	n.e.	↓ TRS	n.e.	(↑ energy generation)
3.3.19 Incineration of odorous gases in a separate furnace + scrubber	↓ S make-up demand/ ↑ S excess	↑ handling system	n.e.	↓ TRS, (↑ NOx)	n.e.	↑ energy generation (burning with heat recovery)
3.3.20 Low NOx auxiliary boilers Low NOx burners in the lime kiln	n.e.	n.e.	n.e.	↓ NOx	n.e.	n.e.
3.3.21 SNCR on bark boilers	↑ urea/NH ₃	↑ handling system	n.e.	↓ NOx (↑ NH ₃)	n.e.	n.e.
3.3.22 Low NOx recovery boiler by using Over Fire Air technique (OFA)	n.e.	n.e.	n.e.	↓ NOx	n.e.	n.e.
3.3.23 Improved washing of lime mud	n.e.	n.e.	n.e.	↓ TRS	n.e.	n.e.
3.3.24 ESP on bark boiler and lime kiln	n.e.	↑ electricity	n.e.	↓ dust	n.e.	n.e.

Notes:
↑ = increase; ↓ = decrease; n.e. = no (or negligible) effect. (↑/↓) = may or may not have an effect/little impact depending on the conditions; ¹⁾ assumed that there is an efficient wastewater treatment

Table 2.31: Overview of available techniques in kraft pulping and their impact on the environment and the mill performance respectively

2.3.1 Dry debarking

Description of the technique: In woodhandling the discharges of organic compounds and suspended solids can be reduced with dry debarking. Wet debarkers rotate logs in a pool of water and remove bark by knocking the log against the side of a drum by using large volumes of water. The water used in this process is recycled but a certain amount is lost as overflow to carry away the removed bark. In wet debarking 3 to 10 m³ of water per tonne of pulp are discharged. Organic compounds like resin acids, fatty acids etc. and highly coloured materials leach out of the bark and into this wastewater stream.

In recent years dry debarking has been installed in many mills. Process water is used only for log washing and de-icing (in cold climates water or steam is used for thawing of wood) and is recirculated effectively with minimum generation of wastewater and water pollutants. Dry debarking creates bark with a lower water content, which will result in a better energy balance for the mill. Less water is needed in the debarking and the dissolved amount of organic substances is reduced.

Raw effluents from a debarking plant are toxic to aquatic life. Biological treatment has proven to be very efficient in eliminating toxicity.

Applicability and characterisation of the measure: Process integrated technique. The dry debarking or one with low wastewater discharges can be applied at both new and existing mills. Dry debarkers already dominate the industry, and wet systems are in the process of being phased out. New mills almost exclusively and an increasing number of existing mills are using dry debarking.

Main achieved environmental performance: With dry debarking, the wood handling wastewater volume is usually in the range of 0.5-2.5 m³/ADt. Decrease in wastewater amount is obtained by increased internal water circulation. By changing from wet debarking to dry debarking, the wastewater amount would decrease often by 5-10 m³/ADt. With dry debarking the total COD loading can be reduced up to 10 %. Typical discharges of dry debarking are as follows:

Debarking technique	Effluent Volume [m ³ /t of pulp]	BOD ₅ [kg/t of pulp]	COD [kg/t of pulp]	tot-P [g/ t of pulp]
Wet debarking and barkpress	3 - 10	5 - 15	20 - 30	25 -35
Dry debarking and barkpress	0.5 - 2.5	0.5 - 2.5	1 - 10	10 20

Table 2.32: Pollution load of wet and dry debarking effluent before biological treatment [Finnish Report, 1997]; BOD₇ has been converted into BOD₅ by use of the formula BOD₇ /1.16 = BOD₅ proposed within the same report; kg pollutant/m³ wood has been converted into kg pollutant/t of pulp by assuming a typical pulp wood consumption of 5 m³ wood/t of pulp

The higher bark dryness in the boiler feed improves the energy efficiency, meaning that emissions per the amount of produced energy will drop.

Cross media effects: Energy consumption in debarking may increase due to the operation of the debarking drum in dry debarking mode. On the other hand, substantial amount of energy may be gained, if the bark is used as an auxiliary fuel at lower water content.

Operational experiences: Where wet debarking is used, improved water recirculation coupled with grit and solids removal systems for water has been applied with success. Dry debarking usually requires fresh wood in order to obtain good debarking results.

Economical aspects: The costs of dry drum debarkers should not differ significantly from a wet system. Typical investment cost of a completely new dry debarking system is about 15 MEuros for a capacity of 1500 ADt/d pulp.

The conversion of an existing wet debarking system to a dry debarking system costs 4-6 MEuros. These costs include equipment and installation. Possible site-specific need for new buildings, special noise abatement costs or similar are not included but they may further increase the costs. Operating costs are 250000– 350000 Euro/a but in both cases it may involve considerable investments.

Driving force for implementing this technique: The dry debarking decreases TSS, BOD and COD load as well as organic compounds like resin acids, fatty acids leaching out of the bark and into this wastewater stream. Some of these substances are regarded as toxic to aquatic life. The measure also increases energy yield.

Reference plants: Numerous plants in Europe and North America.

Literature

[J. Pöyry, 1997a], [SEPA-Report 4712-4, 1997], [Finnish BAT Report, 1997]

2.3.2 Extended modified cooking (batch or continuous) to a low kappa

Description of the technique: Delignification before the bleach plant is done in digesters and, at many mills, also by use of oxygen delignification. Therefore, measure 2.3.2 "extended modified cooking" and 2.3.4 "oxygen delignification" should be considered as a unit because what is essential from an environmental point of view is the total degree of delignification achieved as a result of delignification in the stages before the pulp enters the bleach plant. There should be a balance between kappa reduction in cooking and in oxygen delignification since the selectivity is much higher in the latter system (see 2.3.4). For the mill it is important to control the various processes so that yield and strength characteristics are optimum for a given lignin content.

In order to decrease the lignin content (lower kappa numbers) in the pulp entering the bleach plant so as to reduce the use of the expensive bleaching chemicals, extended delignification (or modified kraft cooking) was introduced in the end of 1970s and at the beginning of 1980s. The reduction in lignin content will reduce the amount of pollutants discharged while increasing the amount of organic substances going to the recovery boiler. Several modified kraft processes in both continuous and batch systems have been developed and applied commercially.

Continuous cooking

In the continuous system, Modified Continuous Cook (MCC), Extended Modified Continuous Cook (EMCC) and Isothermal Cooking (ITC) represent the three alternatives. In the MCC process, the cooking zone in the digester is divided into two zones, namely an initial co-current zone and a subsequent counter-current zone. The charge of the white liquor is split between the two zones. The purpose of the modification has been to decrease the initial alkali concentration, keep an even concentration of alkali during the cooking process and a low concentration of the dissolved lignin in the final part of the cook. EMCC process was developed on the basis of the MCC process. The difference is that in the EMCC process, white liquor is also charged to the washing zone in order to extend further the delignification in the digester.

The newest development within cooking technology is Iso Thermal Cooking (ITC) which is a further improvement of MCC. In ITC the whole digester vessel is used for delignification which means milder conditions (lower cooking temperature) is achieved and consequently the strength of pulp maintained. Depending on the target kappa number the charge of cooking chemicals is either unchanged or slightly higher. Since ITC means a lower cooking temperature there is no increase in steam usage and the impact on yield is limited.

Batch cooking

In the discontinuous system, there are three commercially applied processes: Rapid Displacement Heating (RDH), SuperBatch and EnerBatch. In the RDH and Superbatch processes, a pretreatment (impregnation) with black liquor is carried out in order to decrease the heat consumption and at the same time to increase the initial sulphide concentration and decrease the effective alkali charge. In the Enerbatch process, a pretreatment with white liquor followed by a pretreatment with black liquor is performed. All these displacement cooking processes show a substantial energy saving and an improved pulp quality.

The lignin content is usually measured as the kappa number with a standardised method. Conventional cooking has its limits, regarding how low the kappa number can be brought without deterioration of pulp quality (This kappa number is around 30-32 for softwood and 18-20 for hardwood). By use of several cooking modifications the kappa from the cooking of softwood can be reduced to a level of 18-22 for softwood and 14-16 for hardwood, while the yield and strength properties are still maintained. The kappa reduction depends beside others on the modified cooking technology applied and whether a retrofitted or new installation is used. As an example the Kappa trends in Finnish kraft pulp mills are shown in Figure 2.8.

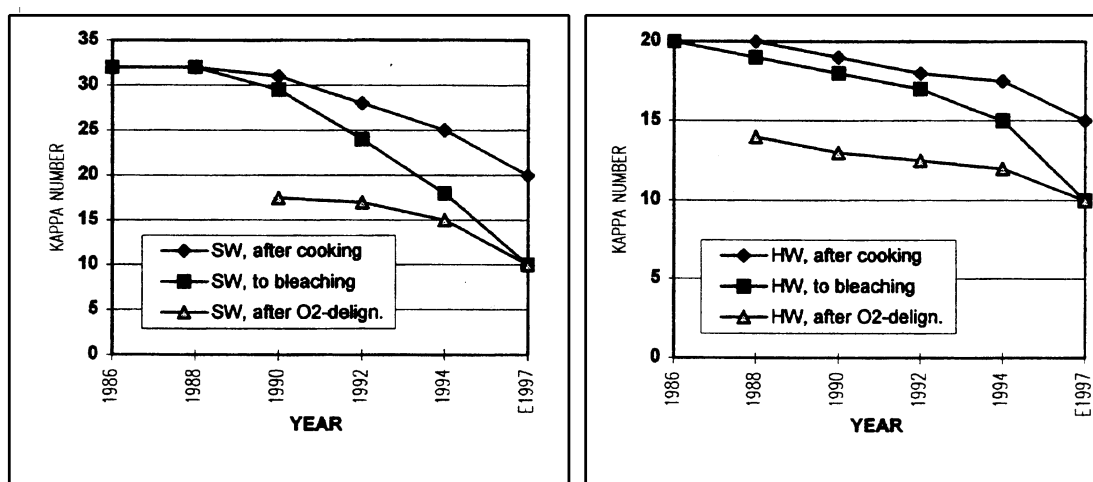


Figure 2.8: Kappa trends in Finnish kraft pulp mills [Finnish BAT Report, 1997]

Applicability and characterisation of the measure: Process integrated technique. The measure can be adopted in new kraft mills and to a limited extent in existing mills.

A number of continuous digesters have been retrofitted to ITC without having to sacrifice production. However, this possibility has to be evaluated in each individual case (this has to do with the dimensions of the pressure vessel in relation to the capacity). Some other continuous digesters have been rebuilt to MCC. To achieve this, white liquor is pumped into the digester at several points. With MCC and ITC it is possible to cook the pulp to lower Kappa number, without losses in quality (Kappa number 20 - 24 for softwoods and 14 - 18 for hardwoods). In

continuous cooking systems the capacity of the plant would decrease with extended cooking and imply higher cost burden to the pulp mill.

In batch cooking, extended delignification is carried out by means of displacement and black liquor recycling techniques. The process is possible to install as retrofit in conventional plants, if the digester capacity is large enough. In a new installation the kappa number from the cook may be kept at 15-16 for softwoods and at about 12 for hardwoods. In practice, the modifications of an existing batch cooking system are possible to carry out with additional batch digesters and additional investment costs without losing the capacity of the cooking plant.

Main achieved environmental performance: Lower lignin content means fewer discharges from the bleach plant of not only organic substances but also nutrients (e.g.). One kappa unit corresponds roughly to 0.15 % lignin in the pulp. If the kappa number of pulp from cooking or oxygen delignification (see 2.1.6) can be lowered by one unit the COD released in the bleach plant would reduce by approximately 2 kg/ADt (COD from TCF-bleaching can be as high as about 3 kg COD/kappa number). However, to get a figure on the total discharge from the bleach plant one has to add the amount of pollutants which has not been washed out in the closed part of the process (see 2.3.10).

Cross media effects: Extended cooking affects several elements in the kraft process:

- the consumption of active alkali (NaOH + Na₂S) may slightly increase
- the amount of dissolved substances going to the recovery system increases
- heat generation in the recovery boiler increases
- the demand for bleaching chemicals decreases
- there is a lower pollutant load in the wastewater from bleaching
- in modified batch cooking the energy consumption and blow steam amount decrease in the cooking, but the steam consumption in the evaporation of the black liquor may increase.

The impact of extended cooking on production is very site specific.

Operational experiences: Kappa number reductions of 6-7 units for softwood and 4 - 5 units for hardwood have been accomplished without loss of strength properties.

Economics: Investment costs for modification of existing conventional cooking system for extended delignification are 4-5 MEuros at the mill producing 1500 ADT/d. In order to utilise BOD- and COD-reduction, the washing efficiency should be increased as well. This would cost 2-4 MEuros more. However, with ITC there is no need to add more washing equipment if the retrofit is made at constant capacity. With continuous digester or when the recovery boiler is already operating with full capacity, the production loss can be 4-8 %. In such cases ways to accommodate for the increase in solids load are to be found as additional evaporation stages to increase the dry solids concentration in the black liquor, anthraquinone addition in pulping or adding of incremental boiler capacity.

Generally, the impact of extended cooking on production is very site specific. If the chemical recovery system is a bottleneck at a mill then introduction of extended delignification risks a loss in production due to the increased demand on that part of the system (see above).

Driving force for implementing this technique: The reduction of emissions to water is the main reason to implement this technique. A beneficial effect is also a reduction of the consumption of expensive bleaching chemicals. This reduction should be compared to the possible loss of yield and increased wood consumption, in order to judge possible net cost savings case by case.

Reference plants: Numerous plants in Europe.

Literature:

[J. Pöyry, 1997a], [J. Pöyry, 1997b], [Finnish BAT Report, 1997], [Bowen, 1990]

2.3.3 Closed screening

Description of the technique: The water system in the brown stock screening plant can be completely closed which is reality in most European mills. With modern wood handling and cooking down less than 0.5 % knots and shives are left in the pulp after cooking. The closing contributes to the reduction of organic compounds in the effluents and they are then recovered and incinerated in the recovery boiler. The idea is to bring the clean counter-currently through the fibrelines, which gradually increases the dry solid content of the liquor.

Applicability and characterisation of the measure: Process integrated technique. The measure can be adopted in new and existing kraft mills.

The closing of the washing and screening may require supplementation or replacement of existing equipment with new units to reach lower wash water consumption and to have better materials to resist corrosion. In a few existing mills the capacity of the evaporation plant or the recovery boiler may need to be increased to cope with the improved closure of the washing and screening departments.

Main achieved environmental performance: The closing contributes to the significant reduction of organic compounds in the effluents. They are then recovered and incinerated in the recovery boiler. Thus, the screening plant has no discharges to water.

Cross media effects: Energy consumption increases due to increased need for evaporation.

Operational experiences: The measure has been applied since 1980s with good experiences. For instance, in Finland closed screening and brown stock washing is reality in almost all mills.

Economics: Investment costs for closed screening case are typically 4-6 MEuros with new mills and 6-8 MEuros at existing mills. Operating costs are 0.3-0.5 MEuros/a for a capacity of 1500 ADT/d.

An important development step in screening is that today it is possible to screen at higher pulp consistencies than before. Consequences are lower investment costs and consumption of electrical energy.

Driving force for implementing this technique: The reduction of emissions to water is the main reason to implement the technique.

Reference plants: Numerous plants in Europe.

Literature

[J. Pöyry, 1997a], [J. Pöyry, 1997b], [SSVL 1974]

2.3.4 Oxygen delignification

Description of the technique: After cooking the fibres still contain some lignin which must be removed before final bleaching. To preserve pulp strength, the lignin must be removed in a selective way with minimum damage to the cellulosic part of the fibres and with minimum yield loss. About half of the remaining lignin in the brown stock can be removed and recovered by adding oxygen to an alkaline fibre suspension. In oxygen delignification oxygen, oxidised white liquor and magnesium sulphate is mixed with the pulp at either high consistency (25-30 %) or medium consistency (10-15 %) in a reactor. An oxygen delignification stage has also been called

oxygen bleaching (oxygen stages are nowadays also used in the bleach plant and in this report oxygen delignification is used for the processing of unbleached pulp). In order to maintain the sodium balance of the mill, the oxygen stage normally uses the oxidised cooking liquor, where sodium hydroxide is the main alkaline chemical and sodium sulphide has been oxidised to thiosulphate. The delignification reactor is pressurised and the temperature is elevated to about 100°C.

The oxygen delignification takes place in one or two stages after the cooking and prior to the bleaching and can achieve a delignification efficiency of 40 to 60%. An efficiency over 40% normally requires two-stage installations. The waste liquor is sent counter-currently to the chemical recovery system. In Figure 2.9 and Figure 2.10 examples for a modern process lay out of one-stage and two-stage delignification are given.

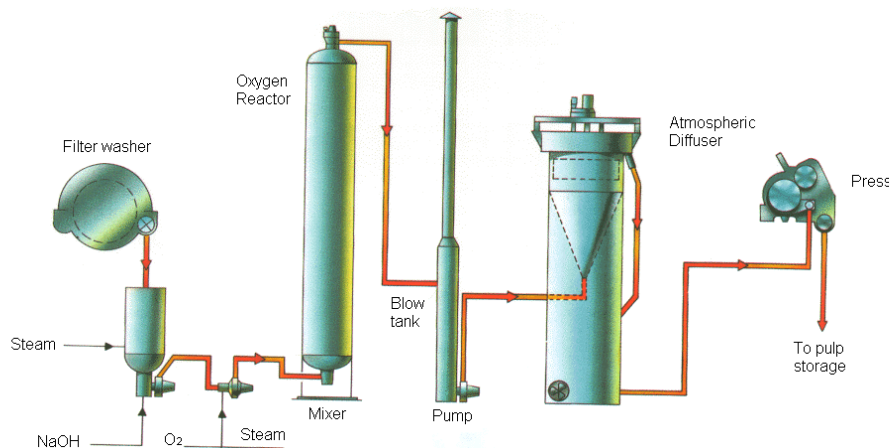


Figure 2.9: One stage oxygen delignification

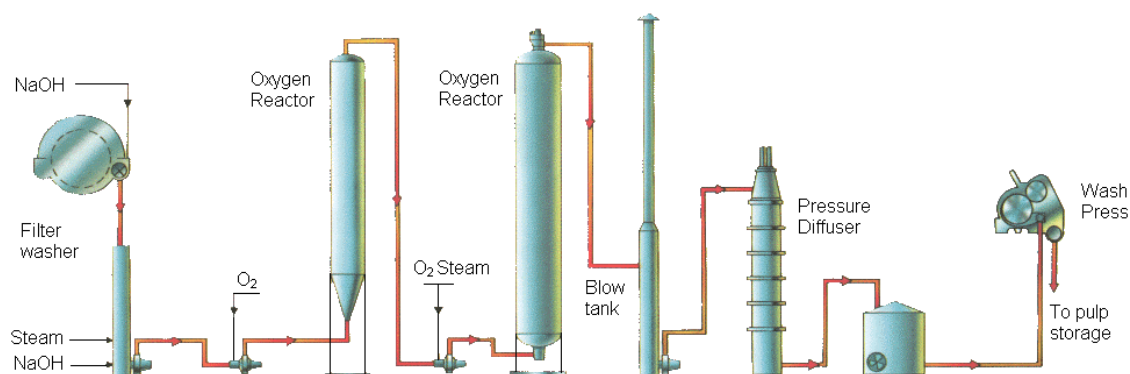


Figure 2.10: Two-stage oxygen delignification

Applicability and characterisation of the measure: The measure can be adopted in new and existing kraft mills but not in the same way and at the same costs.

The installation of oxygen delignification phase in the existing kraft mill may decrease the fibre line production, if there is not enough spare capacity in the whole recovery system.

The additional evaporator steam requirements are from 0 - 4 % for high consistency system and from 4 - 10 % for medium consistency system. The total additional solids load is about 70 kg/t for softwood and 45 kg/t with hardwood. The steam generation of the excess solids is about 1.5 - 2.5 %

less than the increasing of solids load because of a lower heating value of the black liquor from oxygen stage.

Main achieved environmental performance: The major benefits of oxygen delignification are decrease of the amount of chemicals in final bleaching and total costs for bleaching chemicals and decrease of pollution load from the bleaching plant (COD and chlorinated organic compounds from final bleaching in case of ECF bleaching). Modern mills are always designed for a combination of modified cooking and oxygen delignification and for the effect on the environment (discharges of COD and AOX) both techniques have to be considered together.

Table 2.33 summarises kappa numbers currently achieved with different delignification technologies and gives a rough comparison of the effluent loads to be expected with and without extended delignification.

Delignification technologies	Kappa for hardwood	Kappa for softwood	Calculated COD load [kg/t] from the bleach plant	
			Hardwood	Softwood
Conventional cooking	14 -22	30 - 35	28 - 44	60 - 70
Conventional cooking + oxygen delignification	13 - 15	18 - 20	26 - 30	36 - 40
Extended/modified cooking	14 -16	18 - 22	28 - 32	36 - 44
Extended cooking + oxygen delignification	8 -10	8 -12	16 - 20	16 - 24

Table 2.33: Kappa numbers currently achieved with different delignification technologies and comparison of the calculated effluent COD without considering the washing losses

The reduction of kappa, organic substances and the consumption of chemicals in oxygen delignification are strongly related to the efficiency of washing between stages. The mentioned environmental performance is not reached without efficient washing (see 2.3.10).

Cross media effects: In energy consumption the measure means slightly increased energy recovery from dissolved organic substances but also decreased heat value of the black liquor from the inorganic compounds.

An increased recovery could contribute to increased NO_x emissions from the recovery boiler.

Operational experiences: The strength properties of oxygen bleached pulp and conventionally bleached pulp are very similar although oxygen bleached pulp has lower average viscosity. No significant differences are seen in burst factor and tear factor at given breaking length.

According some mill experiences an oxygen stage before softwood bleaching sequence results in more particles and shives.

Economics: Investment cost for an oxygen delignification system is typically 35 - 40 MEuros for 1500 ADt/d bleached pulp production. Its operating costs are 2.5-3.0 MEuro/a. However, the oxygen delignification will decrease the chemical consumption in bleaching. The net effect is a cost saving which depends on the wood species. At existing mills, additional dry solids loads to recovery boiler have been reported up to 10 % and more general it is at least 4-6 % additionally, and 4-6 % more capacity would be required in recaustising and lime kiln. Should this capacity not be readily available, it normally results to a corresponding loss in production capacity of the whole mill.

Driving force for implementing this technique: The reduction of emissions to water (effluent treatment plant and recipient) is major reason to implement the method.

Reference plants: Numerous plants in Europe and in America.

Literature:

[J. Pöyry, 1997b], [Finnish BAT Report, 1997], [J. Pöyry, 1997a], [Bowen, 1990]

2.3.5 Ozone bleaching

Description of the technique: Ozone bleaching is related to the production of ECF and TCF pulps. The main purpose of using ozone is to provide more delignification power. Ozone activates the fibres towards peroxide and this results in higher brightness and lower peroxide consumption.

Ozone is generated by means of silent electrical discharges in a stream of oxygen gas. Ozone-bleaching (O₃) has very high investment costs due to the high costs of ozone generators and auxiliary equipment for ozone generation. Since the ozone concentration will be only about 14-16 % in oxygen, fairly large volumes of oxygen are required. Thus, the operating cost is rather high due to a relatively high cost of oxygen (needed for ozone generation) as well as to the high power consumption. A modern ozone generator may consume 10-15 kWh/kg ozone when feeding it with oxygen.

Applicability and characterisation of the measure: Process integrated measure. The measure can be adopted in new and existing kraft mills.

Main achieved environmental performance: In ECF bleaching replacement for chlorine dioxide further reduces the discharges of AOX ("ECF light"). In TCF bleaching ozone is a common bleaching stage. In TCF mills the use of ozone and other chlorine free bleaching chemicals makes it less complicated to close up the filtrate streams from washing stages (see 2.3.8). A pressurised (PO)-stage at the end of the bleaching sequence is another option to reduce the charge of chlorine dioxide. In TCF pulp mills a PO stage is relatively frequent.

Cross media effects: No major cross media effects.

Operational experiences: Ozone with ECF bleaching plant normally results in pulp with the same papermaking properties.

Economics: Investment costs for a 1500 Adt/d ozone bleaching system are 12-15 MEuro. Corresponding operating costs are 1.8-2.1 MEuro/a.

Driving force for implementing this technique: The reduction of emissions to water (AOX) is the main reason to apply this method.

Reference plants: About 16 plants since 1992 of which 13 plants are for kraft pulp mills.

Literature:

[J. Pöyry, 1997b], [Finnish BAT report, 1997], [J. Pöyry, 1997a], [Fuhrmann, 1998]

2.3.6 ECF bleaching technique

Description of the technique: ECF bleaching (Elemental Chlorine Free) is a bleaching sequence without the use of elemental chlorine (chlorine gas, Cl₂). In ECF chlorine dioxide is usually the main bleaching agent. The lignin removal by bleaching is carried out in several stages, the first two stages primarily releasing and extracting lignin and the subsequent stages stand for

removing the lignin residues and finishing the product. A bleach plant consists of a sequence of separate bleaching stages with different chemicals or combination of chemicals added.

The elemental chlorine can be replaced with chlorine dioxide in the first bleaching stage, because the chlorine dioxide per chlorine atom has a fivefold oxidation power compared with chlorine and it has practically the same selective lignin removal properties. Reinforcing the alkaline extraction stages in bleaching with oxygen and/or hydrogen peroxide results in an enhanced oxidising bleaching effect, which reduces the residual lignin content of the pulp before the final chlorine dioxide bleaching stages.

Increasing the degree of chlorine dioxide substitution decreases the formation of chlorinated organic substances and eliminates the formation of dioxins, which are considered to have adverse environmental effects in the receiving waters.

The increased substitution of chlorine by chlorine dioxide requires generally modifications in the bleaching process and also expansion of the on-site chlorine dioxide plant.

Various technical solutions have been tested and some of them have been proven to be more appropriate for full-scale production. The ECF-bleaching is different for softwood and hardwood, and in existing mills the possible ECF-concept is tied with the current bleaching process. Generally, to reach a certain brightness target hardwood requires fewer chemicals than softwood, which usually means that the number of bleaching stages can be shorter. Table 2.34 is listing a number of options out of the big amount of possible variations. Examples for light ECF sequences are (DZ)(EOP)D, (DQ)(PO), D(EOP)D(PO) and these can be applied for both hardwood and softwood depending on the brightness target.

ECF / Softwood	ECF / Hardwood
D(EP)D	D(EOP)D(EP)D
DPDP	D(EO)D(EP)D
D(EOP)DD	D(EOP)DD
D(EO)DD	D(EO)DD
D(EO)D(EP)D	QDPZP
DQ(PO)	
D(EOP)DED	
D(EO)D(OP)	
D(EOP)D(OP)	
(OP)DQ(PO)	
Notes: D = Chlorine dioxide bleaching stage using a solution of chlorine dioxide (ClO ₂) in water. E = alkaline extraction stage using NaOH; EO = alkaline extraction stage using NaOH with subsequent addition of gaseous oxygen as a reinforcing agent; EP = alkaline extraction stage using NaOH with subsequent addition of H ₂ O ₂ -solution as a reinforcing agent; P = alkaline stage with H ₂ O ₂ as liquid; EOP =alkaline extraction bleaching stage using sodium hydroxide with subsequent addition of oxygen and hydrogen peroxide solution as a reinforcing agent; Q = Acid stage where chelating agent EDTA or DTPA has been used for removal of metals; Z = Ozone bleaching using gaseous O ₃ ; PO = Pressurised peroxide bleaching	

Table 2.34: Bleaching sequences in ECF softwood (SW) and hardwood (HW) kraft processes

Chlorine dioxide has the highest selectivity among technical bleaching chemicals. Bleaching with only chlorine dioxide in the first bleaching stage means that the total charge of effective chlorine has to be increased and oxygen and hydrogen peroxide are more extensively used in the extraction stages compared to a conventional C or C/D stage.

Example of the chlorine dioxide stage (D) characteristics:

Pulp consistency: 10 %; Reaction time: 30 min; Temperature: 60°C; Final-pH: 3.5

Example of alkaline extraction stage characteristics reinforced with oxygen and peroxide (EOP):

Pulp consistency: 12 %; Reaction time: 60 min; Temperature: 60 - 70°C; Alkali charge: 10 - 20 kg/ADt; Oxygen charge: 3 - 6 kg/ADt; Hydrogen peroxide charge: 2 - 4 kg/ADt

Peroxide can be applied in several positions or several different ways:

- Reinforcement of a mild initial oxygen stage (low or moderate charge)
- Reinforcement of alkaline extraction stages (low charge)
- Final brightness adjustment in high density storage towers (low charge)
- Separate delignification/bleaching stage (high charge)
- Separate pressurised delignification/bleaching stage (high charge, PO). The positive impact of having a (PO)-stage in the end of the bleach plant is that ECF pulp can be produced in an existing mill without having to invest in additional chlorine dioxide capacity.

Applicability and characterisation of the measure: The measure can be adopted in new and existing kraft mills. Conversion of existing mill to ECF mill has been possible but require often considerable modifications in the fibre line and chlorine dioxide production: Chlorine dioxide generators have to be upgraded to meet the increased demand of this bleaching chemical. Existing bleach plants have to be retrofitted with different chemical mixing etc. systems. Bleaching chemical cost will increase.

Main achieved environmental performance: Eliminates 2,3,7,8-TCDD and 2,3,7,8-TCDF to non-detectable levels. However, the complete elimination of dioxins in ECF bleached effluents is a question of kappa-number and purity of ClO₂. With high kappa and impure ClO₂ (i.e. high concentration of Cl₂) the probability of forming dioxins increase. Eliminates the priority chlorophenols proposed by the U.S. Environmental Protection Agency (EPA) for regulation to non-detectable levels. Decreases chloroform formation. Decreases chlorinated organic compound (AOX) formation to a level of 0.2-1.0 kg/ADt prior to external effluent treatment. Usually AOX levels < 0.3 kg AOX/ADT can easily be achieved by ECF bleaching.

Cross media effects: Implementation of ECF has required the pulp and paper industry to increase the use of substituting bleaching chemicals which require considerable amounts of energy in manufacturing of chlorine dioxide, oxygen and hydrogen peroxide.

Operational experiences: The production of ECF has been tested and practised in full-scale pulp lines for several years.

Economics: The investment costs for a 1500 ADt/d ECF bleaching system are 8-10 MEuros at new mills and 3-5 MEuros at existing mills. The operating costs are 10-12 MEuro/a. These costs are based on the assumption that an existing bleach plant can be used and the investment costs include then the necessary increase in chlorine dioxide production. The operating costs also contain thus the additional cost of using chlorine dioxide instead of elementary chlorine for bleaching.

Driving force for implementing this technique: The reduction of AOX emissions to water (effluent treatment plant and recipient) is the main reason to implement the method.

Reference plants: Several plants in Europe, North and South America and South Africa.

Literature:

[J. Pöyry, 1997b], [Finnish BAT report, 1997], [J. Pöyry, 1997a], [ECF, 1997], [SEPA-Report 4713-2, 1997]

2.3.7 TCF bleaching technique

Description of the technique: Totally Chlorine Free (TCF) bleaching is a bleaching process carried out without any chlorine containing chemicals. TCF bleaching has been developing rapidly, even if its application has required commonly several modifications in the pulping process. In TCF-bleaching hydrogen peroxide together with ozone (Z) or peracetic acid (PA) are the most commonly used chemicals. Provided that the pulp has a low enough kappa number after extended cooking and oxygen delignification and that transition metals (e.g. Mn^{2+}) have been removed in the necessary chelating stages (Q-stages), it is possible to attain full market brightness with peroxide as the sole bleaching chemical. However, the dose-response curve for brightness versus peroxide consumption is quite shallow at top brightness, which means that even small disturbances in the incoming kappa number can cause rather high bleaching costs and downgrading of the pulp because of low brightness.

One possible option of reducing the hydrogen peroxide consumption is to introduce an ozone stage into the sequence in a position before the peroxide stage (ZQP). Ozone is very efficient to reduce the amount of peroxide required to obtain even very high brightness levels. A drawback with ozone is that in larger charges it has a tendency to attack the cellulose chains.

Peracids have now become commercially available in the form of e.g. peracetic acid (PA). This bleaching chemical is a valuable complement in a stage preceding hydrogen peroxide where it can replace ozone. Full brightness can be achieved even when the unbleached pulp has a slightly higher kappa number than the very lowest. The drawback with peracetic is its still rather high cost.

Examples for different TCF bleaching sequences are listed in Table 2.35.

TCF/SW	TCF/HW
Q(EP)(EP)(EP)	QPZP
Q(OP)(ZQ)(PO)	Q(OP)(ZQ)(PO)
Q(EOP)Q(PO)	Q(EOP)Q(PO)
Q(OP)ZQ(PO)	Q(OP)ZQ(PO)
Notes: Q = Acid stage where chelating agent EDTA or DTPA has been used for removal of metals; EP = Extraction stage using NaOH with subsequent addition of H_2O_2 -solution as a reinforcing agent; EOP =alkaline extraction bleaching stage using sodium hydroxide with subsequent addition of oxygen and hydrogen peroxide solution as a reinforcing agent; EO = Extraction stage using NaOH with subsequent addition of gaseous oxygen as a reinforcing agent; P = Alkaline stage with H_2O_2 as liquid; Z = Ozone bleaching using gaseous O_3 ; PO = Pressurised peroxide bleaching	

Table 2.35: Bleaching sequences for TCF softwood and hardwood (HW) kraft pulping

Example of Q-stage characteristics:

EDTA: 1-2 kg/ADt; pH: 5.7 - 6.2; Pulp consistency: 10 %; Reaction time: 60 min; Temperature: 90°C

Example of E-stage (alkaline extraction stage) characteristics reinforced with oxygen and peroxide (EOP):

NaOH: 10 - 20 kg/ADt; Oxygen: 3 - 6 kg/ADt; H_2O_2 : 2 - 4 kg/ADt; pH: 11; Reaction time: 60 min; Temperature: 60 - 70°C;

Example of P-stage characteristics :

H_2O_2 : 20-40 kg/ADt; pH: 11 - 11.5; Retention time: 4 h; Temperature: 90°C

The first TCF bleaching sequence was based on peroxide under alkaline conditions and an extensive use of hydrogen peroxide is still the main feature of all TCF bleaching sequences.

Decomposition of peroxide is catalysed by certain metal ions which have to be removed in an acidic stage before the peroxide stage.

Peroxide can be applied in several positions or several different ways:

- Reinforcement of a mild initial oxygen stage (low or moderate charge): OP
- Reinforcement of alkaline extraction stages (low charge): EP
- Final brightness adjustment in high density storage towers (low charge): P
- Separate delignification/bleaching stage (high charge): P
- Separate pressurised delignification/bleaching stage (high charge): PO

Pre-treatment of the pulp with a suitable electrophilic agent before peroxide bleaching may “activate” the fibres and improve their response to peroxide. Ozone can promote this kind of effects.

Ozone has become the most common complement to peroxide in TCF bleaching sequences. The main purpose of using ozone is to provide more delignification power. Ozone activates the fibres towards hydrogen peroxide and these results in a higher brightness and a somewhat lower hydrogen peroxide consumption. On the other hand, the selectivity of ozone is poor. Excessive application, too high temperature or other unsuitable treatment may lead to serious cellulose degradation. Ozone should preferably be applied under acidic conditions (pH ≈2-3). Too high temperature (>70°C) impairs the selectivity. High pressure increases the solubility of ozone in the aqueous phase during bleaching (dissolved ozone is claimed to be less aggressive to the carbohydrates than ozone in the gas phase). Pulp consistency is an important parameter in ozone bleaching. Installations of ozone bleaching are operating under medium consistency (8-15 %) or high consistency (>30 %) conditions.

If ozone is applied, a new unit of on-site chemical manufacturing is necessary because of the rapid decomposition of ozone in transportation or storage. The operating costs of TCF pulping are usually somewhat higher than those of ECF pulping.

Applicability and characterisation of the measure: The measure can be adopted in new and existing kraft mills.

In existing mills, using chelating stage a new oxygen stage and washer is usually needed to convert the ECF bleaching sequence to TCF. If hydrogen oxide or ozone stages are used, two new bleaching towers are used and reconstruction of bleaching filters. Ozone bleaching needs ozone generators and reactor. For peracetic acid one bleaching tower is needed.

In new greenfield mills, less modifications and investment costs are required but operating costs are likely to be the same order of magnitude.

Main achieved environmental performance: In TCF bleaching the formation of AOX is zero.

Cross media effects: Today there are no significant differences in chemical and energy consumption, when comparing an ECF and TCF alternative..

Operational experiences: TCF-bleaching is now a well established technology. Many mills in Europe have created a possibility of produce TCF pulp in separate campaigns instead of ECF pulp depending on the market demand. A few mills are manufacturing only TCF pulp. Slightly higher production costs and no improvement in the product quality have, however limited the demand and the share of TCF-pulps has not been increasing in the last couple of years.

Economics: The investment costs for peroxide bleaching at new mills with 1500 ADt/d production rate are 7-8 MEuros with existing pulp mills the costs are 2-5 MEuros depending on

the materials of the existing bleaching equipment. If the materials tolerate hydrogen peroxide the costs are 2-3 MEuros. Operating costs with peroxide bleaching are considerably higher, 18-21 MEuro/a, than with ECF bleaching due to the higher chemical costs.

If both ozone and peroxide bleaching are applied, the investment costs are higher (see also Section 2.3.5 ozone bleaching).

Driving force for implementing this technique: The AOX emissions to the water are reduced and chloro-organic compounds are not formed in the TCF bleaching.

Reference plants: Many plants in Europe and some plants elsewhere in the world.

Literature:

[J. Pöyry, 1997b], [Finnish BAT report, 1997], [J. Pöyry, 1997a], [ECF, 1997], [SEPA-Report 4713-2, 1997]

2.3.8 Partial closure of the bleach plant

Description of the technique: There are limited discharges of pollutants to water before the bleaching stage. If the bleaching stage can be wholly or partly closed, this would result in substantial further reductions in discharges to water of organic substances, nutrients and metals.

The foremost prerequisite when closing the bleach plant, by which is here meant the recycling of the filtrates to the chemical recovery, is to reduce the volumetric flow through the bleach plant. This can be achieved by leading the liquids counter-currently from the last bleach stage through the sequence via the oxygen stage washing apparatus to the brown stock washer as shown by use of example in Figure 2.11 [Alfthan, 1996].

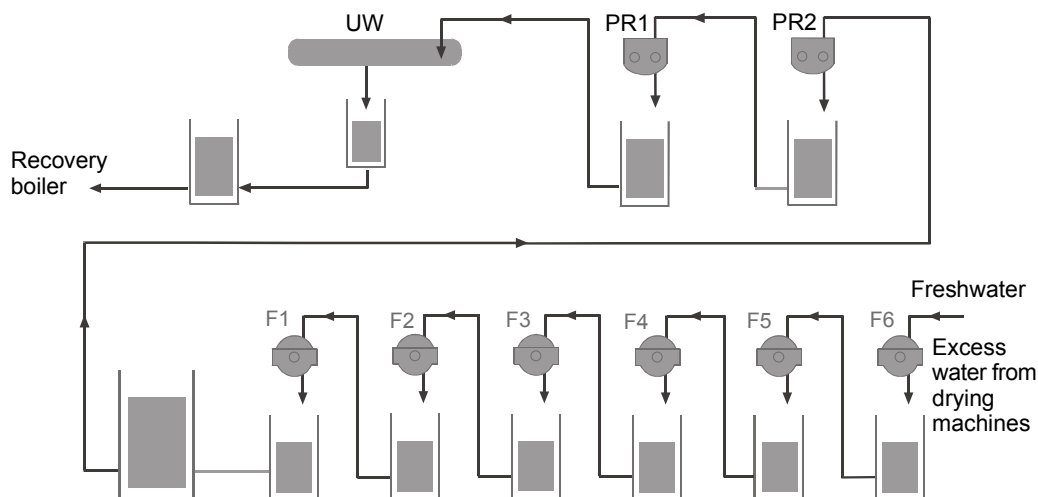


Figure 2.11: Principle of a possible water system in closed up bleach plants

F1 - F6 = Washing filters in the bleach plant; PR1 + PR2 = Washing presses in oxygen delignification; UW = horizontal washer as last stage of brown stock washing; the tanks provide the required storage capacity for internal waters. The water system presented in this figure has only been operated over a period of a few months. Today it is partially re-opened

As shown in Figure 2.11 to increase the closure of the bleach plant extra storage capacity for internal waters and a rebuilt of the water distribution system is necessary.

It is inevitable that dissolved organic substances and reaction products build up in the filtrate circulating around the peroxide stages. The accumulation of dissolved solids causes a considerable extra increase in the consumption of bleaching chemicals. It can even be difficult to reach full brightness at all. A further complication with counter-current washing is that pH-adjustments with sulphuric acid and caustic soda will be costly because of the considerable buffer capacity of the pulp. The sodium-sulphur balance of the mill may therefore be disrupted. The conclusion is that a really closed bleach plant is not an available technique up to now. But it is possible to carry the filtrates in two counter-current streams, one acidic and one alkaline. The alkaline water may be used for washing the pulp in the unbleached part of the process. This will result in a significant reduction of flows and discharges from the bleach plant compared to conventional systems.

It has to be considered that calcium is present in the pulp and during all oxidative bleaching a substantial amount of oxalic acid is formed. When an alkaline filtrate is used as wash water on a pulp coming from an acidic stage or is mixed with an acidic filtrate where calcium is dissolved, there is a risk that solid calcium oxalate precipitates. The tendency for calcium oxalate to precipitate becomes stronger the higher the concentrations of calcium and oxalate. In other words: the more the system is closed or the filtrates are recycled, the higher is the risk for precipitation or scaling. This problem still awaits a solution. It is hardly possible to reduce the discharge from the bleach plant further than down to 5 m³/t, the currently lowest achieved value. More research is therefore needed to find "kidneys" (e.g. ion exchange or precipitation) to purge the system either of calcium or oxalate or probably both. These kidneys are also needed to avoid the build-up of other unwanted species (e.g. so-called non-process-elements) that may impair the bleaching process, the technical equipment or the product.

Finally, increased contents of chlorides may cause corrosion in the process equipment if wastewater from the bleach plant is recycled to the closed system. Therefore, preferably TCF or ECF mills using modest amounts of chlorine dioxide try to increase the degree of closure of the bleach plant.

Applicability and characterisation of the measure: Generally, the reduction of fresh water consumption in the bleach plant can be installed in both existing or new mills. But for existing mills the investments for white water storage, piping system and the implementation of a control system for water management are relatively higher. Newer mills usually have already less water to handle because of more efficient equipment. A prerequisite for these measures is a sufficient capacity in evaporators and recovery boiler. It should be noted that the evaporation of bleach plant effluents is easier to apply in case of TCF bleaching. For safety reasons in ECF bleaching there is an elevated risk of chloride corrosion in the recovery boiler with today's knowledge.

Main achieved environmental performance: This pollution prevention measure results in reduction in COD loads and flows as well. Typical figures for wastewater quantities from a bleach plant are 20 - 40 m³ water/ADt. 20 - 25 m³/ADt should suffice in a modern filter bleachery. It has been reported that partly closure of the bleachery may reach a volume reduction down to 10 m³/ADt and a corresponding COD discharge of about 6 kg/ADt. One mill reported a flow reduction from the bleach plant down to only 5 m³/t and a corresponding COD reduction from 30 kg COD/t down to 14 kg COD/t including a reduction of toxicity in the effluents at the same time.

Cross-media effects: The P and D bleaching stages and alkaline extraction stage as well benefits from the higher temperatures in the water system. Dissolved organic substances from the bleach plant effluents are lead via evaporation plant to the recovery boiler. This requires additional capacity and energy consumption in the evaporation plant. On the other hand, energy and space for external treatment may be saved and less excess sludge may be generated.

Operational experiences: Trials with the closing up of the water systems of a birch line in a Swedish kraft mill started already in 1993. Installations to allow for regular full scale production

without bleach plant effluent have been in operation for some month. As a consequence of scaling and clogging problems (precipitation of calcium-oxalate) the water system has been partly re-opened in the first acid stage to remove the filtrate with the highest calcium concentration. After trimming of the process conditions the mill is now running a partly closed up bleach plant. A few other mills in Europe and North America have partly closed up the bleach plant.

Economics: Considerable investments have to be taken: A total rebuild of the water distribution system in the bleach plant including extra storage for internal waters is necessary. A control strategy for the water management in the plant has to be developed and implemented. Reliable data on costs were not available.

Driving force for implementing this technique: Reduction of discharges of BOD and COD. Pulp mills operating without external biological treatment were the pioneers in reducing the effluents from the bleach plant by process-internal measures.

Reference plants: Some mills in Sweden, Finland and North America

Literature:

[Annergren, 1996], [Alfthan, 1996], [Höök, 1997]

2.3.9 Collection of almost all spillages

Description of the technique: Chemical pulp mills need to carry out in-plant measures to minimise discharges of process effluents. The external effluent treatment, especially when comprising of biological treatment, can be severely upset due to accidental discharges from chemical pulping.

Pulping liquor is lost from seals on brown stock washers, pumps and valves in liquor service, from knotters and screens, sewer evaporator boil-out solutions, and other intentional liquor diversions during maintenance, start-ups and shut downs. Liquor is also lost in spills resulting from process upsets, tank overflows, mechanical breakdowns, operator errors and construction activities.

Chemical pulp mills should be designed around the following concepts:

- Collection of diverted or spilled liquor at the highest possible liquor solids concentration.
- Return of collected liquor and fibre to the process at appropriate locations
- Curbing of isolate critical process areas (including tall oil and turpentine) to avoid concentrated or harmful streams entering the external effluent treatment or contaminating clean water sewers.
- Conductivity or pH monitoring at strategic locations to detect losses and spills (spill control system which makes possible prevention of spillage and monitoring).

Of the process liquors, both the weak liquor coming from the unbleached pulp washing as well as the strong liquor produced out of it in an evaporation plant has special importance for efficient collection. These liquors cause unnecessary loading and occasionally upsets in the external effluent treatment.

The general concept for efficient recovery also requires to arrange the contaminated effluent sewers so that most of the spills, contaminated sealing waters or floor washing in key areas - pulp cooking, washing and screening, used liquor storage and evaporation, cooking liquor preparation - are collected in sumps and pumped either directly or via an intermediate tank into an appropriate liquor storage tank. The need of such recovery must, typically due to economic

reasons, be limited to areas where the mixed spill concentration is at least 2-3 % dry dissolved solids. Floor washing and sealing water in these collection areas dilute the recoverable stream so care must be taken not to dilute process liquors too much.

Hot condensates from pulp cooking and liquor evaporation must also be stored prior to their reuse in the pulp production. These condensates are divided according to their cleanliness to clean, semi-contaminated and contaminated fraction. Especially the last-mentioned may find fewer uses and despite of sufficient storage volume is sewerage causing some organic load and increase in total effluent temperature. Contaminated and semi-contaminated condensate bleedout is decreased simply by improved usage by replacing with them fresh water. One way, also for environmental reasons, is to feed them through steam stripping to remove reduced sulphur and volatile organic compounds and make them fairly clean hot water for a wider variety of process uses.

Inside product areas, such as tall oil plant and turpentine recovery, care shall be taken to avoid spills going to the external treatment. Soap and turpentine contain substances that may cause toxic effects in the biological treatment.

A single line kraft mill would need up to five collection sumps equipped with conductivity actuated recovery pumps. Moderately complex mills would require up to 9 and complex mills up to 12 sumps.

Besides technical aspects covered above training of staff can be a very effective way of reducing discharges of harmful substances.

Applicability and characterisation of the measure: Process integrated measure. Applicable to both new and existing mills. However, the effective spill control system is easier to install when designing and building new installation rather than to retrofit in old mills.

In existing mills the solution to efficient process stream containment lies also in the key process equipment itself. Thus building of spill containment should be done in connection with evaluation of other cost effective improvements, especially in pulp washing and screening, evaporation and liquor filtering.

Main achieved environmental performance: This pollution central measure is connected to BAT 2.3.12 "Use of sufficiently large buffer tanks etc." The achieved environmental performance requires a combination of both BAT's.

A general analysis has indicated that with good process management and properly designed spill containment, recovery and having 5-10 % extra capacity in the evaporation plant a reduction in effluent load of 3-8 kg COD/ADt can be reached in comparison to mills with no or inefficient spill recovery and poor process stability. In total spills can be less than 2 kg COD/ADt.

Additionally the risk of upsets in an external treatment plant is reduced, when accidental discharges with high organic and sometimes toxic load or continuously high or low pH of the incoming stream can be avoided.

Cross-media effects: In order to handle the collected spills, 5-10 % more evaporation capacity would be needed. This would also consume 5-10% more steam and power. However, collection of spills mean recovering of energy and chemicals when it is burned in the recovery boiler.

Operational experiences: Liquor spill and overflow containment in the process and establishment of relevant management policy in the chemical production has been found beneficial and necessary both on the economical and environmental point of view. This matter has been solved efficiently in many mills with fairly simple methods. The limitations to efficient implementation of these measures come from mill-specific process bottlenecks, typically in pulp washing and screening or evaporation.

Economics: The investment cost for spill liquor handling systems at a kraft mill producing 1500 ADt/d pulp mill is 0.8-1.5 MEuro. If evaporation plant needs to be expanded with 0.8 m³/ADt an additional cost of 4-6 MEuros will be required. The operating costs of the system are estimated to be 100000 - 400000 Euro/a, but can vary considerably between existing and new mills. With new mills there is generally more excess heat and the operating costs are in the lower part of the range.

Driving force for implementing this technique: Reduction of discharges of BOD and COD.

Reference plants: Numerous mills around the world.

Literature:

[Tappi Proceedings, 1996], [SEPA-Report 4713-2, 1997]

2.3.10 Efficient washing and process control

Description of the technique: The objective of brown stock washing is to separate the pulp fibres as completely as possible from dissolved organic and inorganic chemicals before the pulp leaves the pulping department thereby recovering as much as possible of the cooking chemicals and of dissolved organic substances.

The washing stage consists of a combination of successive dilution and thickening or displacement. In practice, each combination of washing equipment makes use these methods at different proportions. There is a variety of pulp washing equipment the most typical being vacuum or pressurised drum filters, fourdrinier type washers, atmospheric and pressurised diffuser washers and wash presses. Out of these, the washer press and pressurised drum or diffuser washers represent the best performance. With increased consistency of the pulp, the quantity of contaminated water going with the pulp is reduced.

As the washing is never 100% efficient a certain amount of chemicals and pollutants (carry-over) is transported with the pulp into the bleach plant where it consumes bleaching chemicals and is usually discharged to the sewer.

Applicability and characterisation of the measure: The measure can be adopted in new and existing kraft mills.

In practice, at existing mills the modifications of a washing system may be outweighed also due to practical reasons by the complete set of new washing equipment.

A closed washing system increases the importance of collection of temporary spills. The outgoing washing liquor contains both organic and inorganic substances. Washing waters withdrawn from the process are disposed through the external treatment.

Main achieved environmental performance: The washing loss after a conventional drum washing system could be around 5-8 kg COD/ADt, in comparison to 2-4 kg COD/ADt obtained in a modern washer system comprising a press washer. The remaining substances are adsorbed on or enclosed in fibres. In the latter system, the outgoing pulp consistency increases from roughly 10-15 % to 25-35 % and the water content decreases from 6-10 m³/ADt to 2-3 m³/ADt. Washing stages in series can reach up to 96-98 % recovery efficiency of black liquor.

When efficient washing takes place before an oxygen delignification stage, there will be reduction in the oxygen consumption. If there is an efficient washing system prior to the first bleaching stage, the carry-over of organics to bleaching will drop, resulting in reduced AOX, BOD₅ and COD discharge to the mill sewer.

Monitoring: Standardised methods exist for measuring this carry-over which is often denoted "washing loss". Washing losses were originally measured as the sodium sulphate content in the pulp. As this loss of make-up chemical has become less important, the washing loss is nowadays normally measured as COD.

Cross media effects: The inorganics that stay in the pulp result in increased make-up chemical requirements.

Operational experiences: A basic concept is several years old. The washing technology has been developed over the years and now solutions have been tested and proven on operation.

Economics: Investment costs are typically 4-6 MEuros at new mills and approximately 2-4 MEuros for existing mills. No major additional operating costs are involved.

Driving force for implementing this technique: The reduction of emissions to water is the main reason to implement the method.

Reference plants: Numerous plants in Europe.

Literature:

[J. Pöyry, 1997a], [J. Pöyry, 1997b], [Tappi Environmental Conference, 1992],

2.3.11 Stripping of the most concentrated contaminated condensates and re-use of most condensates in the process

Description of the technique: The aim of the stripping of contaminated concentrated condensates is to reduce fresh water consumption of the mill to reduce organic pollution load to the wastewater treatment plant and to reduce TRS emissions. The stripping and reuse of condensates can reduce the COD load to the effluent treatment plant significantly.

Condensates can be classified as:

- primary condensates - live-steam condensates that are normally clean enough to be reused as boiler feed water (after polishing)
- secondary condensates - contaminated steam condensates that are flashed from black liquor, pulp suspensions, etc.

Condensates originate from the process vapours from digesters and the evaporation plant. In total about 8 - 10 m³/ADt of total condensates are formed with a COD load of about 20 - 30 kg/t and 7-10 kg/ADt of BOD₅. Normally about 1 m³/ADT is heavily polluted, 4 m³/ADt medium and 4 m³/ADt low contaminated.

The COD is mainly methanol (5-10 kg/ADt) with some ethanol and a number of organic sulphuric compounds (1-2 kg/ADt TRS), 1-2 kg turpentine and inorganic nitrous compounds. Foul condensate contains furthermore ketones, terpenes, phenolics, resin and fatty acids and various dissolved gases. A large proportion of nitrogen discharged from a Kraft pulp mill is contained in condensates.

About 1 m³ of condensate per tonne of pulp has a COD concentration of 10 - 20 kg COD/m³. The level is higher in condensates from hardwood pulp than from softwood. These strong condensates are normally treated in a stripper where the removal efficiency for most compounds is over 90% depending on the pH. Stripping systems usually remove malodorous gases (TRS) and COD contributing substances at the same time. Stripped condensates after treatment can be 1 - 1.5 kg COD/m³ of condensate. The stripped gases are either incinerated in a dedicated burner

with subsequent SO₂ scrubbing or burnt in the lime kiln. The latter option may cause problems, which affect the capacity to absorb sulphurous compounds of the lime kiln.

About 7 - 9 m³ of weaker condensates (medium and low contaminated) are formed with COD ranging from 0.5 to 2 kg COD/m³ containing a total of about 8 - 12 kg of COD/t of pulp.

Alternatively, moderately contaminated condensates can be stripped in a system linked to the evaporation plant thereby effecting treatment without any substantial additional use of energy. In this way the total COD load before any reuse is reduced to about 5 kg/t, a reduction of about 50% compared to only treating the most contaminated condensates.

The stripping column can be a separate equipment or it can be integrated part of the evaporation plant. The condensates are fed to the top of the stripping column. Steam or vaporised condensate rises from the bottom of the column in a counter-current manner to the foul condensate. The overhead vapour from the stripping column is sent to a reflux condenser where it is partly condensed. The purpose of the reflux condenser is to condense some of the water in the gases and to increase the concentration of volatile material in the gases leaving the condenser. The non-condensable gases from the condenser contain the majority of the volatile compounds that are stripped in the stripping column. They are led to incineration where the organic and TRS compounds are destroyed by thermal oxidation.

Cleaned condensates are free of metals and therefore particularly useful for washing in the bleach plant when aiming at closing up this part of the process. They can also be reused in brown stock washing, in the causticizing area (mud washing and dilution, mud filter showers), as TRS-scrubbing liquor for lime kilns or as white liquor make-up water. This means that some condensates will be used in closed parts of the process and will not be discharged to waste. Other condensates will be used in open parts, e.g. the bleach plant, and end up in the effluent together with those condensates, which are not reused but discharged directly to waste.

Applicability and characterisation of the measure: Steam stripping is a viable in-plant treatment method for reducing COD and odour from kraft mill foul condensates. The process can be applied at both existing and new kraft mills. The condensate stripping column can be separate or it can be integrated to the evaporation plant. In the former case, live steam would be required whereas in the latter case secondary steam from evaporator effects can be used. However, thermal oxidation of the vapours from stripper system is needed. Lime kilns, power boilers and separate TRS incinerators can be used for this purpose.

Main achieved environmental performance: The best place to reuse the condensates is pulp washing either on the last washer or on the decker in a mill with a closed screen-room water system. The typical wash water demand is 10 - 13 m³/ADt. The evaporator-area and digester-area condensate available for reuse can amount to 6 - 9 m³/ADt, which is the amount of potential water savings. In total stripping of only the heavily polluted condensates would result in 4-6 kg COD/ADT while with stripping of the medium contaminated condensates about 3-5 kg COD/ADT can be achieved. However, condensates discharged to effluent treatment is mostly readily biodegradable. TRS removal is about 97 % from the condensate, methanol removal about 92%.

Cross media effects: When steam stripping is used, the non-condensable gases (NCGs) have to be incinerated separately in order to avoid release of concentrated TRS gases into the atmosphere. This has been discussed in more detail in connection with sections 2.3.18 and 2.3.19.

When stripping of concentrated contaminated condensates is applied, the load to the wastewater plant will be reduced and if there is difficulties to meet the permit new investments in the effluent treatment plant may be avoided. This also means that less energy is needed for aeration and less energy and chemicals in the sludge treatment.

When combining the recovery of clean condensates and stripped condensates, fresh water consumption may be decreased up to 6 m³/ADt. Because the condensates are hot, part of the energy used in the stripping column can be saved.

Fugitive TRS emissions from wastewater treatment plant can be reduced by steam stripping of condensates that removes TRS compounds from foul condensates.

As the stripper off-gases contain 8-12 kg/ADt methanol, there is potential to save fuel oil or natural gas, provided that the stripper gas can replace the fuel.

The stripping of condensates reduces the low level emissions of TRS compounds from foul condensates. The TRS compounds include hydrogen sulphide, methyl mercaptan, dimethyl sulphide and dimethyl disulphide. These emissions are partially responsible for foul odours from a kraft mill.

Operational experiences: The stripping of contaminated condensate has been used many years at modern mills. When, the stripping system is used for high methanol removals, the condensates from the stripping column is relatively clean and can be re-used in the pulp mill for applications such as brown stock washing.

The basic for the design should be the minimising the flow to the stripping system by segregating the condensates to reduced investments. In the evaporation plant, the first liquor vapour condensate can be split into two fractions. Surface condenser can be split into two units or two condensing steps. The blow vapour from a batch digester can be condensed in two steps. Secondary steam can be used as the main steam source to the stripping column.

Economics: The investment costs for the stripper system at a 1500 ADt/d kraft pulp mill are about 2.0 – 2.5 MEuro. Additional investments may be required to increase the capacity of the mill's evaporation plant, but this depends very much on the existing evaporation plant configuration. Retrofitting costs can vary between 1-4 MEuros.

The operating costs of condensate stripping consist mainly of the cost of steam used in stripping and maintenance. If the stripper is operated separate from the evaporation plant, the operating costs are significantly higher due to the demand of fresh steam. The costs are about 0.6 – 0.7 MEuros/a. If the stripper is connected between the evaporation stages, the operating costs are lower. The operating costs in the latter case are 0.3-0.4 MEuro/a.

Driving force for implementing this technique: Kraft mills may face COD discharge problem. It may have inadequately sized or operating wastewater treatment system or have new more stringent limits or a mill expansion or process modification which increase in the COD load to the wastewater treatment plant. Thus there is a need to re-use condensate in the pulp mill processes. The reuse of foul condensates without treatment has adverse effects on pulp quality.

Reference plants: Numerous mills in Europe.

Literature:

[Sebbas, 1988], [Zunich, 1993]

2.3.12 Use of sufficiently large buffer tanks for storage of concentrated or hot liquids from the process

Description of the technique: Chemical pulp mills need to carry out careful in-mill measures to minimise discharge of concentrated or hot process streams out as effluents. First, the external effluent treatment, especially when comprising of biological treatment, can be severely upset

due to accidental discharges from chemical pulping. Second, some process liquor streams have economical importance due to their fuel value or the chemicals they contain.

This pollution control measure is connected to BAT 2.3.9 "Collection of almost all spillages". For spill control system please refer to this paragraph. For prevention of unnecessary loading and occasionally upsets in the external effluent treatment process cooking and recovery liquors and dirty condensates should have storage capacity exceeding normal operating volumes by at least 30 % extra. Clean streams are diverted from potential spill areas to avoid dilution of recovered process liquors.

The volumes available to control these weak and strong liquors from sulphate or sulphite production especially in start-up, shutdown or upset conditions are crucial. A basic demand for storage volumes is caused by the liquor concentration, measured as dry solids content. For instance, in an old kraft pulp mill the weak black liquor can be at 8 % and strong liquor at 60 % concentration opposed with 16 % and 75 % of a modern mill. This means that proportionally the storage volumes must be considerably larger in mills with low-efficiency washing of unbleached pulp or standard evaporation plant without liquor concentrator units.

The spare volume required above the normal condition must be able to contain peak process flows of a few hours due to operational disturbances. The spare volume must further make sure that enough weak liquor can be stored that the evaporation plant can operate normally despite of a short shutdown in cooking and washing or that a part of a multi-line or a single-line evaporation plant can be shut down for short maintenance. The storage volume must also be large enough to store enough strong liquor so that problems or short-lived production cut in recovery boiler can be solved without decreasing evaporation throughput or that the evaporation plant can be shut down for short maintenance.

Existing mills considering the implementation of oxygen delignification must assess their weak and strong liquor storage and evaporation plant capacity, because this process step is likely to increase the amount of water going through evaporation.

Liquors after the recovery boiler and with additional process steps reformed to fresh cooking liquor are free from organics but have very high pH-value. These liquor tanks equally need buffer capacity for short-lived peak flows or for instance shutdowns in connected process units such as liquor filters. These liquors, if sewerage out to the effluent treatment plant cause pH shocks which, if poorly controlled before biological treatment, result in upsets.

Applicability and characterisation of the measure: Process integrated measure. Optimisation of necessary buffer storage capacity for hot or concentrated streams is applicable for both existing and new mills and is in many ways a must. These measures do not only help to maintain valuable process chemicals in the production and improve process economy, but they considerably affect the environmental performance of the mill. In existing mills the solution to efficient process stream containment lies also in the key process equipment itself. Thus building of buffer storage and spill containment should be done in junction with evaluation of other cost effective improvements, especially in pulp washing and screening, evaporation and liquor filtering.

Main achieved environmental performance: This pollution control measure is connected to BAT 2.3.9 "Collection of almost all spillages". The achieved environmental performance requires a combination of both BAT's.

The risk of upsets in an external treatment plant is reduced, when accidental discharges with high organic and sometimes toxic load or continuously high or low pH of the incoming stream can be avoided. The effect on hydraulic loading is not as pronounced except in mills where washing and screening water system is open.

Monitoring: Conductivity probes are suitable for detecting and evaluating mill liquor spills, because in many cases a conductivity-liquor concentration correlation for each specific stream can be established. In low-concentration streams with varying pH, an on-line pH probe is standard.

Hot streams needing specific monitoring in the sewer can be readily monitored with on-line temperature probes

Cross-media effects: Changes in liquor and hot liquid tanks and control often require changes or improvements in other equipment, especially in pulp washing or evaporation. The handling of hot liquids requires 5-10 % more energy in the evaporation plant

Operational experiences: These are many ways to solve liquor spill and overflow containment in the process and establishment of relevant management policy in the chemical. The limitations to efficient implementation of these measures come from mill-specific process bottlenecks, typically in pulp washing and screening or evaporation.

Economics: Investment costs for 1500 ADt/d pulp production about 0.8 - 1.0 MEuros for two 3000 m³ storage tanks including necessary piping, insulation and pumps with electrification and process control.

Driving force for implementing this technique: These measures are promoted by environmental and process safety reasons.

Reference plants: Numerous modern mills around the world.

2.3.13 Secondary or Biological Treatment - Aerobic Methods

Description of the technique: Secondary or biological treatment is carried out for the removal of organic matter (organic substances), which is achieved by biological degradation. Prior to the secondary treatment there is commonly a set of primary treatment stages including solids removal, neutralisation, cooling and equalisation. These primary stages aim at protecting the secondary treatment from excessive loads and shocks and overall at providing more cost-efficient purification of effluents. In most cases pulp and paper mill effluents are treated with aerobic methods. The most common aerobic treatment methods used in pulp and paper industry are aerated lagoon and activated sludge process. The former achieves less reduction of pollutants but is cheaper.

Aerated lagoon

An aerated lagoon has a large volume with residence times for the effluent within 3-20 days. The micro-organisms grow in suspension in the bulk of liquid, reaching in the lagoon relatively low solids concentration, 100-300 mg/l. The growth of microbes requires oxygen, which is provided almost exclusively by mechanical aeration equipment. Surface turbine aerators are the most common aeration units, but in deep lagoons also bottom aerators with self-induced or compressed air feed are also used. Aeration equipment provides also mixing required to keep solids in suspension and enhance microbial action.

Aerated lagoons are due to the large area and volume they require earth basins and can be constructed with or without a settling zone. In the first case the end of the lagoon is left without aeration and mixing, thus allowing solids to settle. In the latter case this settling is carried out in a separate pond. The biological process does not involve recirculation of biomass from the end to the beginning of the basin. The settled sludge is removed seldom, once in 1-10 years.

The use of aerated lagoons has recently become less common for many reasons, one important being its lower removal efficiency of effluent contaminants in comparison with the activated sludge process.

Activated sludge process

The activated sludge plant consists of two main units, the aeration basin and the secondary clarifier (sedimentation basin). In the first stage, the aeration basin, the effluent is treated with a culture of micro-organisms (the activated sludge), which is present in a high concentration. Activated sludge plants at kraft pulp mills have a retention time of about 15-48 h with the higher values in recent installations.

The sludge is separated from the water in the clarifier. The main part of the sludge is recycled to the aeration basin, which is necessary for keeping the high sludge concentration. A small part of the sludge, corresponding to the net growth, is removed from the system as the excess sludge.

Oxygen and mixing is provided to the aeration basin by mechanical aeration equipment. Various types of aerators are in use, such as surface aerators, submerged turbine aerators, fine bubble aerators and jet aerators. The three last mentioned types require compressed air from blowers or compressors.

A large number of different process and plant designs exist for the activated sludge process. These alternatives may be different regarding design of the aeration basin, the clarifier, the aeration equipment, as well as the sludge recycling. One special process design is the pure oxygen activated sludge, where pure oxygen or oxygen-enriched air is used instead of regular air.

Applicability and characterisation of the measure: End-of-pipe technique.

Aerated lagoon

The aerated lagoon can be applied at both existing and new kraft pulp mills. However, its use is in decline, mainly due to its low to moderate removal of effluent contaminants, the large land area and basin volume it requires, high energy requirement for and poor energy efficiency in aeration and mixing. In addition effluent foam and smell problems are sometimes encountered. The settled sludge removal and disposal can also generate problems. It is doubtful whether it can be still considered as BAT.

Activated sludge process

The process can be applied at both existing and new kraft pulp mills. In the existing mills some kind of water consumption reduction measures should preferably be carried out to reduce the investment costs. The activated sludge process is often used, when high or very high treatment efficiencies are required. In the latter case, however, a two-stage biological process is an optional choice.

Activated sludge plants are used widely in the pulp and paper industry. As rough estimate the activated sludge process is used in 60-75% of all the biological effluent treatment plants in this pulp and paper industry. This is also the most common process used in recently built plants.

Advantages of the activated sludge process are the potential of high or very high treatment efficiencies, the possibilities to control the process (particularly the oxygen consumption), and the relatively low space demand.

Disadvantages are the relatively high vulnerability to disturbances and consequently a risk of operational instability without any protective measures, such as an equalisation basin, high production of biological waste sludge and the high operating costs.

Alternatives to activated sludge systems exist which are more compact and less expensive. The experience from such installations is more limited but they are claimed to have equivalent reduction levels to activated sludge systems.

Main achieved environmental performance:**Aerated lagoon**

Treatment efficiencies vary widely depending on the type of effluent, design of the treatment plant and operating conditions. Typical removal efficiencies are 40-85 % for BOD₅, 30-60 % for COD and 20 - 45 % for AOX being in the higher end of the range after the high residence time, 15-30 days, lagoons and when the effluent temperature or the contaminants do not effectively inhibit the growth. There is no nitrogen removal and less phosphorus removal being in the range of 0 - 15 %.

The removal of solids is very case specific and in some instances the outlet effluent contains more solids than the inlet stream. The incoming solids are adequately removed in a lagoon with a settling zone, but the microbial growth produces biosolids with poor settling characteristics. The discharge of solids is lower from high residence time lagoons and settling zones.

In comparison to the activated sludge process there can be also adverse effects, such as occasional heavy mist in humid and cold weather and odour from anaerobic or anoxic basin areas.

Activated sludge process

Treatment efficiencies vary and depend on effluent type, plant design and operating conditions. Typical values are within the ranges of 85-98 % BOD₅ removal and 60-85 % of COD removal. AOX-reduction is in the range of 40-65 %, phosphorus and nitrogen is reduced by 40-85 and 20-50% respectively. The overall efficiency of TSS-removal of primary and secondary treatment is about 85-90 %.

Typical concentrations after activated sludge treatment are given in Table 2.36. At well designed and run plants the easily degradable part of the organic substances, measured as BOD₅ can be brought down to about 20 - 40 mg/l and the amount of Total Suspended Solids (TSS) to about the same level. Concentrations of phosphorous and nitrogen are to a high degree correlated to TSS as the amount of dissolved nutrients can be reduced to very low levels by running the plant properly. For COD, which is a measure of total load of organic substances, the concentration after treatment depends on the content of heavily degradable matter.

Parameter	BOD₅	COD	TSS	Total-P	Total-N
Concentration	20-40	300 - 500	20 - 40	0.2 - 0.4	2 - 4

Table 2.36: Typical concentrations in mg/l in effluents of kraft pulp mills after biological treatment (activated sludge plants) assuming well designed and run facilities

Cross media effects:**Aerated lagoon**

The lagoon process requires large land areas, which are not always available next or inside the mill area. The lagoon treatment produces less sludge than the activated sludge process, but the sludge is difficult to dewater efficiently. Thus, the sludge disposal by burning requires typically more dewatering chemicals and support fuel per dry weight than the sludge generated by the activated sludge process.

Activated sludge process

The effluent treatment plant produces sludge which after dewatering can be burned, providing in some cases net positive heat value. The treated wastewater is clean enough for reuse in some points of the production process. The problem is that usually the wastewater treatment plant is located so far from the mill that recycling is not economical.

Operational experiences:**Aerated lagoon**

Aerated lagoons have been used for a long time in many pulp and paper mills to reach medium level removal of effluent contaminants. However, currently many of the existing lagoons in the industry have been closed down or retrofitted into a high-efficiency activated sludge process or supplementary effluent treatment basins.

Activated sludge process

Activated sludge plants have been used for many years in all types of kraft mills with good results.

Aerated lagoon

The cost of this process is very dependent on where and how the aerated lagoon can be built. If it can be built by reclaiming a bay in the receiving waters and closing its open side with an earth dam the cost is substantially lower than when the lagoon must be built on dry land.

Thus the investment costs vary a lot, being in the range of 16- 20 MEuros for a 1500 ADT/d kraft pulp mill. This cost covers also the primary treatment and sludge dewatering. The corresponding operating costs are 1.3-1.7 MEuros/a, comprising mostly of the cost of electrical power required for aeration and mixing in the lagoon.

Activated sludge process

The investment costs for a completely new activated sludge treatment plant are approximately 19-24 MEuros for a kraft pulp mill with 1500 ADT/d production, being at the lower end of the cost range for an unbleached kraft pulp mill. These costs include also the necessary primary treatment and sludge handling. The corresponding operating costs are 2.0-2.6 MEuros/a.

Driving force for implementing this technique: The aerated lagoon can be used, when low to medium level removal of organics, contained by the effluent, is sufficient. The activated sludge process is preferably used, when high or very high treatment efficiencies are required.

Reference plants: Numerous plants all over the world for all types of effluents.

Literature:

[J. Pöyry, 1997b], [Finnish BAT Report, 1997], [SEPA-Report 4713-2, 1997]

2.3.14 Tertiary treatment of wastewater with chemical precipitation

Description of the technique: In some cases it is necessary to extend the effluent treatment with a tertiary treatment. In most cases the tertiary treatment is simply chemical precipitation. The dissolved organic substances are separated by precipitation and subsequent filtration or clarification.

The chemicals used for precipitation are usually the following:

- aluminium salts - $\text{Al}_2(\text{SO}_4)_3$ and $\text{Al}_n(\text{OH})_m\text{Cl}_{3n-m}$
- ferric salts (Fe(III)) - FeCl_3 and $\text{Fe}_2(\text{SO}_4)_3$
- ferro salts (Fe(II)) - FeSO_4
- lime

To optimise the flocculation, polyelectrolytes are used in the mixing phase.

Applicability and characterisation of the measure: Applicable to both and existing mills.

Main achieved environmental performance: Tertiary treatment with chemical precipitation is mainly applied to reduce nutrient especially phosphorus. Results from Swedish pilot plant studies on biological treatment combined with chemical precipitation have shown that the following reduction rates can be achieved: Phosphorus 80-90%, nitrogen 30-60%, COD 80-90%, AOX 80-90 % [PARCOM, 1994].

Cross media effects: The precipitation of organic material in the effluent with inorganic chemicals results in a great quantity of a slimy sludge, very difficult to dewater and dump as landfill. The chemical cost is substantial and the purification is selective; neutral substances cannot be captured as efficiently as dissociated ions.

Operational experiences: No specific problems are known which are linked to the application to this technique.

Economics: The investment costs amount to 2.6 MEuros for a kraft pulp mill with a capacity of 250000t/a and 3.8 MEuros for a mill with 500000 t/a capacity respectively. The investment costs for chemical precipitation includes equalisation tank, chemical dissolving equipment, chemical dosing equipment, precipitation and flocculation unit and tertiary clarifier. Operating costs amount to about 50000 Euros being somewhat lower for the mill with less capacity.

Driving force for implementing this technique: Usually tertiary treatment of wastewater is only regarded as necessary when the nutrient concentrations in the effluent have to be lowered i.e. if the mill discharges to very sensitive recipients.

Reference plants: Biological treatment plus chemical precipitation of wastewater from the manufacturing of bleached kraft pulp is used on commercial scale e.g. in Sweden (Skoghall, integrated kraft and CTMP pulp mill).

Literature:

[PARCOM, 1994], [SEPA-Report 4713-2, 1997]

2.3.15 Increase in the dry solids content of black liquor

Description of the technique: In the recovery boiler the inorganic substances are reduced and separated as a smelt (mainly as Na_2S and Na_2CO_3) from the bottom and the organic substance oxidised and thereby generating heat. In a conventional recovery boiler there is an oxidising zone in the upper part and a reducing part in the lower part. The strong black liquor is introduced through one or several liquor nozzles into the reducing zone (see Figure 2.3). Combustion air is usually supplied at three different levels as primary secondary and tertiary air (from the bottom up-wards).

Emissions from the recovery boiler consist mainly of particulates, nitrogen oxides and sulphur dioxide. The emission levels are kept as low as possible by optimising the combustion parameters such as temperature, air supply, black liquor dry solids content and the chemical balance.

The aim of enhanced evaporation is to achieve as high content of dry solids (DS) as possible in the strong black liquor. After a conventional evaporation the DS content in the strong black liquor is about 65 %. By installing a superconcentrator, DS content up to 80 % can be achieved. However, the achievable DS-content depends on the wood species. A target for optimal dry solid content of thick liquor in a balanced mill could be 72-73% after evaporation but measured before the recovery boiler mixer.

Applicability and characterisation of the measure: Process integrated technique. The process can be applied at both new and existing kraft mills. A superconcentrator can be implemented as a separate phase also to existing evaporation plants.

However, the maximum DS content is limited by the increase of the viscosity and scaling tendency of the strong black liquor. This depends on the wood species and temperature. In practise, with eucalyptus and some other hardwood species it is difficult to achieve higher than 70 % DS content.

Main achieved environmental performance: The sulphur emission from the recovery boiler is down to 5-50 mg S/Nm³ or 0.1-0.3 kg S/ADt of pulp or sometimes almost down to zero because more sodium will vaporise and react with sulphur.

Cross media effects: The reduction of sulphur emissions by high DS-content increases the emissions of particulates prior to flue gas cleaning. To compensate this, more efficient and expensive electrostatic precipitator has to be installed.

At high dry solid content (TS >80%) there is a considerable release of sulphur compounds from the last evaporator stage, which have to be collected and incinerated.

Increasing dry solids content of black liquor have the tendency to increase NO_x emissions from the recovery boiler if no counter-measure is taken (see 2.3.22).

Operational experiences : This measure has been tested in several pulp mills in Northern Europe. It is in operation in full scale in Northern and Southern Europe.

Economics: In existing mills the cost of improved evaporation and concentration of strong black liquor is tied to the target concentration. At existing mills with 1500 ADt/d kraft pulp production the investment costs for increase in black liquor concentration from 63 % upward are as follows:

Concentration from 63 % to 70 %, 1.7-2.0 MEuro

Concentration from 63 % to 75 %, 3.5-4.0 MEuro

Concentration from 63 % to 80 %, 8.0-9.0 MEuro

The operating costs of the improvements are not significant because of the increase in energy economy (this being 1-7 %) and gain in recovery boiler capacity. The increase of dry solids into the recovery boiler may even result in some net savings.

Driving force for implementing this technique: Kraft mills may face sulphur dioxide emission problem and these emissions in the recovery boiler can be reduced by increasing the dry solids content of black liquor. Another case by case achievable result is the increase of the capacity of the recovery boiler (4-7 %).

Alternatively, flue gas scrubbers can be installed for the same purpose (see 2.3.16).

Reference plants: Numerous plants in Scandinavia and at least one in Spain.

Literature

[Finnish BAT Report, 1997]

2.3.16 Installation of scrubbers on the recovery boiler

This measure can be applied alternatively to the BAT under 2.3.15.

Description of the technique: In order to decrease the emissions of sulphur dioxide from the recovery boiler, it can be equipped with a flue gas scrubber. A kraft recovery boiler scrubber of the wet type may include three process stages (from the bottom up, see Figure 2.12).

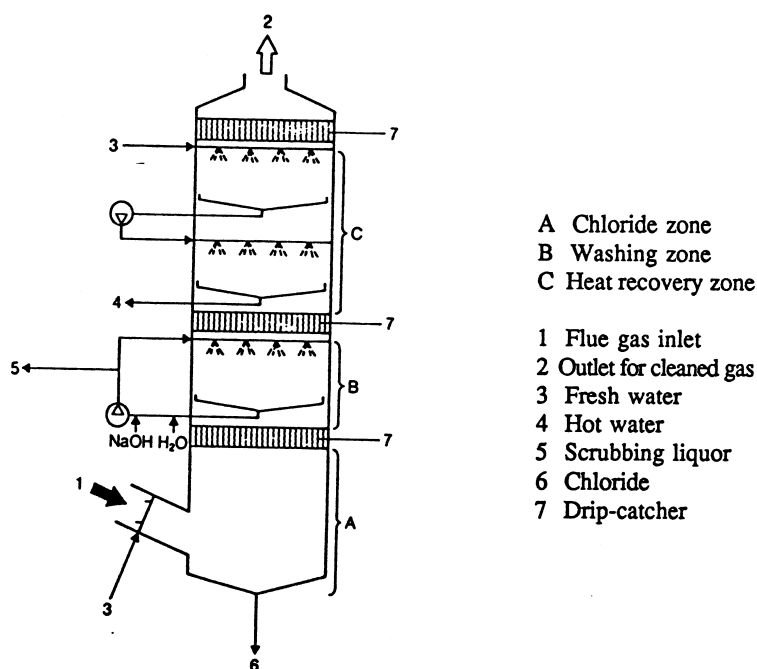


Figure 2.12: Flue gas scrubber for recovery boilers
 [SEPA-Report 4008, 1992]

Chloride is absorbed by cold water introduced in the flue gas inlet. The chloride efficiency is normally 60-70%. In the washing zone, SO_2 and particulates are removed. Scrubbing takes place at a pH of 6-7. The pH value is controlled with addition of sodium hydroxide, weak liquor or oxidised white liquor. SO_2 reacts with the scrubbing liquor and Na_2SO_3 and also some Na_2SO_4 is formed. TRS in the form of H_2S can be removed together with SO_2 . However, to remove hydrogen sulphide from the flue gases, a high pH of the scrubbing liquor would be required. At such a high pH, also carbon dioxide would be absorbed, which is unrealistic due to the relatively large amounts of carbon dioxide being formed in the combustion. Surplus liquor from the scrubber is recycled to the process, normally to the white liquor preparation.

Applicability and characterisation of the measure: Installation of a scrubber is preferably done at the same time as a new boiler is installed, although at much higher cost also existing boilers can be equipped with scrubbers. Recovery boilers burning high dry solids black liquor normally give rise to low sulphur emission which makes the installation of scrubber less interesting.

Main achieved environmental performance: The removal efficiency for SO_2 is typically > 90%. A scrubber on the recovery boiler can reduce the sulphur emissions from 0.5 - 2 kg/ADt down to 0.1 - 0.3 kg S/ADt or concentrations from 50-200 mg/Nm^3 down to 10 - 50 mg/Nm^3 .

Monitoring of emissions: Continuous SO_2 measurement prior to and after the scrubber is needed to control the operation of the scrubber.

Cross media effects: By introduction of fresh water in top of the scrubber, hot water can be produced (if there is a need). The water is normally clean enough to be used as wash water in

the bleach plant. The scrubber needs alkali in the form of oxidised white liquor, weak liquor or sodium hydroxide, which can increase the capacity demands on the recovery department.

Operational experiences: Scrubbers on recovery boilers can be operated without problems.

Economics: The equipment comes usually as a package from the supplier. The investment costs for a bleached kraft mill with a production capacity of 250000 and 500000 t/a amount to 7.2 MEuros and 10.4 MEuros respectively. They include scrubber, scrubber liquor pumps, circulation pumps, electrification and instrumentation. Operating cost amount to 580000 Euro/a and 920000 Euros respectively.

Driving force for implementing this technique: Reduction of SO₂ emissions. Heat recovery. With high dry solids the primary SO₂ emission can be substantially reduced and for such mills the driving force is small. The internal energy situation of the mill might or might not motivate warm water production in the scrubber. In a modern kraft recovery boiler, especially if it operates on high dry solids, the H₂S is normally not a problem that needs scrubbing to resolve.

Reference plants: Scrubbers have been installed on numerous recovery boilers in the last decades.

Literature:

[SEPA-Report 4713-2, 1997], [SEPA-Report 4008, 1992]

2.3.17 Collection of weak gases for incineration in recovery boiler

Description of the technique: Control of TRS emissions can be divided to treatment of concentrated malodorous non-condensable gases (NCGs) which contain about 4 kg TRS/t (measured as S) and diluted or lean malodorous gases which contain about 0.5 kg TRS/t (measured as S). The treatment of concentrated NCGs is generally carried out by collection NCGs from the cooking and evaporation departments (see 2.3.11) and their disposal by incineration. There are different options available.

The incineration of concentrated malodorous gases in the recovery boiler is on possible option., There are a few mills in Europe and about 4 mills in the world burning strong malodorous gases in the recovery boiler.

High volume and low concentration gases are formed in black and white liquor handling, pulp washing and floor channels with black or white liquor residues. The actual composition will vary greatly case by case.

The collection is carried out with gas pipelines and blowers for gas transfer. The collected lean malodorous gases can be incinerated as secondary or tertiary air of the recovery boiler. Depending on the volume of diluted NCGs and the lay out of the pulp mill there can be several TRS-destruction systems for different departments. An alternative for incineration is alkaline scrubber or oxidising scrubber. The recovery boiler is able to destroy diluted malodorous gases. However, the recovery boiler is only one alternative for incineration of diluted gases.

Normal amount of diluted NCGs at a 1000 tonnes/d mill is about 50000 - 100000 m³ /h. The amount of the gases depends on the mill concept; with continuous cooking and diffuser washing the volumes are lower than with batch cooking and pressure washers.

Applicability and characterisation of the measure: The measure can be adopted in new and existing kraft mills.

In the existing pulp mills may be very difficult to retrofit a collection and treatment of diluted NCGs. This is due to the limitations of the lay out and long distances between sources of malodorous gases and the recovery boiler.

Main achieved environmental performance: The TRS emissions of the high volume (low concentration) gases can be reduced almost totally by collecting and burning.

Cross media effects: No cross-media effects.

Operational experiences: The methods have been used at reference mills several years without problems.

The tertiary air flow rate into a recovery boiler is limited and other burning alternatives may be needed, as well.

Economics: The investment costs for the weak malodorous gas collection and their disposal in the recovery boiler are 3.6-4.5 MEuros for a kraft mill with 1500 ADt/d production. However, because much of the costs are for piping the costs can be considerably higher at mills, which spread on a large area. The operating costs for the system are 0.3-0.5 MEuro/a.

Driving force for implementing this technique: The more efficient reduction of TRS emissions of the kraft mill is the main reason to implement this technique.

Reference plants: Numerous pulp mills.

Literature:

[TAPPI, Proceedings, 1997], [TAPPI, Proceedings, 1994], [J. Pöyry, 1997a], [J. Pöyry, 1997b], [SEPA-Report 4713-2]

2.3.18 Collection and incineration of odorous gases (strong and weak gases) in the lime kiln

Description of the technique: Control of malodorous gas caused primarily by Total Reduced Sulphur (TRS) emissions can be divided to treatment of concentrated non-condensable gases (NCG) and diluted or lean malodorous gases. The treatment of concentrated NCGs is generally carried out by collection and incineration of NCGs from cooking and evaporation departments. Incineration of concentrated NCG can be carried out in the lime kiln or in a separate NCG-incinerator equipped with an SO₂-scrubber. The concentrated NCGs contain over 90 % of all TRS-compounds generated in the cooking of pulp.

High concentrated and low volume gases are formed in turpentine recovery system, continuous digester flash steam condensers, foul condensate storage tanks, evaporator non-condensable gas relief and hotwells, and in batch cooking blow heat recovery system instead of continuous digester flash steam condensates. The actual composition will vary greatly from case by case.

The main sources of lean malodorous gases are washing and screening equipment of unbleached pulp, several tanks of pulp and washing liquor in the washing and screening, storage tanks of black liquor in the evaporation plant and storage tanks of white liquor in the recausticising plant.

The collection is carried out with gas pipelines, ejectors and blowers for gas transfer. The collected lean malodorous gases can be incinerated as secondary air of lime kiln or in a separate NCG-incinerator, in a bark boiler or other auxiliary boiler or as secondary or tertiary air of the recovery boiler. Depending on the volume of diluted NCGs and the lay out of the pulp mill there can be several TRS-destruction systems for different departments.

Applicability and characterisation of the measure: The measures can be adopted in new and existing kraft mills. In the existing pulp mills it may be difficult to retrofit a collection and treatment of diluted NCGs.

Main achieved environmental performance: The TRS emissions of the kraft mill can be reduced over 90 % by only collecting and burning the concentrated TRS-compounds.

Cross media effects: The advantage of burning the malodorous gas in the lime kiln is that no extra furnace is needed. In addition, the sulphur in the gas can be absorbed in the lime, which decrease the emission of sulphur dioxide. However, only a limited amount of sulphur can be absorbed in the lime kiln by gaseous sodium forming sodium sulphate. The main sulphur absorbing compound is thus the sodium carbonate (Na_2CO_3) in the lime mud. When this capacity is exhausted, SO_2 is released. This effect is enhanced when malodorous non-condensable gases are incinerated in a kiln. Therefore, SO_2 emissions are usually a clear function of the amount of malodorous gas flow. To minimise the formation of SO_2 either the sulphur content in the fuel can be reduced or if malodorous non-condensable gases (NCGs) are to be burnt in the lime kiln, sulphur compounds can be scrubbed out of these gases prior to burning in the lime kiln.

TRS-control can reduce also the malodorous components released in the wastewater treatment.

An average 10-15 % of the fuel used in a lime kiln can be replaced by the heat value of the concentrated malodorous gases. However, the variation of the amount of energy of the gas may make it difficult to hold a lime of good and uniform quality. Condensation of methanol after the stripper column can minimise the problem with varying gas quality, but require additional investment costs.

Operational experiences: The measure is widely used. Some problems have appeared in the modern lime kiln because of using low excess oxygen level.

Economics: Investment costs of collection and incineration of both strong and weak gases are typically 4-5 MEuros at new mills and 5-8 MEuros at existing mills with a capacity of 1500 ADt/d. No major increase in operating cost, if the heat value of recovered methanol can be utilised. Otherwise, an increase of 0.3-0.5 MEuros/a is anticipated.

Driving force for implementing this technique: The reduction of TRS emissions of the kraft mill is a major reason to implement this technique

Reference plants: Numerous plants in Europe and North America.

Literature:

[TAPPI, Proceedings, 1997]

2.3.19 Collection and incineration of odorous gases (strong and weak gases) by use of a separate furnace equipped with scrubbers for SO_2

Description of the technique: Incineration of odorous gases (see 2.3.17 and 2.3.18) can also be carried out in a separate NCG incinerator equipped with a SO_2 scrubber. A separate furnace can take care of the heat value in a boiler.

Applicability and characterisation of the measure: The measure can be adopted in new and existing kraft mills.

In the existing pulp mills may be difficult to retrofit a collection and treatment of diluted NCGs.

Main achieved environmental performance: The TRS emissions of the kraft mill can be reduced over 90 % by only collecting and burning the concentrated NCGs.

Cross media effects: Incineration of odorous gases in a separate furnace has the tendency to increase NO_x emissions if no counter-measure is taken.

Operational experiences: The technology is used at many mills several years without problems.

Economics: Investment costs are typically 7-8 MEuros at new mills and 8-11 MEuros at existing mills with 1500 ADt/d production capacity. Operating costs usually increase with 0.3-0.5 MEuros/a because the heat value of recovered methanol cannot be utilised.

Driving force for implementing this technique: The reduction of TRS emissions of the kraft mill is a major reason to implement this technique.

Reference plants: Numerous plants in Europe.

Literature:

[TAPPI, Proceedings 1997]

2.3.20 Installation of low NO_x technology in auxiliary boilers (bark, oil, coal) and the lime kiln

Description of the technique: In chemical pulp mills, a variety of regenerative or fossil fuels - bark, coal, lignite, oil or natural gas - may be used for supplemental steam production, typically coupled with turbines for electric power production. In burning of these fuels environmentally sound incineration techniques are called for to minimise particulate, SO₂ and also NO_x emissions.

Low NO_x technology applied to burning of solid fuels and pulp and paper mill wastes with fluidised bed boilers is discussed in 6.3.12. Coal and lignite suit well to be burned as major or support fuel in fluidised bed systems, which by careful operation control promotes low NO_x formation.

In conventional oil or natural gas fuelled boilers, the burners feeding the fuel-air mixture, must apply designs that maintain low NO_x burning conditions. Also coal or peat is often burned as finely ground dust in conventional boilers, fed through burners that with proper designs provide low NO_x burning.

The primary burning air is brought through the burner in the fuel-air mix. Secondary and tertiary air is fed in separately to maintain an appropriate primary:secondary:tertiary air balance in the flame area to maintain low NO_x combustion. Some air may still be fed, if necessary above the main flame area to complete the fuel combustion.

The purpose of the multi-phase air feed is to burn the fuel without excess air and actually even under reducing conditions, meaning that

- there is not enough oxygen to promote strong NO_x formation.
- the flame temperature is lower than in conventional burners which further decreases NO_x formation.

Part of the NO_x formed will reduce back to elementary nitrogen for instance when a residual amount of the fuel is burned in the outer flame area or outside it.

Applicability and characterisation of the measure: Low NO_x burners can be used both in existing and new boilers.

When powdered solid fuels, such as coal or peat, are used it is important that if they have high humidity they are pre-dried to support fast and efficient burning. Additionally they require that the burning air is preheated to assure quick ignition and complete burning.

Main achieved environmental performance: Generally, emissions vary with the fuel. In comparison to conventional burners with 250-500 mg/MJ NO_x emissions the low NO_x burners can reach 120-140 mg/MJ level in stack emissions.

Monitoring of emissions: Emission monitoring with online NO_x meters can be carried out. Also oxygen meters can help to determine that low NO_x burning conditions are maintained. For accurate measurements in-field sampling and lab analysis is required.

Cross-media effects: No major effects.

Operational experiences: Low NO_x burners have been applied successfully in the retrofit of existing boilers and construction of new ones.

Economics: The investment costs are typically 0.5 - 0.8 MEuros. No major increase in the operating costs is anticipated.

Driving force for implementing this technique: Low NO_x burners are mainly used to reduce NO_x emissions from auxiliary boilers.

Reference plants: Numerous mills in Northern and Western Europe.

Literature:

[Rentz, 1996], [J. Pöyry, 1997 b], [Finnish BAT Report, 1997], [Ministry of Education, 1994]

2.3.21 SNCR on bark boilers

Description of the technique: Due to the low combustion temperature bark boilers give relatively low NO_x emissions. Emissions are typically 70-100 mg NO_x/MJ when only bark is fired. At times when oil is used in the bark boiler an increase of NO_x to about 100 - 150 mg NO_x/MJ can be determined. Excess oxygen effects the NO_x formation and should therefore be avoided. Too low excess oxygen increase however the risk for emissions of CO and VOC.

Primary NO is formed in furnaces either through reaction with nitrogen in air (thermal NO) or through oxidation of nitrogen in fuel (fuel NO). Formation of thermal NO increases with increasing temperature of the flame. A part of the NO is further oxidised to NO₂.

In the SNCR process, NO is reduced by urea to nitrogen, carbon dioxide and water according to the conceptual reaction

$$2 \text{NO} + (\text{NH}_2)_2\text{CO} + 1/2 \text{O}_2 \rightarrow 2 \text{N}_2 + \text{CO}_2 + 2 \text{H}_2\text{O}.$$

The reaction occurs around 1000°C.

Applicability and characterisation of the measure: Equipment to inject urea (or ammonia) can be installed in both existing and new boilers. The optimal reaction conditions can be difficult to obtain in existing boilers, thus reducing the potential NO_x reduction to about 40 %.

Main achieved environmental performance: The total NO_x-reduction achievable in a bark boiler is about 30-50% by making changing in the combustions techniques (see 2.3.20) and/or by applying an SCNR process. The NO_x emissions would then amount to 40-60 mg/MJ equal to

about 100-200 mg/Nm³. Emissions of gaseous sulphur are low or about 10-20 mg/MJ when burning bark.

Monitoring of emissions: Continuous NO_x measurement can be installed and experience shows reliable results.

Cross media effects: Depending on the stoichiometry the urea is added a slight increase of ammonia (slip) may be determined.

Operational experiences: Installations of the technique have been in operation since the early 1990ies. Good availability is normally reported, but a number of incidents have occurred where the injection of urea solution has caused damages inside the boiler. As this is both, a safety risk and a cost installations have to be made with care and the operation properly monitored.

SNCR technique is difficult to control because of relatively fast changes of load might happen in bark boilers. This results in variations in NO_x reductions achieved by these techniques.

The process can be a potential source of emission of N₂O or NH₃ but measurements demonstrate the risk to be marginal. At least in Sweden SNCR on bark boiler is an established technique.

Economics: The investment costs for adding SNCR to the bark boiler for a bleached kraft mill with a production capacity of 250000 and 500000 t/a amount to 690000 Euros and 1.15 MEuros respectively. The investment costs include injection equipment, pipes, pumps, tanks and rebuild/adoption of the boiler. The operating costs are mainly urea. About 1-2 kg urea is required per kg NO_x removed.

Driving force for implementing this technique: NO_x has an acidifying potential and may increase eutrophication. In some sensitive lake areas in Europe a further reduction of NO_x emissions by secondary measures as SNCR technique is therefore regarded as necessary. A fee on NO_x emissions in Sweden may also give an incentive for further NO_x reduction.

Reference plants: Some mills in Sweden

Literature:

[SEPA-Report 4008], [SEPA-Report 4713-2, 1997], [Personal information from a Swedish mill]

2.3.22 Over Fire Air Technique (OFA) on recovery boilers

Description of the technique: The kraft recovery boiler operates with a reducing atmosphere in the bottom. Accordingly the NO_x formation in the recovery boiler is lower than that in other furnaces. However, modifications to the air feed system have proved successful with respect to NO_x reductions. Thermal NO_x by fixation of nitrogen in the combustion air can be reduced by limiting the amount of air in the combustion zone. In purpose designed systems air injection ports are installed at quaternary level. A reduced NO_x formation can be achieved in a kraft recovery boiler through modifying the air feed system such as introducing a fourth air inlet in the upper part of the boiler. The reduction of NO_x emissions attributable to the use of this technique is variable, dependent on the boiler type and design and the method of OFA application, and will normally be 10-25%.

Applicability and characterisation of the measure: Applicable to both and existing mills.

Main achieved environmental performance: The achieved NO_x-reduction seems to be different from recovery boiler to recovery boiler. In some Swedish kraft pulp mills the following experiences have been reported:

Case 1: Installation and use of OFA-technique on an existing recovery boiler and operation since 1990: 30% NO_x-reduction achieved.

Case 2: Installation of the OFA technique on an existing recovery boiler. The new air feed system is not any more used because of the increase of temperature in the overheater.

Case 3: Installation of the OFA technique on an existing recovery boiler in 1995: 20% NO_x-reduction achieved and in operation since the beginning of 1997.

Case 4: First new recovery boiler with OFA technique in 1996: The reduction of NO_x emissions of the latter are summarised in the table below:

Combustion air distribution on the recovery boiler	Normal operation	Over Fire Air (OFA) Technique Trials Operation in May 98	
Primary air [%]	45	35	40
Secondary air [%]	45	45	40
Tertiary air [%]	10	10	5-15
Quartary air [%]⇒ OFA	0	10	5-15
Observed effects on			
NO _x [mg/m ³ ndg]	135	80	90
SO ₂ [mg/m ³ ndg]	20	35	< 20

Table 2.37: Reduction of NO_x emissions by use of over fire air technique in a new recovery boiler

Cross-media effect: No cross-media effects occur.

Operational experiences: The reduction of NO_x emissions attributable to the use of this technique is variable, dependent on the boiler type and design and the method of OFA application. It has to be adapted to the specific conditions of recovery boilers. The application of this technique - which is widely used in other combustion processes - may result in increases in carbon monoxide and unburned carbon emissions if not well controlled.

Economics: The investment costs for modifying the air introduction to the recovery for a bleached kraft mill with a production capacity of 250000 and 500000 t/a amount to 1.7 MEuros and 2.3 MEuros respectively. The investment costs include new air inlets to the recovery boiler, instrumentation, pipes and fans. There is no change in operating costs.

Driving force for implementing the technique: NO_x has an acidifying potential and may increase eutrophication. In some sensitive lake areas in Europe a further reduction of NO_x emissions by secondary measures is therefore regarded as necessary.

Reference plants: A few mills in Sweden

Literature:

[SEPA-Report 4713-2, 1997]

2.3.23 Installation of improved washing of lime mud in recausticizing

Description of the technique: Lime (CaO) is used to causticize green liquor (Na₂S + Na₂CO₃) into white liquor (Na₂S + NaOH). After causticizing, lime mud (CaCO₃) is formed. Normally lime mud is recycled in a lime kiln, where lime mud is burned and new lime is created. Before the lime is sent to the kiln, it must be washed in order to remove residual sodium hydroxide, sodium sulphide and other sodium salts, and then dewatered.

The equipment used for lime mud washing is usually either clarifiers or press filters. In the past, two-stage mud washers were in widespread use but more recently single-stage mud washing in a unit-type clarifier with storage or in a pressure filter has become dominant.

Improved lime mud washing can reduce the residual content of white liquor in the mud from 100 mg/dm³ to 0-30 mg/dm³ in modern filters. The lime mud dryness can also be increased from 50-60 % to 70-80 %. More efficient washing reduces the concentration of sulphide in the lime mud, thus reducing the formation of hydrogen sulphide in the lime kiln during the reburning process.

Applicability and characterisation of the measure: Applicable to both and existing mills.

Main achieved environmental performance: Possible reduction of H₂S (TRS) in the lime kiln, which depends mainly on the availability of sodium in the lime and the sulphur content of all fuels fed to the lime kiln. At the lowest sulphur input a small reduction can be achieved but with higher sulphur inputs the effect can be non-existent or detrimental.

Cross-media effects: If washed to a too low sodium content, the emissions of TRS and also particulate emissions from the lime kiln tend to increase.

Operational experiences: Improved washing of lime mud has been practised over 10 years at pulp mills in Europe. Monitoring of residual sodium (NaOH) is required to avoid damming of the lime kiln.

Economics: Investment costs are typically 1 -1.5 MEuros.

Driving force for implementing this technique: Reduction of H₂S (TRS) and odours from the flue gases of the lime kiln.

Reference plants: Numerous plants in Europe.

Literature

[SEPA-Report 4713-2, 1997]

2.3.24 Electrostatic precipitator for dust reduction in bark boiler and lime kiln

Description of the technique:

Bark boiler

Wood residues (from bark and wood waste) are burnt to a large extent for steam production. Steam from boilers is often used for power generation through back-pressure turbines. This heat and power generation are necessary to reduce emissions of fossil fuels. With incineration, fewer wastes are produced for disposal. Nowadays, a new incineration plant always requires a sophisticated incineration system combined with advanced flue gas cleaning system.

The main emission from waste wood boilers is particulate matter. The particles consist of ash and a residue of unburned material. Normally bark boilers have cyclones for dust collection (85% efficiency). Today, electrostatic precipitators with cleaning efficiency above 95% are also used more and more.

Lime kiln

A proper design of the lime kiln will minimise the dust formation. The sodium vaporisation mechanism is related to the amount of sodium in the kiln and the high temperature of

calcination section of the kiln. The extent of vaporisation can up to a certain level be controlled by a proper adjustment of flame shape and position.

The use of different fuels also effects the dust emission. An oil flame at the hot end of the kiln will, due to its good radiation properties, give a high extent of sodium vaporisation from the lime producing sodium sulphate with sulphur dioxide. In order to minimise CaO, Na₂SO₄ and Na₂CO₃ particles, an electrostatic precipitator can be installed. The electrostatic precipitator has better dust removal properties than a scrubber. If there also are scrubbing facilities, the electrostatic precipitator should be situated prior to the scrubber. The electrostatic precipitator requires regular maintenance and monitoring. Overloading or uneven loading may cause clogging of the chambers in the precipitator.

Applicability and characterisation of the measure: The measure can be adopted in new and existing kraft mills.

Main achieved environmental performance: The main achieved environmental performance with bark boilers is reduction of particulates from a level of 250-500 mg/m³n to a level of 100-150 mg/m³n when using cyclones. An electrostatic precipitator for the flue gas from bark boiler can achieve cleaning efficiency above 95% corresponding to dust emissions of about 20-40 mg/Nm³ (at 10% O₂ and dry gas)

The dust emissions from lime kiln will be 20 - 100 mg/m³n after the electrostatic precipitator.

The major part of dust leaving the kiln with the flue gas is CaO. It mostly escapes from the feed end of the kiln. The amount of dust coming from the hot end of the kiln is significantly lower. The main components of the dust emission of the stack are fine Na₂SO₄ and Na₂CO₃ particles, because CaO particles are more efficiently captured in flue gas cleaning equipment

Cross media effects: No major effects.

Operational experiences: The measure has been applied in a number of pulp mills.

Economics: In a 1500 ADt/d kraft mill, the investment costs for an electrostatic precipitator at the bark boiler are about 3-4 MEuros and at the lime kiln 5-6 MEuros. The operating costs are increased with less than 0.3 MEuros/a in both cases.

Driving force for implementing this technique: The reduction of dust emissions to air is major reason to implement the method.

Reference plants: Numerous plants in Europe.

Literature:

[J. Pöyry, 1997a], [J. Pöyry, 1997b], [SEPA-Report 4713-2, 1997]

2.4 Best Available Techniques

2.4.1 Introduction

In understanding this chapter and its contents, the attention of the reader is drawn back to the preface of this document and in particular the fifth section of the preface: “How to understand and use this document”. The techniques and associated emission and/or consumption levels, or ranges of levels, presented in this chapter have been assessed through an iterative process involving the following steps:

- identification of the key environmental issues for the sector; for integrated kraft pulp and paper mills the major concerns are water use, wastewater discharge (COD, BOD, suspended solids, N, P, AOX), energy consumption (steam and electricity), solid waste such as rejects, sludge and ash, air emissions from energy generation (SO₂, NO_x, CO₂, dust), noise, waste heat to water and sometimes odour; the latter three stand for local impacts;
- examination of the techniques most relevant to address those key issues;
- identification of the best environmental performance levels, on the basis of the available data in the European Union and world-wide;
- examination of the conditions under which these performance levels were achieved; such as costs, cross-media effects, main driving forces involved in implementation of this techniques;
- selection of the best available techniques (BAT) and the associated emission and/or consumption levels for this sector in a general sense all according to Article 2(11) and Annex IV of the Directive.

Expert judgement by the European IPPC Bureau and the relevant Technical Working Group (TWG) has played a key role in each of these steps and in the way in which the information is presented here.

On the basis of this assessment, techniques, and as far as possible emission and consumption levels associated with the use of BAT, are presented in this chapter that are considered to be appropriate to the sector as a whole and in many cases reflect current performance of some installations within the sector. Where emission or consumption levels “associated with best available techniques” are presented, this is to be understood as meaning that those levels represent the environmental performance that could be anticipated as a result of the application, in this sector, of the techniques described, bearing in mind the balance of costs and advantages inherent within the definition of BAT. However, they are neither emission nor consumption limit values and should not be understood as such. In some cases it may be technically possible to achieve better emission or consumption levels but due to the costs involved or cross media considerations, they are not considered to be appropriate as BAT for the sector as a whole. However, such levels may be considered to be justified in more specific cases where there are special driving forces.

The emission and consumption levels associated with the use of BAT have to be seen together with any specified reference conditions (e.g. averaging periods).

The concept of “levels associated with BAT” described above is to be distinguished from the term “achievable level” used elsewhere in this document. Where a level is described as “achievable” using a particular technique or combination of techniques, this should be understood to mean that the level may be expected to be achieved over a substantial period of time in a well maintained and operated installation or process using those techniques.

Where available, data concerning costs have been given together with the description of the techniques presented in the previous chapter. These give a rough indication about the magnitude of costs involved. However, the actual cost of applying a technique will depend

strongly on the specific situation regarding, for example, taxes, fees, and the technical characteristics of the installation concerned. It is not possible to evaluate such site-specific factors fully in this document. In the absence of data concerning costs, conclusions on economic viability of techniques are drawn from observations on existing installations.

It is intended that the general BAT in this chapter are a reference point against which to judge the current performance of an existing installation or to judge a proposal for a new installation. In this way they will assist in the determination of appropriate "BAT-based" conditions for the installation or in the establishment of general binding rules under Article 9(8). It is foreseen that new installations can be designed to perform at or even better than the general BAT levels presented here. It is also considered that existing installations could move towards the general BAT levels or do better, subject to the technical and economic applicability of the techniques in each case.

While the BREFs do not set legally binding standards, they are meant to give information for the guidance of industry, Member States and the public on achievable emission and consumption levels when using specified techniques. The appropriate limit values for any specific case will need to be determined taking into account the objectives of the IPPC Directive and the local considerations.

Manufacture of kraft pulp is not a single process but a series of unit processes, often linked and inter-dependent. Therefore, it is always a suitable combination of techniques that constitutes BAT for kraft pulp and paper mill. The order of priority and the selection of the techniques or combinations of techniques depend on the local circumstances.

Best available techniques given below are, if not stated otherwise, applicable to new and existing plants. In kraft pulp and paper mills, the applicability of a technique is less driven by the fact whether a mill is new or existing. Pulp and paper mills are characterised by the fact that machinery is rebuilt rather than replaced whole-scale. The modular rebuilding and development of plants means that each site is a unique product of its location and history. On the other hand, there is a series of unit processes, which are common in all countries.

Criteria to be considered in the determination of BAT in the specific cases are rather that specific costs for smaller mills are relatively higher (economies of scale). Other factors to consider are limitations of space, which some older mills might face, or unsuitable material or lay out of older equipment, which does not fit for a higher degree of water closure. More water system closure usually is combined with higher complexity of the system that needs to be monitored, controlled and understood. Smaller mills might sometimes not have the knowledge available which would be necessary to run and control more complex process solutions most efficiently.

2.4.2 BAT for kraft pulp and paper mills

Below, the techniques or combination of techniques that are considered as BAT for integrated and non-integrated kraft pulp mills are given. The following list of BAT is not considered exhaustive and any other technique or combination of techniques achieving the same (or better) performance can also be considered; such techniques may be under development or an emerging technique or already available but not described in this document. For integrated kraft pulp and paper mills it is refer to Section 6.4 where further details on BAT for papermaking are given. If not stated otherwise, the data refer to yearly average values.

General measures

1. Training, education and motivation of staff and operators. Pulp and paper mills are operated by people. Therefore, training of staff can be a very cost-effective way of reducing discharges of harmful substances.
2. Process control optimisation. To be able to reduce different pollutants simultaneously and to maintain low emissions, improved process control is required.
3. To maintain the efficiency of the technical units of pulp mills and the associated abatement techniques at a high level, sufficient maintenance has to be ensured.
4. Environmental management system which clearly defines the responsibilities for environmentally relevant aspects in a mill. It raises awareness and includes goals and measures, process and job instructions, check lists and other relevant documentation.

Measures for reducing of emissions to water

1. Dry debarking of wood
2. Modified cooking either in batch or continuous system
3. Highly efficient brown stock washing and closed cycle brown stock screening
4. Oxygen delignification
5. ECF or TCF final bleaching and some, mainly alkaline, process water recycling in the bleach plant
6. Purification and reuse of condensates
7. Effective spill monitoring, containment, and recovery system
8. Sufficient black liquor evaporation plant and recovery boiler to cope with the additional liquor and dry solids loads due to collection of spills, bleach plant effluents etc.
9. Collection and reuse of clean cooling waters
10. Provision of sufficiently large buffer tanks for storage of spilled cooking and recovery liquors and dirty condensates to prevent sudden peaks of loading and occasional upsets in the external effluent treatment plant
11. Primary treatment of wastewater
12. External biological wastewater treatment

The efficiency of each of these measures varies considerably with the design and operation practices at different mills. To be regarded as a BAT measure it must also be well designed and operated. A combination of the techniques of item 1 to 10 including the general measures result in a range of emissions as shown in Table 2.38. The examples of mills stand for well performing mills in Europe that have implemented a reasonable set of these techniques. All mills have primary treatment and most of them also secondary effluent treatment. However, the values in Table 2.38 all refer to water discharges after only primary treatment. The effect of biological treatment of pulp mill effluents is discussed further below.

Mills	COD [kg/ADt]	BOD ₅ or 7 [kg/ADt]	TSS [kg/ADt]	AOX [kg/ADt]	Tot N [kg/ADt]	Tot P [kg/ADt]	Flow [m ³ /ADt]	Production 97 [ADt/a]	Remarks
ENCE, Huelva mill, Spain	28	n/a.	5.2	0.17	n/a.	n/a.	41.2	310000	Bleached hardwood ECF market pulp (eucalyptus)
Soedra Cell, Varö mill, Sweden	36	n/a.	n/a.	0	0.3	0.04	35	305000	Bleached softwood TCF market pulp
Soedra Cell, Mönsterås mill, Sweden ¹	31	14	n/a.	0	n/a.	n/a.	45	507000	Bleached softwood/hardwood TCF market pulp
NSI, Tofte Industrier, Norway	35		2.3	0.19	n/a.	0.07 - 0.1	30	340000	Bleached ECF market pulp
Pöls AG, Austria ⁶	38	13	n/a.	0.5	n/a.	n/a.	46 ⁷	280000	Bleached softwood ECF market pulp
Stora, Celbi Portugal	17.3	4.9	2.7	0.16	0.15	0.11	52	270000	Bleached hardwood ECF market pulp (eucalyptus)
Modo Alizay, France (all site)	42.3	11	12.3	n/a.	n/a.	n/a.	61	244500 pulp 220000 paper	Integrated ECF bleached pulp & paper mill
Enocell, Finland ⁴	54	17	n/a.	0.67	0.19	0.04	38	586000	Bleached softwood/hardwood (birch) ECF and TCF market pulp
Metsä-Rauma, Finland ²	28	11	n/a.	n/a.	n/a.	0.021	10	500000	Bleached TCF soft-wood market pulp
Modo, Husum mill, Sweden ³	37	19	n/a.	0.30	0.19	0.060	77	677000 pulp 485000 paper	Integrated ECF bleached pulp & paper mill
SCA, Östrand, Sweden ³	38	15	n/a.	-	0.40	0.060	39	n/a.	Bleached softwood TCF market pulp
Soedra Cell, Mörrum mill, Sweden	41	17	n/a.	0.25	0.30	0.040	73	376000	Bleached softwood TCF/ECF market pulp
AssiDomän Kraftliner mill, Sweden ⁵	13	6.4	n/a.	-	0.06	0.008	24	562000	Unbleached Kraft + kraftliner, 19% recycled fibres
SCA, Munksund mill, Sweden ⁵	16	7.9	3.3	-	0.07	0.012	41	338000	Unbleached Kraft + kraftliner, 33% recycled fibres
SCA, Obbola mill, Sweden ⁵	19	9	3.5	-	0.15	0.013	12	363000	Unbleached Kraft + kraftliner, 41% recycled fibres
Smurfit CdP Factice mill, France ⁵	17.3	7.7	1.6	-	0.25	0.009	28.4	350000 - 400000	Unbleached Kraft + kraftliner, 20% recycled fibres, 10% purchased pulp
Mill 5, Portugal ⁵	18	6	2.9	n/a.	n/a.	n/a.	25	270000	Unbleached Kraft + kraftliner

n/a. = not data available

Notes: 1) Average data of the second half of 1998 after primary treatment
2) Greenfield mill built in 1996; data from "Fifth Global Conference on Paper and the Environment, Session 3, 1997"
3) COD data for 1998; the rest is for 1997
4) Data for 1998
5) Per tonne of liner produced
6) Values are levels before secondary treatment. The mill runs a biological treatment
7) The figure for water flow excludes paper production. The contribution of a small paper production is negligible for the other parameters.

Table 2.38: Examples of achieved emission levels to water after only primary treatment of some existing pulp mills in Europe (reference year: 1997). Most of these mills have also implemented secondary biological treatment (see Table 2.40).

The list of mills is a selection of mills where data were available or provided and is therefore not intended to be complete. It contains mills from every pulping country in Europe. Further examples are given for mills after biological treatment in Table 2.40 below. The data are derived from environmental reports of the companies, personal communication and SEPA report 4924 "The Forest Industry's emissions to water and air, amounts of waste and energy consumption, 1997" (in Swedish only). The method of analysing is the one used in the respective country. In Sweden and Finland the values for BOD are given as BOD₇

Depending on the type of pulp wood used, the specific process-integrated measures implemented and the technical character of the mill the following emission to water associated with the use of BAT can be generally achieved **before** biological treatment:

Parameters	Units	Bleached Kraft ¹	Integrated unbleached Kraft ³
COD	kg/ADt	30 ² - 45	15 - 20
BOD	kg/ADt	13 ² - 19	6 - 9
TSS	kg/ADt	2 - 4	2 - 4
AOX	kg/ADt	(-) - 0.4	*
Total P	kg/ADt	0.04 - 0.06 ⁴	0.01-0.02
Total N	kg/ADt	0.3 - 0.4	0.1 - 0.2
Process wastewater amount	m ³ /ADt	30-50	15 - 25

Notes:

*This parameter is not relevant here. Low emissions of AOX may occur from re-pulping of purchased bleached pulp

- 1) Emission levels for non-integrated and integrated bleached Kraft pulp mills per tonne of pulp.
- 2) Lower values are achievable when only hardwood is pulped
- 3) Unbleached Kraft pulp mills are all integrated mills. They produce kraftliner, unbleached board grades and sack and other Kraft paper. Many of them use recycled fibres and purchased bleached pulp. Higher emission levels are usually found in mills using more recycled fibres as raw material. Figures are per tonne of liner/paper/board produced
- 4) Due to the higher content of phosphorus in the pulp wood eucalyptus pulp mills can not achieve this values. Current mill data for P emissions to water range from 0.037 - 0.23 kg P/ADt. The average of the reported data is 0.11 kg P/ADt

Table 2.39: Emission levels associated with the use of a suitable combination of best available techniques achieved after primary treatment
Values for bleached and unbleached kraft pulp mills are given

When implementing suitable combinations of BAT achievable emission levels for non-integrated and integrated Kraft pulp mills are considered to be in the same range as far as the pulping side is concerned. For integrated mills, to the measures related to pulp mills (Chapter 2) and additionally the measures described under the corresponding chapter on papermaking (Chapter 6) have to be considered.

However, there are some techniques to consider that refer solely to integrated pulp mills as for example

- Effective separation of the water systems of the pulp and paper mill from each other
- Recycling of the pulp dilution water between the pulp and paper mills.
 The recirculation of process water from the paper machine to the pulp mill is not possible when the mill sells part of its pulp production to the open market or the mill has two or more paper machines making different types of paper, the white waters of which are incompatible or when coloured paper is manufactured.

External biological wastewater treatment

In addition to the process-integrated measures and primary treatment (item 1 to 10) biological treatment is considered BAT for Kraft pulp mills. Activated sludge plants consisting of equalisation basin, aeration basin, secondary clarifier and sludge handling show excellent performance for the treatment of pulp mill effluents. Low loaded activated sludge plants with a sludge load below 0.15 kg BOD/(kg MLSS*d) and typical retention times in the aeration basin of about one day (up to 2 days) are regarded as BAT. They can achieve high removal efficiencies and a stable treatment system.

It should be noted that any other treatment with comparable emission levels and comparable costs can also be regarded as BAT.

Table 2.40 shows achieved emission levels of some pulp mills in Europe that have implemented a set of process-integrated BAT measures but not necessarily all and not necessarily to their full extent but together with biological wastewater treatment. Figures give within brackets in Table 2.40 are in terms of concentration [mg/l].

Pulp mills	Reported achieved emission levels after biological treatment (annual averages)							Type of treatment
	COD [kg/Adt]	BOD _{5 or 7} [kg/Adt]	AOX [kg/Adt]	TSS [kg/Adt]	Total P [kg/Adt]	Total N [kg/Adt]	Flow ³⁾ [m ³ /Adt]	e.g. normal-/low-load
Soedra Cell, Mönsterås, Sweden ¹	13 (300)	0.9 (20)	(-)	1.7 (40)	0.03 (0.7)	0.31 (7)	45	Activated sludge with long retention time (>2 d)
Pöls AG, Austria	17.6 (400)	0.64 (15)	0.30 (6.6)	1.45 (30)	0.07 (1.5)	0.06 (1.5)	45.8 ⁶	Activated sludge with 14 h retention
Modo Alizay, France (all site) ⁴	11.1 (180)	0.6 (10)	0.1 (1.6)	2.24 (37)	0.08 (1.3)	0.38 (6.2)	61	Activated sludge
Enocell, Finland	12 (300)	0.2 (5)	0.14 (5)	0.3 (8)	0.004 (0.1)	0.08 (2)	39	Activated sludge with 24 h retention + aerated pond
MB Kaskinen, Finland	14 (300)	0.3 (7)	0.07 (1.4)	1.0 (20)	0.02 (0.4)	0.15 (3)	49	Activated sludge
Sunila, Finland	22 (160)	1.4 (10)	0.14 (0.2)	2.1 (15)	0.026 (0.2)	0.21 (6)	70	Activated sludge
MB Äänekoski, Finland	24 (750)	0.6 (5)	0.38 (11.9)	1.9 (60)	0.012 (0.4)	0.17 (5)	32	Activated sludge
UPM Kymi, Finland, integrated ⁵	23 (360)	2.7 (40)	0.22 (3.5)	1.1 (20)	0.02 (0.3)	0.19 (3)	63	Activated sludge
Metsä-Rauma, built in 1996, Finland ²⁾	4 (270)	0.4 (30)	(-)	0.7 (45)	0.015 (1)	0.14 (10)	15	Activated sludge
Alberta-Pacific, Alberta, Canada	6.9 (130)	0.2 (4)	0.05 (0.8)	1.66 (30)	n/a.	n/a.	50 - 60	Activated sludge with about 40 h retention time
Bäckhammars mill, Sweden, unbleach. Kraft + Kraft-paper	7 (80)	1.5 (20)	-	0.9 (10)	0.007 (0.1)	0.47 (5)	85	Biological treatment + chemical precipitation

n/a. = no data available
Notes:
1) Average data for the second half of 1998
2) Values calculated by the mill. The mill was built as a greenfield mill in 1996 and has a common treatment with an adjacent mechanical pulp and paper mill
3) Water flow excludes cooling water
4) Figures are per tonne of finished product. Figures per tonne of bleached Kraft pulp produced would be different, e.g. for COD 13 kg/ADt, BOD 0.63 kg/ADt, TSS 2.82 kg/ADt, flow 64 m³/ADt; data refer to 1998
5) Figures are per tonne of finished product (fine paper). Figures per tonne of bleached kraft pulp would be: COD: 28 kg/ADt; BOD₇: 0.5 kg/ADt; AOX: 0.33 kg/ADt; TSS: 0.8 kg/ADt; tot-P: 0.02 kg/ADt; tot-N: 0.2 kg/ADt; flow: 42 m³/ADt
6) Value excludes paper production. The contribution of a small paper production is negligible for the other parameters.

Table 2.40: Examples of achieved emission levels to water after biological treatment of existing pulp mills in Europe (reference year: 1997)

The list of mills is a selection of mills where data were available or provided and is therefore not intended to be complete. The data are derived from available environmental reports, statistics from Finnish Environment Institute and from personal communication. The method of analysis is the one used in the respective country. In Sweden and Finland the values for BOD are given as BOD₇.

Assuming adequate design and capacity of the wastewater treatment plant and appropriate operation and control by skilled operators the following discharge **after** biological treatment is generally achievable. The emissions to water do not differ very much between integrated and non-integrated kraft pulp mills when down at these levels associated with BAT.

Parameters	Unit	Bleached Kraft ¹	Unbleached Kraft + kraftliner or sackpaper ²
COD	kg/ADt	8 – 23	5.0 – 10
BOD	kg/ADt	0.3 - 1.5	0.2 - 0.7
TSS	kg/ADt	0.6 – 1.5	0.3 - 1.0
AOX	kg/ADt	(-) - 0.25	-
Total P	kg/ADt	0.01 - 0.03 ³	0.01 - 0.02
Total N	kg/ADt	0.1 - 0.25 ⁴	0.1 - 0.2
Process wastewater amount ⁵	m ³ /ADt	30-50	15-25

Notes:

- 1) Emission levels for non-integrated and integrated bleached Kraft pulp mills
- 2) Emission levels for integrated unbleached Kraft pulp and paper/liner mills
- 3) Due to the higher content of phosphorus in the pulp wood some eucalyptus pulp mills can not achieve this values if P is in excess of the need of the biological treatment plant. Emission will be determined by P-content of the wood. No phosphorus needs to be added to the wastewater treatment plant.
- 4) Any nitrogen discharge associated with the use of complexing agents should be added to the figure of tot-N
- 5) Cooling water and other clean water are discharged separately and are not included

Table 2.41: Emission levels associated with the use of a suitable combination of best available techniques after biological treatment

Values for bleached and unbleached kraft pulp mills are given

Table 2.41 should be read together with the following additional explanations:

- **Chemical oxygen demand (COD):** The reduction rate for COD is related to the types and amounts of effluents treated (e.g. condensates are more degradable than spills), the construction and hydraulics of the treatment plant and appropriate adjustment of the operating parameters. COD removal rates of 65 - 75 % are achieved by well designed and controlled low loaded plants. However, long retention times means big aeration basins and more consumption of pumping and aeration energy is needed. To be regarded as well performing plant the COD reduction rates in treatment should exceed 55%. Consequently, emission levels of 8 - 23 kg COD/ADt can generally be achieved by bleached Kraft pulp mills. The concentration measured in effluents of these mills is in the range of 250 - 400 mg COD/l.

The most common reasons for less performing activated sludge plants are chosen design and too high load. On the other hand, the best plants achieving a COD-removal of about 75% are operating at a level where further reduction of organic matter (measured as COD) is very limited by means of biological treatment.
- **Biological oxygen demand (BOD_{5 or 7}):** In well designed treatment plants BOD is removed almost completely (95% + removal) from pulp mills wastewater when the carbon-phosphorus-nitrogen ratio and oxygen supply is maintained sufficient and well controlled. In case of disturbances or if some of the running parameters are moving away from the target level, the BOD concentration in effluents will start to increase. This calls for adjustment of the running parameters and/or analysis of the biomass. The BOD concentration in the effluent is related to the control of system and can be used as an indicator of the health of the active biomass.

The BOD concentration in treated effluents between 10 and 25 mg/l are associated with BAT. Depending on the water flow this corresponds to 0.3 kg BOD₅/Adt (at 10 mg/l and 30 m³ flow/Adt) and 1.3 kg BOD₅/Adt respectively (at 25 mg/l and 50 m³ flow).
- **Total suspended solids (TSS):** Under normal operation conditions, the water from the secondary clarifier is fairly clear and suspended solids content is in the range of 20 to 30 mg/l. This corresponds to discharges of 0.6 – 1.5 kg TSS/Adt (at a water flow of 30 - 50 m³/Adt). The values depend on the surface load of the secondary clarifier and the characteristics of the biomass.

- **Adsorbable organic halogen (AOX):** Discharges of chlorinated organics are usually in the range of 0 - 0.5 kg/Adt before biological treatment as the bleaching process was modified towards ECF or TCF bleaching in most European pulp mills. Activated sludge treatment result in AOX reduction between 40 and 60 %. ECF mills achieve emission levels of < 0.25 kg/Adt. TCF mills discharge virtually no chlorinated organics (no formation in bleaching).
- **Phosphorus and nitrogen (Tot-P and Tot-N):** Mineral nutrients are usually added to the biological treatment plant to keep the balance C : P : N which is of crucial importance for the growth of active biomass. Therefore, only focussing on incoming concentration or reduction rates for N and P will not achieve its purpose. It is rather necessary to find and keep a balance between incoming N- and P-compounds that are available for biomass and the amount of nutrients, if any, added which requires a certain fine-tuning of the nutrient feed. Often, pulp mills do not add phosphorus to their wastewater whereas nitrogen addition (usually as urea) is essential for pulp mills. When the system is well optimised the phosphorus discharge of 0.2 - 0.5 mg tot-P/l and 2 - 5 mg tot-N/l are achieved. The corresponding loads are 0.01 - 0.03 kg P/Adt and 0.1 - 0.25 kg N/Adt respectively (at a water flow of 50 m³/Adt). Tot-P from bleached pulp is slightly higher than from unbleached because phosphorus is dissolved out in the bleach plant.

To ensure a continuously well running wastewater treatment plant an emergency basin to protect the biomass from toxic or hot concentrated liquors and an equalisation basin to equalise load and flows can be beneficial.

Measures for reducing of emissions to air

1. Collection and incineration of concentrated malodorous gases from the fibre line, cooking plant, evaporation plant, condensate stripper, and control of the resulting SO₂. The strong gases can be burnt in the recovery boiler, the lime kiln or a separate, low NO_x furnace. The flue gases of the latter have a high concentration of SO₂ that is recovered in a scrubber.
2. Collection and incineration of diluted malodorous gases from e.g. the fibre line, various sources as tanks, chip bins, smelt dissolver etc. The weak malodorous gases can be burnt in e.g. the recovery boiler mixed with combustion air or in an auxiliary boiler depending on the volume.
3. Mitigation of the TRS emissions of the recovery boiler by computerised combustion control and CO measurement and in the case of the lime kiln by controlling the excess oxygen, by using low S-fuel, and by controlling the residual soluble sodium from the lime mud fed to the kiln.
4. Control of SO₂ emissions from the recovery boilers by firing high dry solids concentration black liquor in the recovery boiler to mitigate SO₂ formation and/or by using a flue gas scrubber.
5. Control of NO_x emissions from the recovery boilers and lime kiln by controlling the firing conditions and by ensuring proper mixing and division of air in the boiler, and for new or altered installations also by appropriate design;
6. Control of NO_x emissions from auxiliary boilers by controlling firing conditions and for new or altered installations also by appropriate design.
7. Reducing SO₂ emissions from auxiliary boilers by using bark, gas, low sulphur oil and coal or controlling S emissions with a scrubber.
8. Cleaning of the recovery boilers, auxiliary boilers (in which other biofuels and/or fossil fuels are incinerated) and lime kiln flue gases with efficient electrostatic precipitators to mitigate dust emissions.

A combination of these techniques result in a range of emissions for the major sources as shown in Table 2.42. The examples of mills stand for well performing mills in Europe that have implemented a reasonable set of these techniques. In all mill cases the gaseous emissions are cleaned with modern gas cleaning equipment as electrostatic precipitators and scrubbers according to practical application needs. Process related emissions cover recovery boiler (s),

lime kiln (s), fugitive emissions and other furnaces (e.g. for TRS incineration) linked to the process, if any.

It should be noted that a direct comparison of the emission levels between countries is difficult due to uncertainties in the basis of data (lack of harmonisation in the methods of analysis and calculating emissions).

Reported emissions to the atmosphere from Kraft pulp mills (annual averages)											
Emission of gaseous sulphur (SO₂ and TRS) in kg S/ADt of pulp							Emission of NO_x in kg NO_x/Adt (expressed as NO₂)				
Mill	Recov. boiler¹	Lime kiln¹	Separate furnace¹, if any	Auxiliary boiler²	Fugitive emissions³	Total from process	Recovery boiler	Lime kiln	Separate furnace, if any	Auxiliary boiler	Total from process
Aspa, Sweden	0.36	0.10	-	n.a.	0.37	0.83	1.29	0.20	-	n.a.	1.49
Iggesund, Sweden	0.40	0.11	0.14	0.30	0.23	0.89	1.50	0.13	-	0.82	1.63
Husum, Sweden ⁴	0.30	0.01	0.16	0.16	0.33	0.79	1.21	0.11	0.07	0.39	1.50
Mönsterås, Sweden	0.11	0.05	-	0.10	0.50	0.66	0.95	0.21	-	0.12	1.16
Östrand, Sweden	0.06	0.40	-	0.07	0.47	0.93	1.36	0.08	-	0.47	1.44
Skutskär, Sweden	0.14	0.10	0.09	0.02	0.43	0.76	1.26	0.19	-	0.37	1.45
Skärblacksa, Sweden ⁴	0.17	0.05	0.05	0.10	0.03	0.29	0.66	0.23	-	0.72	0.89
Skoghall, Sweden ⁴	0.17	<0.01	0.05	0.49	0.30	0.52	1.14	0.15	0.13	0.53	1.42
Vallvik, Sweden	0.07	0.29	-	0.19	0.12	0.48	1.44	0.22	-	0.28	1.65
Varö, Sweden	0.06	0.29	-	0.04	0.49	0.74	1.51	0.26	-	0.20	1.79
Dynäs, Sweden ⁴	0.04	<0.01	0.24	0.22	0.45	0.74	1.24	0.22	-	0.52	1.66
Frövi, Sweden ⁴	0.03	0.01	0.06	0.26	0.21	0.31	1.01	0.21	0.29	0.99	1.51
Obbola, Sweden ⁴	0.11	<0.01	0.03	0.05	≈ 0.3	0.4	1.02	0.18	-	0.31	1.20
Bäckhammar, Sweden ⁴	0.14	0.01	-	0.25	≈ 0.2	0.4	1.22	0.04	-	0.37	1.26
Huelva, Spain	0.41	0.67	-	0.17	n/a.	1.08	0.88	0.06	-	0.31	0.94
Pöls AG, Austria	0.04	<0.01	-	-	0.009 ⁶	0.04	1.6	0.45	-	-	2.05
Stora Celbi, Portugal	0.06	0.02	0.02	0.62	n/a.	0.10	1.02	0.17	0.19	0.37	1.38
Enocell, Finland ⁵	0.011	0.133	0.029	0.015	0.125	0.30	1.186	0.171	0.164	0.292	1.52
Oulu, Finland ⁴	0.046	0.006	0.292	-	0.050	0.39	0.810	0.270	-	-	1.08
Ääneskoski, Finland	0.380	0.059	-	-	0.095	0.53	1.748	0.101	-	-	1.85
Kaskinen, Finland	0.392	0.044	-	-	0.095	0.53	1.366	0.160	-	0.611	1.53
Sunila, Finland	0.433	0.061	0.012	0.313	0.298	0.80	1.029	0.275	0.042	0.404	1.35
Joutseno, Finland	0.036	0.012	-	-	0.719	0.77	1.013	0.168	-	0.261	1.18
Wisaforest, Finland	0.178	0.030	0.069	0.189	0.082	0.36	0.864	0.326	0.403	0.758	1.59

n/a. = no data available; "≈" means that figures are estimated mainly from previous reports; n.a. = the mill has no auxiliary boiler

Explanatory notes:

- Gaseous sulphur is mainly SO₂-S. Usually only very small amounts of H₂S is released (usually below 10 mg H₂S/Nm³)
- The emissions from auxiliary boilers are not included in the figures "total from process"
- Fugitive emissions are mainly reduced sulphur compounds (TRS). This emission is usually not monitored regularly by European chemical pulp mills (However, in Finland TRS emissions are monitored regularly by every kraft pulp mill). Figures reported include estimates of these emissions, based on the latest monitoring carried out.
- Integrated pulp and paper mills
- Emissions in 1998
- All relevant diffuse emissions are extensively collected and are therefore negligible. Only in case of maintenance or failures diffuse emission are occasionally released. The TRS emissions are the TRS contributions of the RB and lime kilns.

Table 2.42: Examples of achieved emission levels to air of some well performing existing pulp mills in Europe (reference year: 1997)

The total process emissions do not include the auxiliary boilers. The list of mills is a selection of mills where data were available or provided and is therefore not intended to be complete. It contains rather mills from different pulping countries in Europe. The data are derived from environmental reports of the companies for 1997, personal communication, SEPA report 4924 "The Forest Industry's emissions to water and air, amounts of waste and energy consumption, 1997"(in Swedish only) and from statistics of the Finnish Environment Institute. The method of analysing is the one used in the respective country

The balance between different gaseous emissions (SO₂, TRS, NO_x) and the recovery process itself should be kept in mind and carefully assessed when determining emission ranges. Depending on the type of the specific process-integrated measures implemented and the technical character of the mill the following atmospheric process emissions associated with the use of BAT can be generally achieved:

Parameters	Units	Bleached and unbleached kraft pulp mills
TSP	kg/ADt	0.2-0.5
SO ₂ as S	kgS/ADt	0.2-0.4
NO _x as NO ₂	kg/ADt	1.0-1.5
TRS as S	kgS/ADt	0.1-0.2

Table 2.43: Emission levels from the pulping process associated with the use of a suitable combination of best available techniques (emissions from any auxiliary boiler are not included) Process related emissions include recovery boiler(s), lime kiln(s), fugitive emissions and separate furnaces (e.g. for TRS incineration) linked to the process, if any. Values for bleached and unbleached Kraft pulp mills are not distinguished because there is no significant technical difference to consider

Table 2.43 should be read together with the following additional explanations. As far as concentrations of emissions are given they refer to daily averages and standard conditions of 273 K, 101.3 kPa and dry gas. The reference oxygen content is 5% for lime kilns and 5% for recovery boilers.

Dust emissions: In kraft pulp mills, emission of particulates are controlled by electrostatic precipitators and sometimes also in SO₂ scrubbers. TSP emissions for recovery boilers between 30 - 50 mg/Nm³ or 0.2 - 0.5 kg TSP/ADt (with a gas flow of 7000 - 9000 m³/ADt) are considered as BAT. This level can generally be achieved by more modern recovery boilers by use of ESP only. Old recovery boilers achieve this levels when they apply ESP and scrubbers. However, scrubbers are mainly applied for removal of SO₂. 100-150 mg dust/m³ is achievable at many existing mills which do not have a scrubber.

With an SO₂-scrubber after the ESP, emissions at about 15 mg/Nm³ are achievable.

For lime kilns 30 - 50 mg/Nm³ or 0.03 - 0.05 kg/ADt (with a gas flow of 1000 m³/ADt) can generally be achieved when using an ESP.

SO₂ emissions: If changes in the fuel or the operation do not give enough reduction of SO₂ emission, removing sulphur oxides from flue gases by absorption in alkaline liquid is considered BAT. The removal efficiency for SO₂ is usually well above 90%.

- From recovery boilers equipped with a scrubber SO₂ emissions between 10 - 50 mg S/Nm³ or 0.1 - 0.4 kg S/ADt are achieved. Recovery boilers operating with high dry solid content of black liquor release very low SO₂ emissions normally below 0.1 kg S/ADt or down to 5 - 10 mg S/Nm³.
- The SO₂ emission levels of the lime kiln depend mainly on the fuel used, sulphur in the lime mud and whether NCG are also fed to the kiln. Oil fired kiln without NCG incineration achieves 5 - 30 mg SO₂/Nm³ or 0.005 - 0.03 kg SO₂/ADt. Oil fired kiln with NCG incineration achieve 150 - 300 mg SO₂/Nm³ or 0.1 - 0.3 kg SO₂/ADt. Depending on the amount of sulphur (NCG) applied to the lime kiln a scrubber may be required. Another option for SO₂ reduction would be to choose another location for incineration of NCG than the lime kiln or use less sulphur containing oil burned as fuel.

NO_x emissions: The emission of nitrogen oxides can be controlled by burner design (low NO_x burners) and modified combustion conditions (primary methods).

- The design of the recovery boiler (staged air feed systems) can result in relatively low NO_x concentrations. The recovery boiler is however responsible for the largest contribution to the total NO_x emission because of the large amount of liquors that are being burnt. Increased black liquor dry solids can lead to a slightly increase of NO_x emissions. Achievable emission levels are in the range of 80 - 120 mg NO_x/Nm³ (40 - 60 mg NO_x/MJ) or 0.7 - 1.1 kg NO_x/ADt respectively. Process steam production is between about 13 and 18 GJ/ADt of pulp.
- The lime kiln is also a source of NO_x emission in kraft mills because of the high combustion temperature. In lime kilns the type of fuel also influences the NO_x formation. Higher NO_x levels are measured with gas firing than with oil firing. In oil firing the NO_x emission of the lime kiln is in the range of 100 - 200 mg/Nm³ or 0.1 - 0.2 kg NO_x/ADt whereas gas fired kilns achieve 380 - 600 mg/Nm³ or 0.4 - 0.6 kg NO_x/ADt. Combustion of malodorous gases in the lime kiln can also increase NO_x emissions. The possibilities to decrease the NO_x emissions by adjusting the kiln running parameters, the flame shape, the air distribution and the excess oxygen is limited but can lead to slight reduction of NO_x formation (about 10 - 20%).
- A separate furnace for TRS burning adds about 0.1 - 0.2 kg NO_x/ADt.

Secondary methods as selective non-catalytic reduction (SNCR) are not in operation.

TRS emissions (malodorous gases): Pulp mill malodorous gases are collected and treated in different ways depending on the concentration and volume of the gases. The malodorous gas streams are divided into strong and weak gases. The systems for treatment of concentrated malodorous gases include a back-up system, which is activated when there are disturbances, maintenance or other downtimes of the normal system. Treatment methods for malodorous gases are incineration and alkaline scrubbing. There are different options for incineration of malodorous gases: lime kilns, dedicated incinerators or recovery boilers.

- When low volume concentrated malodorous gases are incinerated in the lime kiln, sulphur is partly absorbed. TRS emissions from the lime kiln are controlled by efficient lime mud washing and combustion condition control. A level of below 15 mg H₂S/Nm³ (10% O₂) can be achieved with a modern lime filter. If a further reduction of the TRS emissions is required an alkali scrubber must be installed after the ESP. This can bring the H₂S emissions down to about 1.5 mg/Nm³ but is linked to a high consumption of alkali.
- Incineration of concentrated malodorous gases in a dedicated incinerator transform TRS to SO₂ emissions. The incinerator therefore always has to be equipped with a scrubber.
- The incineration of concentrated gases in the recovery boiler operated with high solid content leads to very low sulphur emissions both SO₂ and TRS.
- High volume, diluted malodorous gases can be sent to the recovery boiler where they are mixed into the secondary or tertiary combustion air or be burnt together with concentrated TRS in a separate dedicated burner. In lime kilns diluted malodorous gases can be mixed into the secondary air.

Besides the chosen gas treatment system the final TRS emissions are determined by the number of units that are connected to the gas collection system and the availability of the treatment system including back-up systems. Released fugitive TRS emissions consist mainly of non-collected diluted malodorous gases. The availability depend on the gas treatment system, the number and type of back-up systems and the monitoring and control of the system. High availability of the gas treatment system can be achieved for instance by

- use of a dedicated incinerator with SO₂ scrubber as the major unit and by use of the lime kiln or an alkaline scrubber as one back-up and a flare as a second back-up.
- incineration of the strong and weak gases in the recovery boiler and use of the lime kiln as one back-up and a flare as a second back-up.

Auxiliary boilers

Depending on the actual energy balance of the mill, the type of external fuels used and the fate of possible biofuels as bark and wood-waste additionally there are atmospheric emissions from auxiliary boilers to consider. Emission levels associated with BAT from auxiliary boilers incinerating own biofuels and different fossil fuels are given in Table 2.44. The total releases to air are very site specific (e.g. type of fuel, integrated or market pulp mill, production of electricity). It should be noted that many mills use fuel mixes.

Released substances	Coal	Heavy fuel oil	Gas oil	Gas	Biofuel (e.g. bark)
mg S/MJ fuel input	100 - 200 ¹ (50 - 100) ⁵	100 - 200 ¹ (50-100) ⁵	25-50	<5	< 15
mg NO _x /MJ fuel input	80 - 110 ² (50-80 SNCR) ³	80 - 110 ² (50-80 SNCR) ³	45-60 ²	30 -60 ²	60 -100 ² (40-70 SNCR) ³
mg dust/Nm ³	10 - 30 ⁴ at 6% O ₂	10 - 40 ⁴ at 3 % O ₂	10-30 3% O ₂	< 5 3% O ₂	10 - 30 ⁴ at 6% O ₂
Notes:					
1) Sulphur emissions of oil or coal fired boilers depend on the availability of low-S oil and coal. Certain reduction of sulphur could be achieved with injection of calcium carbonate.					
2) Only combustion technology is applied					
3) Secondary measures as SNCR are also applied; only larger installations					
4) Achieved values when electrostatic precipitators are used					
5) When a scrubber is used; only applied to larger installations					

Table 2.44: Emission levels associated with the use of BAT for different fuels

It has to be noted that auxiliary boilers within the pulp and paper industry are of a very variable size (from 10 to above 200 MW). For the smaller only the use of low-S fuel and combustion techniques can be applied at reasonable costs while for the larger also control measures. This difference is reflected in Table 3.19. The higher range is considered BAT for smaller installations and is achieved when only quality of fuel and internal measures are applied; the lower levels (in brackets) are associated with additional control measures like SNCR and scrubbers and are regarded as BAT for larger installations

In a modern non-integrated mill the heat generated from black liquor and incineration of bark exceeds the energy required for the entire production process. However, fuel oil will be needed at certain occasions like start-up and also at many mills in the lime kiln.

Solid waste

1. Minimisation the generation of solid waste and recover, re-cycle and re-use these materials as far as possible.
2. Separate collection of waste fractions at source and, if necessary, intermediate storage of residuals/waste to make possible an appropriate handling of remaining waste products
3. Incinerating all non-hazardous organic material (bark, wood waste, effluent sludge, etc.) in an auxiliary boiler, specially designed for burning of moist, low calorific value fuels (as e.g. fluidised bed boilers)
4. External utilisation of residuals/waste as substitutes in forestry, agriculture or other industries, if possible

It should be noted that there is little detailed and reliable information available on achievable amounts of solid wastes. There is a lack of statistical data and various terms for different waste fractions are used in Europe. Some countries report only those solid waste - primarily inorganic solid wastes - which no longer can be recycled or reused, but have to be disposed off to landfill. This implies that all the organic wastes which have a reasonable heating value and/or which can be incinerated without the risk of hazardous emissions in the auxiliary boiler of a mill are

already excluded from the given solid waste amounts (bark and wood waste, primary and biosludge from wastewater treatment). Hence, the solid waste disposed of at landfill comprises mainly boiler ashes, causticizing dregs, lime mud, green liquor sludge, some wood and bark waste rejects and miscellaneous cleaning and mixed household-type wastes.

Therefore, it is difficult to present achievable values on the amount of non-hazardous solid waste. To give an indication about the amount of solid waste that might be expected at Kraft pulp mills that apply BAT some examples on the main types of solid waste for landfill are given in Table 2.45. It is assumed that bark and other wood residues as well as the mixed sludge from wastewater treatment are utilised for energy production in the auxiliary boiler. The waste amounts are all given as bone dry kilos per tonne of final product (100% DS).

Examples	Type of waste	Amount [kg DS/ADt]	Total [kg DS/ADt]
Bleached Kraft market pulp mill	- Ashes	2.0	15
	- Dregs	10.0	
	- Bark, wood waste etc.	3.4	
	- Rejects	0.3	
Bleached Kraft market pulp mill	- Lime mud	9.7	45
	- Green liquor dregs	8.1	
	- Bio- & primary sludge	8.7	
	- Reject (woodhandling)	2.1	
	- Wood ashes	3.9	
	- Other	10.5	
Integrated unbleached Kraft pulp mills	Not specified	No data available	30 - 50 (range of 3 examples)

Table 2.45: Examples for the amount of solid waste for landfilling from some Kraft pulp mills [Data from mill examples and environmental reports]

A small amount of hazardous waste is generated in all mills. Such waste include oil and grease residues, used hydraulic and transformer oils, waste batteries and other scrap electrical equipment, solvents, paints, biocide and chemical residues, etc. Normally they amount to about 0.05-0.1 kg/t of product.

Energy saving measures

In order to reduce the consumption of fresh steam and electric power, and to increase the generation of steam and electric power internally, a number of measures are available.

1) Measures for a high heat recovery and a low heat consumption:

- High dry solids content of black liquor and bark
- High efficiency of steam boilers, e.g. low flue gas temperatures
- Effective secondary heating system e.g. hot water about 85 °C
- Well closed-up water system
- Relatively well closed-up bleaching plant
- High pulp concentration (MC-technique)
- Pre-drying of lime
- Use of secondary heat to heat buildings
- Good process control

- 2) Measures for low consumption of electric power
 - As high pulp consistency as possible in screening and cleaning
 - Speed control of various large motors
 - Efficient vacuum pumps
 - Proper sizing of pipes, pumps and fans
- 3) Measures for a high generation of electric power
 - High boiler pressure
 - Outlet steam pressure in the back-pressure turbine as low technically feasible
 - Condensing turbine for power production from excess steam
 - High turbine efficiency
 - Preheating of air and fuel charged to boilers

The effect of this energy saving measures can often not be easily been shown in form of values because improvements depend on the situation of the mill before the measures were implemented.

In many European countries, information on energy balances of whole pulp and paper mills is poorly available in public. In Europe, different reporting schemes are used. Energy balances also depend to a certain extent on local conditions. Therefore the ranges of energy consumption of pulp mills shown in Table 2.46 should only be taken as an indication about the approximate need of process heat and power at energy efficient Kraft pulp mills. Further examples of energy efficient Kraft pulp mills including the specific conditions might be possible to add in a reviewed version of the BREF.

Type of mill	Process heat consumption (net) in GJ/ADt	Power consumption (net) in MWh/ADt	Remarks
Non-integrated bleached Kraft pulp	10-14 GJ/ADt About 2-2.5 GJ/ADt can be used for power generation giving a heat surplus of 0.5-1.0 GJ/ADt.	0.6 - 0.8 MWh/ADt Modern pulp mills are power self-sufficient	An integrated mill reported 10 GJ/ADT heat consumption in the pulp mill (pulp at 2.2% consist.) ¹
Integrated bleached Kraft pulp and uncoated fine paper	14 - 20 GJ/ADt ²⁾ There is a heat surplus of 4.0-4.5 GJ per tonne of pumped bleached pulp which is used in the paper mill	1.2 - 1.5 MWh/ADt There can be a surplus power from the pulp mill of 0.1 - 0.15 MWh per tonne of pumped bleached pulp which is used in the paper mill	The surplus of electricity, if any, depends on if back-pressure turbines are installed
Integrated kraftliner, Unbleached	14.0 - 17.5 GJ/ADt There is a heat surplus of 1.5-2 GJ per tonne of pumped unbleached pulp which is used in the paper mill	1.0-1.3 MWh/ADt There is a surplus power from the pulp mill of 0.15 - 0.2 MWh per tonne of pumped unbleached pulp which is used in the paper mill	
Integrated sackpaper, Unbleached	14.0 - 23 GJ/ADt	1.0 - 1.5 MWh/ADt	
The units can be converted from MWh to GJ according to 1 MWh = 3.6 GJ and 1 GJ = 0.277 MWh Notes: 1) including activated sludge treatment 2) Paper drying is more energy consuming than pulp drying			

Table 2.46: Energy consumption associated with the use of BAT for different types of production per tonne of product

[Data from Jaakko Pöyry, 1998, SEPA report 4712, Finnish BAT report, 1998, data from mill case studies]

Chemical usage

1. Availability of a database for all used chemicals and additives containing information on the chemical composition of the substances, degradability, their toxicity for men and environment and potential of bioaccumulation.
2. The principle of substitution is applied i.e. less hazardous products are used when available.

2.5 Emerging Techniques

A number of new promising technologies are presently being developed that result in reduction of emissions or energy savings. The improvements of environmental performance may not always have been the main driving force, but plays an important role in the development. Some of these techniques are described in the subsections below. This Chapter includes addressing environmental issues that have only recently gained interest and research programmes related to the development of environmentally improved solutions for the production of high-quality pulp and paper products.

2.5.1 Gasification of Black Liquor

Description: Gasification is a suitable promising technique for pulp mills for the generation of a surplus of electrical energy. Production of a combustible gas from various fuels (coal, wood residues, black liquor) is possible through different gasification techniques. The principle of the gasification of black liquor is to pyrolyse concentrated black liquor into an inorganic phase and a gas phase through reactions with oxygen (air) at high temperatures. A number of gasification processes for black liquor have been proposed. Conceptually, they fall into two categories. One is low temperature gasification, where the gasifier operates below the melting point of the inorganic salts (700-750 °C). Fluidised beds are suitable for a low temperature gasification process, and are used in all of the low temperature processes under development. The other category includes those processes which operate above the melting point and use a water quench to cool and dissolve the molten sodium salts. One example of gasification processes is described in this context:

Example: The Chemrec Process

At the Frövifors mill (Sweden), black liquor is taken from the evaporation plant in the pulp mill and heated to 130 to 135°C using indirect steam. The black liquor is at approximately 65 % dry solids content. The heated liquor then enters the first portion of the Chemrec process, which is a gasifier.

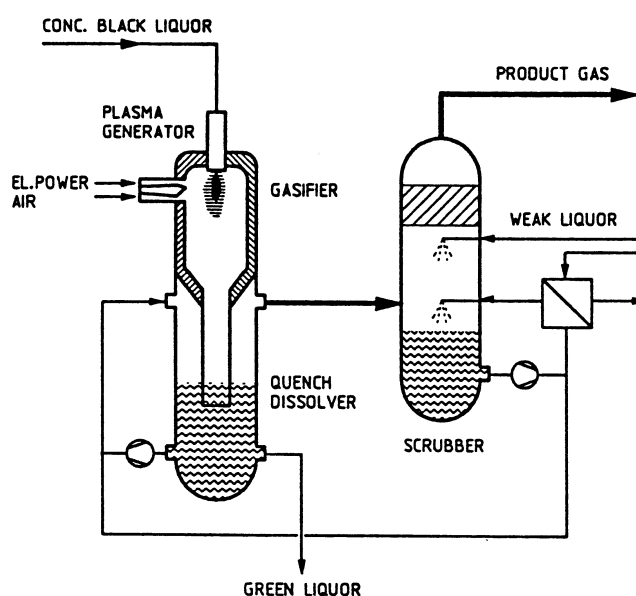


Figure 2.13: The Chemrec process with a gasifier and a quench dissolver for green liquor production and with a weak liquor gas scrubber for hydrogen sulphide absorption

The black liquor is introduced in the gasifier, where it is atomised by high-pressure air (12 bar) and sprayed into the upper part of the reactor. The main air flow needed for the process is pressurised to 0.5 bar and preheated from 80 to 500 °C. The atmosphere in the chamber is approximately 950 °C, and the atomised black liquor forms small droplets that are partially combusted. The inorganic compounds in the black liquor are converted to small smelt droplets of sodium sulphide and sodium carbonate, and this mist drops through the reactor and down to the quench cooler, which is an integrated portion of the reactor unit. The organic compounds are converted to a combustible gas containing carbon monoxide, methane and hydrogen.

The smelt droplets and combustible gas are separated when they are simultaneously brought into direct contact with a cooling liquid in the quench cooler that drops the temperature to 95°C. The smelt droplets dissolve in the weak wash to form a green liquor solution that is pumped to the dissolving tank under the recovery boiler. Some weak green liquor is recirculated to the quench. A screen is used ahead of the pump to catch small particles and undissolved smelt droplets.

One of the most interesting opportunities with the black liquor gasification processes are to run a gas turbine in combination with a steam turbine in a combined cycle as shown in Figure 2.14 and Figure 2.15. The difficulty to be overcome is primarily the cleanness of the gas to avoid disturbances in the gas turbine.

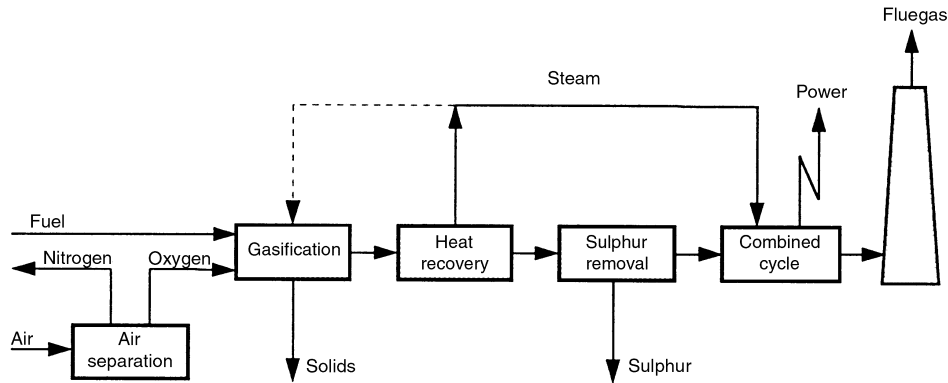


Figure 2.14: Integrated gasification with combined cycle (IGCC)

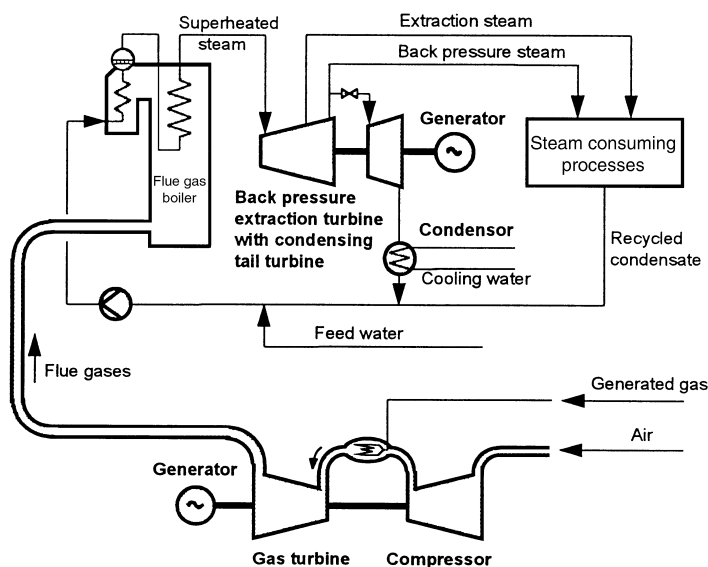


Figure 2.15: Combined cycle for power production by means of gas turbine and steam turbine with condensing tail

Status of development: The first demonstration plant of black liquor gasification using Chemrec concept has been operated at Frövifors Mill in Sweden since 1991. A pressurised demonstration gasifier of this type has also been in operation in Skoghall in Sweden. This type of process is also applied commercially in the U.S.A. since 1997.

The Integrated Gasification with Combined Cycle Technology (IGCC) can only gradually be introduced in the Paper Industry, mainly because of the life time of present recovery boiler. Furthermore, the gasifiers will initially only be designed for smaller capacities than for a large pulp mill. Before the year 2010, the IGCC technology is only expected to play a marginal role in the overall kraft industry. It might be interesting for some mills where the recovery boiler is the bottleneck in the production and an increase of the chemical recovery capacity would solve these limitations.

Environmental implications: The possible advantages of black liquor gasifiers are:

- Increased electric power generation through the use of combined cycle (gas turbine plus steam turbine). Theoretical balance calculations show that a black liquor based IGCC concept may reach a power efficiency of about 30 % calculated on the heat value of the black liquor. This may be compared with 12-13 % for the conventional recovery boiler. However, at the same time the overall efficiency (power + steam) would decrease by about 5 % to about 75 %. Thus, the production of process steam decreases. In a situation with a surplus of steam, this appears as an interesting option for an increased power production for export.
- Low emissions to the atmosphere
- Enabling pulp mills restricted in capacity, because of recovery boiler limitations, to increase production. The system is particularly beneficial in mills having a built-in but unused pulping capacity, and where fibre line modifications add more dry solids to the recovery system (e.g. low Kappa pulping, oxygen delignification, increased recycling of effluents from bleaching system)

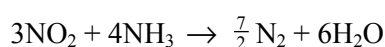
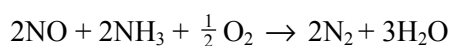
If the kraft industry should introduce the IGCC technology the industry should have the potential of producing about 1700 kWh/ADt as compared with the present level of about 800 kWh/ADt. Thus the potential increase corresponds to about 900 kWh/ADt. At the same time the heat generation would be reduced by about 4 GJ/ADt, which is more than a typical surplus in a modern kraft mill.

Economic considerations: No data available

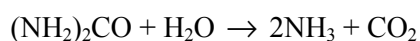
Literature: [SEPA-Report 4713-2,1997]

2.5.2 Use of SNCR on the recovery boiler

Description: The NO_xOUT-process is one of several existing processes which are utilising the principal of Selective Non Catalytic Reduction ("SNCR") to cut down NO_x emissions, which means the thermal reduction of nitrogen oxides by ammonia to nitrogen according to the following reaction equations:



If urea is used the following primary net reaction occurs in which ammonia is formed:



The reducing agent in a full-scale test in Sweden was a chemically enhanced water-based solution of urea. The process utilises the furnace as a 'chemical reactor' and does not require any additional equipment downstream of the boiler. The reaction normally occurs within a narrow temperature band around 1000 °C. When the temperature is too high more NO_x is produced. When the temperature is too low, ammonia is formed. In the NO_xOUT process, the temperature band is widened and chemical enhancers suppress the by-production of ammonia. Ammonia (NH₃-slip) produced by unwanted side-reactions and consumption of chemicals are the major parameters when optimising and running the NO_xOUT process.

Status of development: A Swedish kraft pulp company commissioned a full-scale test of the patented NO_xOUT-process in one of its existing recovery boilers. During the test period, the boiler operated between 95 and 105 % of maximum continuous rate. A number of injection ports for reduction chemicals was installed at several levels. The project has shown that thermal reduction of nitrogen oxides using the NO_xOUT process can successfully be applied to recovery boilers.

Environmental implications: Compared with other combustion processes the recovery boiler shows low emissions of nitrogen oxides. Typical nitrogen oxide levels are found to be between 50 and 80 mg NO_x/MJ. Despite of relative low flue gas NO_x concentrations the recovery boiler is the largest source of NO_x emissions in a kraft pulp mill (due to high gas flows). Thus, flue gas treatment measures applied to the recovery boiler would give the greatest effect on the total emissions. Furthermore, an increase of NO_x emissions from modern, high efficiency recovery boilers may be expected mainly caused by the demand for increased dry content of the black liquor and higher furnace loads.

Analysis assuming a stoichiometry of 1:1 indicates the following performance of the NO_xOUT-process:

- An average NO_x level without NO_xOUT of 80 mg/m³n (standardised m³, dry gas at 3% O₂)
- An average NO_x level with NO_xOUT of about 55 mg/m³n (about 30% reduction)
- A slight increase of ammonia (slip) in the order of 3-4 mg/m³n (stoichiometry 1:1)

Depending on stoichiometry applied up to 50% NO_x-reduction (stoichiometry 2:1) is achievable despite the low NO_x level without treatment (but then linked to an increase of ammonia-slip). No disturbances or other negative effects on the operation of the recovery boiler were observed during the full-scale test runs. No negative effect in the chemical recovery cycle was observed. The total operating costs is relatively low. The alteration required on the recovery boiler may be done during a normal maintenance stop.

The use of urea in SNCR-processes can eventually cause corrosion problems due to the possible formation of corrosive by-products. For security reasons it has therefore in Sweden been recommended to avoid the use of urea-injection in recovery boilers. Because of that the Swedish kraft Pulp Company has performed several new trials with the use of NH₃ (gaseous or liquid) instead of urea resulting in NO_x-reductions between 20 - 50 % (stoichiometry from 1:1 to 2:1) with varying NH₃-slips. A NO_x-reduction of about 30 % seems to be reachable with acceptable low NH₃-slip. The company is planning a long-time trial before come to decision about a final installation or not. The investment costs for installation at recovery boilers are today much lower compared to the below figures and are estimated to be below 1 MEuros (with the use of liquid NH₃).

Economic considerations: The investment costs for a complete installation of the NO_xOUT process at a recovery boiler similar to that in the tested mill (black liquor load: 1600 t dry solids/day) amount to about 2.2 - 2.8 MEuros. Operating costs for the system include chemical supply (urea and enhancers), electricity, heat used to condensate injected water and labour. Of these, the most influencing factor is the price of urea. It is difficult to give a meaningful estimate

of the operating costs due to the variation in world-wide prices. However, during the test period in Sweden the urea costs about 154 Euros/t, the total operating cost calculated for the given recovery boiler was in the range of 1 to 1.4 Euros/kg reduced NOx.

Literature: [Lövblad, 1991]

2.5.3 Removal of chelating agents by modest alkaline biological treatment or by use of kidneys

Description: The chelating agents ethylenediaminetetraacetic acid (EDTA) and diethylenetriaminepentaacetic acid (DTPA) has been used for many years in the pulp and paper industry. They are applied because of good sequestering properties, i.e. their ability to suppress the activity of the dissolved transition metal ions without precipitation (in the following the shortage "Q" will be used for both of them). These metal ions are able to catalyse the decomposition of the bleaching agent hydrogen peroxide into radicals. Totally chlorine free (TCF) bleaching is currently only possible by treating the pulp with Q before the hydrogen peroxide stage. Increased concentrations of Q are therefore found in wastewaters generated from the production of TCF pulps. In wastewater analyses of a TCF mill producing market kraft pulp 25-40% of charged Q has been identified. This corresponds to Q contents of 10 and 15 mg Q/l in the effluent at a charge of 2 kg Q per tonne of pulp. Although EDTA is non-toxic to mammals at environmental concentrations, there is some concern about the potential of EDTA to remobilize toxic heavy metals out of sediments and the difficulties to biodegrade this substance. In the following only experiences from the use and fate of EDTA are discussed.

Option 1: Biological treatment with and without activated sludge systems commonly used in the pulp and paper industry is successful in reducing COD and BOD of the effluents. However, the system can not significantly reduce EDTA of the mill effluent. It has been found that EDTA is resistant to aerobic biodegradation in the activated sludge plant operated under "normal" conditions (pH 7). Furthermore, EDTA does not adsorb onto sludge so that EDTA passes through treatment plants without notable degradation. A recent study [Virtapohja, 1997] investigated the biodegradation of EDTA in a full-scale activated sludge plant under modest alkaline conditions (pH 8 - 9). An average EDTA reduction of about 50% (about 10% at pH 7) was obtained.

Option 2: Another technical option to reduce the consumption and discharge of Q used before the peroxide stages in TCF mills is the use of kidneys. One Swedish pulp mill will put in operation a kidney for recovery of EDTA from Q-stage effluents at the end of 1998. There, it is expected that the consumption of EDTA can be reduced by 65% with TCF. In the given Swedish kraft pulp mill it is planned to apply the Kemira NetFloc system which has been demonstrated to be a very efficient tool to remove problematic substances like extractives and metals from pulp and paper filtrates.

In the Netfloc system [Rampotas, 1996] the pH is increased and carbonate dosed for precipitation. Metals bound to EDTA (or DTPA) are released and precipitated. A high molecular weight polyethylene oxide (PEO) for flocculation is added to the selected filtrate. In the actual application, a water solution of the PEO is made in a polymer preparation unit and the PEO solution is dosed into a filtrate pipe. The flocculation reaction between PEO and extractives is fast and it is completed before the filtrate leaves the pipe. It has been discovered recently that the PEO-resin flocs collect any undissolved substances in the filtrate. This means that precipitated metal salts (e.g. hydroxides, sulphates) will end up in the resin sludge. The final operation includes separation of resin sludge from the filtrate, which is usually done by mechanical means as e.g. a flotation unit. The treated filtrate with the recovered Q is reused in the process and the resin sludge may be either pumped to the green liquor sludge filter or burned

in the bark boiler directly or after de-watering in a press. The principle of application this kidney is shown in Figure 2.16.

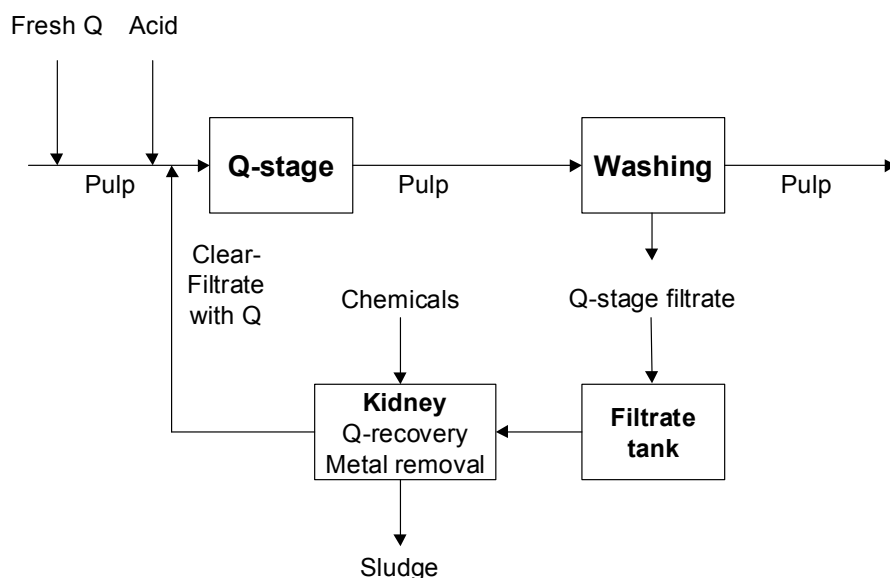


Figure 2.16: Recovery of chelating agents in bleach plant filtrates by use of a kidney

By reducing the amount of metals entering the bleach plant, a smaller charge of chelating agents is needed prior to the peroxide stage. Additionally the recovery of Q itself reduces the consumption needed. Expected reduction rates are over 80% for calcium, manganese and iron. The recovery of Q results in a lower charge of fresh Q. Thus, lower levels of metal complexes will be found in the effluent.

Status of development: The biodegradation of EDTA in activated sludge plants under alkaline condition looks promising. The treatability of EDTA containing wastewaters from bleaching plants in activated sludge plants under moderate alkaline conditions has been confirmed by investigations both in laboratory-scale experiments [C.G. van Ginkel, 1997 a+b] and full-scale activated sludge plants. Detailed information about EDTA complexes and the influence of sludge retention time, temperature etc. is probably required in order to improve the assessment of EDTA removal from paper mill wastewater (Fe(III)EDTA complexes are well-known as recalcitrant, Mn and Ca salts of EDTA are more readily biodegradable). A low sludge retention time and the Fe(III)EDTA complex may account for only partial removal. On the other hand, photodegradation of the FeEDTA complex has been reported [Kari, 1996] i.e. FeEDTA is the only EDTA complex that may be photochemically transformed in surface waters. In continuously sunny areas FeEDTA will probably degraded in the effluent receiving waters.

Recently, the first full-scale application of the Kemira NetFloc system for recovery of EDTA from bleach plant effluents has been put into operation. Operational experiences are not available.

Environmental implications: In a full-scale activated sludge plant under modest alkaline conditions (pH 8 - 9) an average EDTA reduction of about 50% (about 10% at pH 7) was obtained. The results also indicated that the pH adjustment to 8 - 9 with calcium oxide (dosage about 90 mg CaO/l) did not interfere with the normal operation of the activated sludge plant. Concentrations of EDTA in the samples with accelerated biodegradation remained relatively constant (2 - 4 ppm).

Biodegradation of EDTA increases the release of nitrogen. Enhanced degradation of EDTA in activated sludge plants is therefore of clear benefit, not only for environmental reasons but also as a means to increase the level of nutrient nitrogen, which usually is deficient in wastewaters from pulp and paper mills.

Economic considerations: Additional costs for the biodegradation of EDTA in activated sludge plants under alkaline conditions are primarily caused by the CaO consumption.

For the application of the Kemira NetFloc system no data on economics are available.

Literature:

[Virtapohja, 1997], [Rampotas, 1996], [van Ginkel, 1997a], [van Ginkel, 1997b], [Kari, 1996]

2.5.4 Increased system closure combined with the use of kidneys

Description: Since it is mainly the bleach plant which constitutes the open part of the mill, efforts have been made to minimise the amount of lignin that goes to the final bleaching. The integration of filtrates to the recovery systems remains a problem area. The filtrates have to be recycled within the bleach plant in order to reduce the filtrate volume. This leads to an accumulation of dissolved substances and non-process elements (NPE) in the bleaching stages with associated problems like high chemical consumption and deposition of solids. Kidneys for purging the system of such substances are still needed, both in the bleach plant and in the chemical recovery.

In an ongoing project of the European Commission [Tomani, 1997] it is the intention to continue the research into different possibilities of reusing bleach plant filtrates. With reference to Figure 2.17 the following items will be investigated.

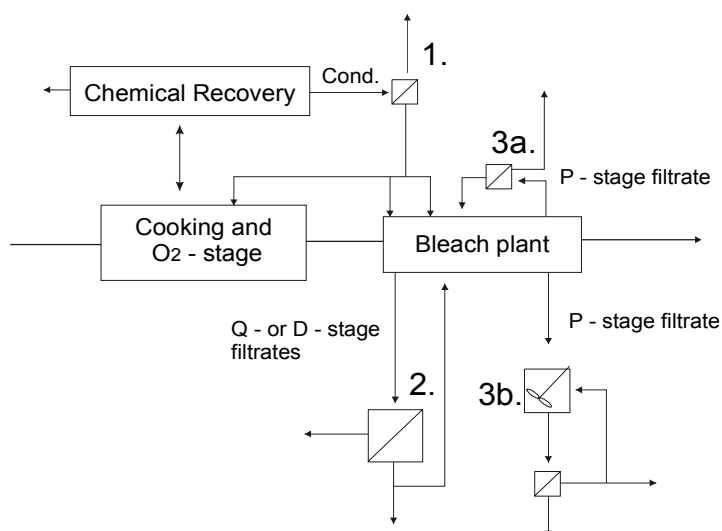


Figure 2.17: Kidneys under development in a current EU-project on separation methods for closed loop technology in bleached kraft pulp production

1. The re-use of condensates from black liquor evaporation either as wash water in bleaching or as other process water. It is essential that this condensate is utilised if low water usage is to be achieved. A major problem is to eliminate the odour due to minor impurities.

2. Acid (Q- or D-stage filtrates) and neutral bleach plant filtrates are the main sources of non-process elements (NPEs) such as Al, Si, P, Ca, Ba, Mn etc. which have to be purged. The objective is to develop a crystallisation/precipitation step together with a separate evaporation unit and to determine the best use of reclaimed water
3. Concerning alkaline filtrates, the objective is
 - 3a. to develop suitable mineral membranes for nanofiltration that can be used to reduce the amounts of both organic and inorganic substances from hydrogen peroxide bleaching stage. It is also intended
 - 3b. to look into the possibility of combining membrane filtration with biodegradation for the destruction of organic compounds

Finally, process simulation techniques will be used to determine the consequences for the water, chemical and in some respects also the energy balances, when the proposed separation methods are integrated into the process. The risk for deposits will also be assessed.

A recently started Swedish comprehensive research project "The potential of pulp and paper production as an energy-producing and truly ecocyclic process" (short name: "The ecocyclic pulp mill") [Ecocyclic pulp mill, 1999] is aiming at a proposal for environmentally optimal basic solutions for the increased closure of kraft pulping processes, making possible efficient usage of the energy potential of biomass. The reasons for closing the liquid flows in the pulp and paper mill is not to create a 'completely closed' mill, but rather

- To virtually eliminate the discharges of organic and inorganic material to water
- To facilitate the separation of non-process elements from recirculating streams
- To minimise the dilution of energy released within the system

The main idea of the project is to reduce the heat losses that can theoretically be converted into useful energy. Although it is now possible for a modern bleached kraft pulp mill to be totally independent of external energy sources large amounts of low grade heat still leave the system through emissions and discharges to air and water. The conversion of this low grade heat offers huge future energy potential and is the focus of this program. Increased closure and pressurisation would facilitate the energy generation of a sufficiently high quality for external use. Then, it may be possible to turn the kraft mill into an important **net** energy supplier. Several opportunities for converting waste heat into useful energy exist, including lower water usage. For example, a reduction in water consumption by closure from 40 m³ per tonne of pulp to less than 10 m³ per tonne of pulp would theoretically release approximately 15 GJ per tonne of pulp for external use. It should be pointed out that there is currently no technology available that could facilitate the utilisation of more than a fraction of this potential. Today, when the aqueous discharges from pulp are lowered, excess heat has to be removed through cooling towers, as no other economic alternatives are available. The challenge is to upgrade waste heat to a valuable resource.

The research program comprises among others projects on "process chemistry" and "separation processes". This projects focus on the way in which substances which disrupt the process and which are concentrated in the event of greater closure, should be handled to avoid problems such as scaling, chemical decomposition, increased energy consumption and poorer product quality. The use of kidneys for the removal of these process substances is therefore of great interest. Membrane techniques are displaying promising potential for separating harmful organic and inorganic substances from process streams, thus facilitating increased system closure. Membrane technology may therefore play a key role in a future system. Another possibility may be to remove non-process elements before the digester.

According to other results obtained of the work carried out so far one good example of more efficient energy use is pre-evaporation of bleach plant filtrates, where the heat is taken from

waste heat from black liquor evaporation. Pre-evaporation of bleach plant filtrates may be combined with membrane separation, resulting in less energy demand.

Pressurised black liquor gasification (see Section 2.5.1) has the potential to increase electricity production by about 100% compared to conventional recovery boiler. However, the gasification process would be less complicated and less capital demanding if the cooking process was carried out without the use of sulphur. Sulphur-free cooking is therefore an interesting area for the future.

Status of development: There are various research projects investigating different aspects of the closed cycle mill concept.

In the concept towards a closed cycle mill for bleached pulp, areas can be found where new technology has been introduced which facilitates this goal, but also areas where more development is needed. Total system closure during pulp production - that theoretically enables the realisation of an effluent-free pulp mill - is not yet possible because the non-process elements which enter the process mostly with the wood, but also with the chemicals and the process water, accumulate in the process and must be purged out of the system.

Environmental implications: The developments towards closed cycle mills are aiming at eliminating virtually the discharges of organic and inorganic material to water and to minimise the dilution of energy released within the system.

Economic considerations: No data available

Literature:

[Tomani, 1997], [Ecocyclic pulp mill, 1999]

2.5.5 Organosolv pulping

Description: Within the last decade many research efforts aimed at the development of new pulping processes. There are several unconventional cooking procedures under development, which show considerable promise. The main objectives of these new processes are:

1. Reduced pollution (low water consumption, TCF-pulp, sulphur free)
2. Simpler cooking process and far-reaching closed up recovery of cooking chemicals
3. Improved use of the raw material wood (high yield, alternative use of wood components etc.)
4. Application to all wood species and achieving good pulp properties
5. Lower investment costs

The new pulping processes are based on organic solvents (Organosolv pulping). For some of these processes it can be expected that the gaseous emissions of sulphur dioxide and odorous compounds are reduced because of the use of sulphur-free technology. All new pulping processes intend to achieve a closed mill by direct recovery of the solvent after the cooking step by distillation and burning of the dissolved wood components or its alternative use as chemical feedstock for different products. Such a concept intends to solve the ecological problems of actual pulping processes as well as improves the economy of pulping.

In Table 2.47 those new pulping processes under development are selected which show a certain potential for industrial application and which have reached at least pilot plant scale [Ministry of Food, Agriculture and Forestry, 1997]. The systems are compared in some different respects. Main process parameters and expected environmental impacts of the Organosolv processes are compiled. For comparison the tables include also some data on modified kraft pulping.

Pulping process	Raw materials	Cooking chemicals	Cooking process parameters	Kappa before bleaching
ASAM	Softwood Hardwood Annual plants	Sodium sulphite (alkaline) alcohol	175- 185°C 11 - 14 bar	13 - 20
FORMACELL	Softwood Hardwood Annual plants	Acetic acid Formic acid	160 - 180°C	2 - 10
MILOX	Hardwood Annual plants	Formic acid Hydrogen peroxide	60 - 80/ 90 - 110°C	30 - 35
Modified. SULPHATE	Softwood Hardwood Annual plants	Sodium hydroxide Sodium sulphide	155 - 175°C 8 bar	10 - 20

Table 2.47: Comparison of Organosolv pulping processes with modified kraft pulping
Raw materials, cooking chemicals and conditions, achievable kappa after cooking [Ministry of Food, Agriculture and Forestry, 1997]

The new pulping processes can be classified in organic acid based, alcohol/water based and mixed processes which are using inorganic and organic pulping chemicals.

Status of development: A recently published study on market chances of different Organosolv pulping processes in Germany [Ministry of Food, Agriculture and Forestry, 1997] concluded that ASAM and Milox process is ripe for production but this is not confirmed on full-scale experiences till now. Formacell has not yet reached the stage that a full-scale mill could be built.

Since none of the proposed Organosolv processes has been implemented successfully in full scale (a full-scale Organocell plant in Kehlheim, Germany, had to be shut down after arising problems could not be solved) it is too early to make a conclusive judgement on the alternatives.

Environmental implications: For the new pulping processes information on the environmental impact is fragmentary and is mainly derived from pilot-scale. Whether the advantages can all be achieved in full-scale plants is to a certain extent doubtful or at least not proven.

Economic considerations: In Organosolv pulping, much more costly organic solvents replace water. In most processes the liquor ratio is increased and in addition the solvents are used in pulp washing. The economy of these processes depends largely on the recovery rate of the solvent, which should exceed 99 %. A requirement, which in the development of many processes has been underestimated, is the availability of reliable and proven technology. Pulp mills are highly capital intensive and the risk of a new process implementation has to be minimised.

Literature: [Ministry of Food, Agriculture and Forestry, 1997], [Young, 1998]

3 THE SULPHITE PULPING PROCESS

The production of sulphite pulps is much smaller than the production of kraft pulps and sulphite pulps are more used in special purposes in papermaking rather than being an alternative market pulp grade for kraft pulps. Very little unbleached sulphite pulp is made and the yield is a little higher which can be attributed to the lower pH in the cooking.

The main reasons of more limited applicability of sulphite pulps are as follows:

- it is not possible to use pine as raw material in the acid cooking process which limits the raw material base of sulphite pulping
- the strength properties of the pulps as measured by the papermaker are generally not as good as those of kraft pulp, although for some speciality pulps these properties may be equally good or even better
- environmental problems have in many cases been more expensive to solve and this has decreased the cost-competitiveness compared to the kraft pulping (e.g. pH-regulation of evaporation condensates, minimisation of sulphur emissions and removal of organic compounds).

The sulphite process is characterised by its high flexibility compared to the kraft process, which is a very uniform method, which can be carried out only with highly alkaline cooking liquor. In principle, the entire pH range can be used for sulphite pulping by changing the dosage and composition of the chemicals. Thus, the use of sulphite pulping permits the production of many different types and qualities of pulps for a broad range of applications. The sulphite process can be distinguished according to the pH adjusted into different types of pulping the main of which realised in Europe are compiled in Table 3.1.

Process	pH	Base	Active reagent	Cooking temperature °C	Pulp yield %	Applications
Acid (bi)sulphite	1-2	Ca ²⁺ , Mg ²⁺ , Na ⁺	SO ₂ *H ₂ O, H ⁺ , HSO ₃ ⁻	125-143	40-50	Dissolving pulp, tissue, printing paper, special paper
Bisulphite (Magnefite)	3-5	Mg ²⁺ , Na ⁺	HSO ₃ ⁻ , H ⁺	150-170	50-65	printing paper, tissue
Neutral sulphite (NSSC) ²	5-7	Na ⁺ , NH ₄ ⁺	HSO ₃ ⁻ , SO ₃ ²⁻	160-180	75-90	Corrugated medium, semi-chemical pulp
Alkaline sulphite	9-13.5	Na ⁺	SO ₃ ²⁻ , OH ⁻	160-180	45-60	Kraft-type pulp

Table 3.1: Main sulphite pulping processes in Europe
According to [Uhlmann, 1991]

The sulphite cooking process is based on the use of aqueous sulphur dioxide (SO₂) and a base - calcium, sodium, magnesium or ammonium. The specific base used will impact upon the options available within the process in respect of chemical and energy recovery system and water use. Today, the use of the relatively cheap calcium base is outdated because the cooking chemicals cannot be recovered. In Europe there is still one mill (FR) using ammonium as a base. The dominating sulphite pulping process in Europe is the magnesium sulphite pulping

² Neutral Sulphite Semi Chemical (NSSC) is the most common type of semichemical pulp which is produced by a combination of chemical and mechanical pulping. Wood can be used without prior debarking. In the process wood chips are partially digested to weaken the bonds between fibres and lignin. The chips are then mechanically treated in a refiner. Some stand alone plants in Europe have no recovery of chemicals while some mills practice "cross-recovery" in which spent liquor is burnt in an adjacent Kraft pulp mill recovery boiler.

with some mills using sodium as base. Both magnesium and sodium bases allow chemical recovery. The lignosulphonates generated in the cooking liquor can be used as a raw material for producing different chemical products. Because of its importance in terms of capacity and numbers of mills running in Europe in the following the focus is on magnesium sulphite pulping.

3.1 Applied processes and techniques

Sulphite pulping consists of three main entities: the fibre line, recovery of chemicals and energy (excluding calcium sulphite pulping where recovery is not possible but where the spent cooking liquor can be evaporated and the components used for other purposes) and external wastewater treatment. As in kraft pulping some auxiliary systems like reject handling, manufacturing of bleaching chemicals and auxiliary power generation are connected to the main departments.

In many respects the kraft and sulphite processes have similarities not least regarding the possibilities of taking different internal and external measures to reduce emissions to environment. Due to this number of similarities only some process steps of sulphite pulping technology are discussed in detail. For process steps of which the principals are same or which are even identical to kraft pulping it is referred to the corresponding paragraphs. This is true for

- Wood handling (see Section 2.1.1 to - 2.1.3)
- Washing and screening (Section 2.1.5)
- Bleached stock screening (Section 2.1.8)
- Drying (Section 2.1.9, only for market pulp).

For these chapters only some remarks are given to what extent sulphite pulping differs from the situation described for kraft pulping. Apart from that, we focus on differences between kraft and sulphite pulping and on *magnesium* sulphite pulping as this is the main sulphite process currently practising within Europe.

The major differences between the two chemical pulping processes from an environmental point-of-view are to be found in the chemistry of the cooking process, the chemical recovery system and less bleaching sequences required because of better initial brightness of sulphite pulp. Furthermore, the sulphite process does enjoy less of an inherent odour problem compared to the kraft process, which tends to be surrounded by unpleasant odours in the neighbourhood of the mill. These differences result in different emission ranges and some differences concerning the abatement techniques applied.

The main unit processes of manufacturing of magnesium sulphite pulp are shown in Figure 3.1.

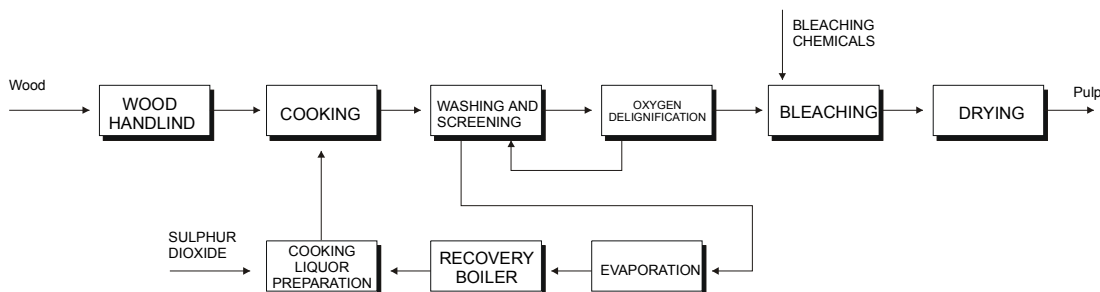


Figure 3.1: Main unit processes of manufacturing of magnesium sulphite pulp [CEPI, 1997b]

A sulphite pulp mill includes usually the production unit's wood room, digester house, wash room, screening room and bleach plant. Raw-water treatment, bleaching chemicals preparation, drying machine (optional), recovery system and a boiler house.

3.1.1 Woodhandling

The wood raw material consists usually of roundwood and sawmill chips. Debarking is needed when wood is delivered to the mill as unbarked roundwood. A certain amount of wood can be delivered as woodchips from sawmills. In debarking of pulpwood debarking takes place in drums where the contact between rolling logs and water debarks them. After debarking wood chips are produced from roundwood logs and they are screened and stored in big chip piles prior to feeding in the next process stage. Sawmill and other off-site chips require only screening and storage in the woodhandling.

Bark and screening rejects from chipping and chip screening are excess solid wastes generated in this process stage. Most of them are usually collected, dewatered and incinerated for energy recovery in a special bark and wood waste boiler (see 4.3.11).

3.1.2 Cooking and delignification of unbleached pulp

In the manufacturing of conventional unbleached pulp the lignin is extracted from the wood using a concentrated cooking liquor with magnesium sulphite and magnesium bisulphite as active constituents. In the cooking stage the wood chips and the liquors are charged into a batch digester where the cook is carried out in elevated temperature and pressure. When a desired residual lignin content (measured as kappa number) is reached, the contents are discharged to a blow tank and the cooking cycle is repeated. Batch digester plant consists of a series of batch pressure vessels, which are operated according to a certain cooking program. Cooking can also be carried out in a continuous digester, but this has been practised with sulphite pulping much less than with kraft pulping (the principles are same and it is referred to the Section 2.1.4). In the magnefite process (see 3.1.7) the delignification of softwood (spruce) can be brought down to a kappa number of 21-23 in order to maintain acceptable pulp strength properties. In acid sulphite cooking common kappa numbers are between 14-22 for softwood and 10-20 for hardwood. The kappa number can be further decreased before bleaching by an oxygen stage. Two stage sulphite cooking can bring the kappa number down to less than 10. Cooking can be extended further to produce a speciality pulp for dissolving uses but at the expense of yield.

From the digesters, the pulp is blown to blow tanks. From these tanks, the pulp is then pumped to the wash room.

3.1.3 Screening and washing of unbleached pulp

After the cooking the pulp is washed in drum washers or screw presses and screened with pressure screens and centricleaners. The objective of screening is to separate knots and fibre bundles from the main pulp stream with a series of vibrating equipment, filtration through pressure screens and centrifugal separation of fibres and other particles with different specific weights (see 2.1.5). The cooking liquor with its content of dissolved wood substance is separated from the pulp, and so-called spent liquor or weak liquor is obtained. Coarse reject and other reject from the screening are normally dewatered and burned in the boiler house. After screening, the pulp is bleached.

3.1.4 Oxygen delignification/bleaching

The distinction made here between delignification and bleaching is that effluents from a bleaching stage cannot be recirculated into the chemicals recovery system, whereas from delignification this is possible. Consequently oxygen can be used as delignification and bleaching chemical in the same mill.

Oxygen delignification for sulphite pulping is more rare than in kraft pulping where it is widely and increasingly used. However, there are a number of sulphite mills in Europe using this technique for further delignification thereby reducing the kappa number by about 10 units. This is mainly due to the fact that also without oxygen delignification only a short bleaching sequence is necessary to achieve full brightness of pulps. Furthermore for oxygen delignification a pressurised process is necessary and a base is needed to increase pH up to alkaline conditions. The chemical base used has to be compatible with the cooking chemicals i.e. for magnesium bisulphite MgO has to be used. Only in that case the organic material that is dissolved during oxygen delignification can be recovered and led to the chemical recovery system without major changes in the process. One mill in Germany has applied this technique thereby losing some points of brightness.

It has however been shown to be possible to concentrate the effluent with ultra-filtration and burn the concentrate in the bark boiler. Measured as COD the reduction is about 50% of the discharges of organic substances from the oxygen stage.

Finally most sulphite pulp mills are producing TCF pulp.

3.1.5 Bleaching, screening and drying

Bleaching at sulphite pulp mills within Europe is carried out without the use of molecular chlorine and in many sulphite pulp mills chlorine dioxide is no longer used neither as bleaching chemical i.e. pulp manufactured is thus TCF-pulp (Totally Chlorine Free). Usually oxygen, sodium hydroxide and hydrogen peroxide are used as bleaching chemicals. EDTA is added as complex former (0.5 – 2 kg/t). The bleaching chemicals used are usually bought from external producers.

The bleaching of pulp increases primarily the brightness of pulp and secondarily it also removes non-fibrous particles and extractives from the pulp. Like in kraft pulping bleaching of sulphite pulp is based on lignin removing methods and it can be considered as continued and selective lignin removal stage.

The lignin removal by bleaching is carried out in a sequence of one or two bleaching stages where oxygen and peroxide is added. In a two stage bleaching sequence in the first place the pulp is heated up to 60-80°C and sodium hydroxide, oxygen and/or peroxide is added. The first bleaching stage reduces the residual lignin by 45-55%. The bleached pulp is then pumped to washing filters and sometimes lead to a twin wire press in order to reduce the carry-over of undesirable substances from the first bleaching stage and to further de-water the pulp. In several European sulphite mills (Ahlfeld, Ehingen, Stockstadt, DE; Gratkorn, AU) the second peroxide bleaching stage (EP) is carried out as high consistency bleaching (symbolic shorthand: EP(HC) = 35 – 40% DS). Advantages of HC bleaching are energy (steam) savings by high pulp density, lower COD emissions by soft bleaching conditions, low pulp losses in the bleaching stage and less consumption of bleaching chemicals. After the second bleaching stage the pulp is diluted with water and another washing takes place. In the sulphite process, the specific process heat and power demand for TCF bleaching are lower than those needed for ECF bleaching.

Major bleaching sequences applied in European sulphite pulp mills are compiled in Table 3.2.

Cooking techniques	kappa	Bleaching sequences	COD [kg/t]	Example mills
Magnefite process	21-23	EOP-Q-EP-EP (HC)	90-115	Gratkorn, AU
Magnefite process	21-23	EOP-Q-EP-EP	100-120	Mill 2, SE
Sulphite process	14-16	EOP-EP (HC)	50-60	Mill 3, DE
Sulphite process	12-15	EOP-Q-EP (HC)	45-60	Mill4, DE
Sulphite process	11-13	EOP-Q-EP-EP	35-45	Mill 5, AU
Notes: 1) The data are derived from personel communication. It can not be guaranteed that they are all reflecting the last developments.				

Table 3.2: Examples for different sequences for bleaching used in European sulphite pulp mills and the corresponding discharge of organic substances from the bleach plant measured as COD

After bleaching there is generally a final screening of pulp and the reject is burned in the boiler house. The pulp to be sold externally (if the pulp is not used for manufacturing of paper at the same mill site) is dried and the remaining pulp is pumped to the paper mill for the manufacture of different paper grades (fine paper, tissue etc.) paper. Sulphite pulp mills are mainly integrated mills manufacturing paper at the same site.

3.1.6 Chemicals and Energy Recovery System

The cooking chemical recovery includes evaporation of the spent liquor to concentrated liquor, combustion of the concentrated liquor and preparation of new cooking acid from recovered chemicals. The degree of liquor recovery is at least 97%.

The recovery of chemicals of the unit processes for unbleached pulp consists typically of the following major principles:

- Counter current washing and evaporation of weak cooking liquor
- Incineration of the concentrated liquors (bio-fuel) in a recovery boiler where substantial amount of energy can be produced for steam and power generation of the pulp mill.
- During the combustion, solid magnesium oxide (ash) and gaseous sulphur dioxide are formed. The magnesium oxide is separated from the flue gases in electrofilters and converted to magnesium hydroxide by dissolving in water.
- This slurry is used to absorb the sulphur dioxide and trioxide from the flue gases from the recovery boiler and the collected gases from digesters, washers and evaporators by use of multi-stage venturi scrubbers. The liquid from the flue gas purification is clarified (sedimentation or filtration) and reinforced with sulphur dioxide from either combustion of elemental sulphur in a sulphur burner or addition of liquid sulphur dioxide. The freshly formed cooking acid (magnesium bisulphite) is pumped into the digester house after separation of soot particles and other undissolved impurities.

An overview of the circuits of chemicals is presented in Figure 3.2 [BMU Austria, 1995] illustrating the main process steps and their functions.

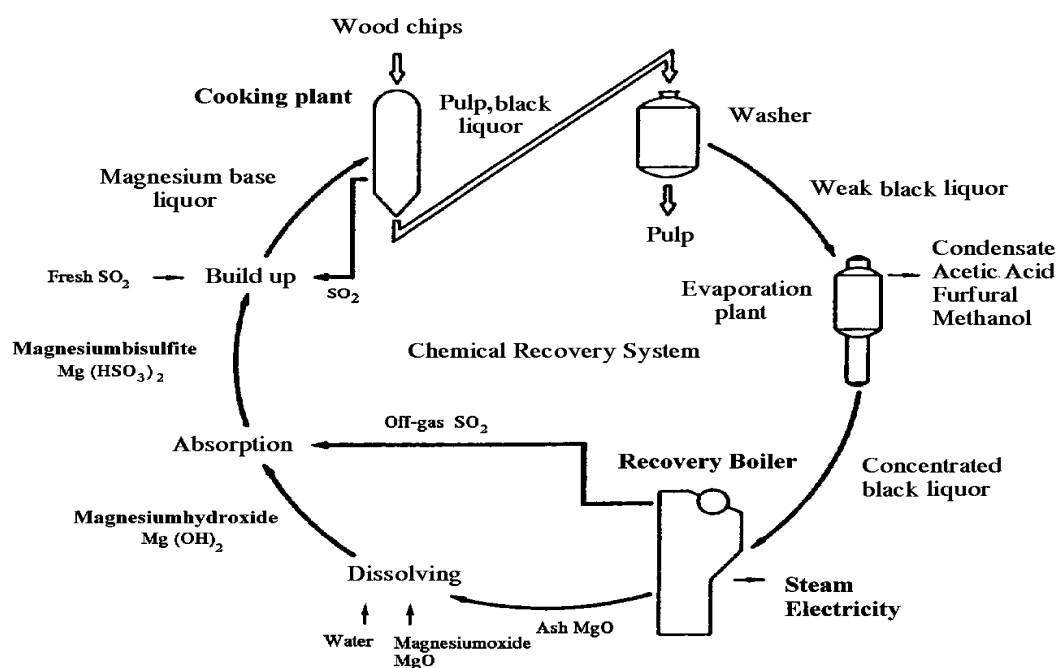


Figure 3.2: Recovery cycles for a sulphite mill

Magnesium based mills have difficulty in recycling water from associated stages where sodium hydroxide is used to control the pH. A key issue for sulphite mills is the separation of effluents containing different chemical bases. For instance, sodium hydroxide may be needed to achieve the required pH conditions in some brightening stages and measures. In that case it is not possible to lead the bleach plant effluents back to the recovery island because sodium has to be prevented from contaminating a magnesium based cooking process.

Besides the recovery of cooking chemicals the recovery boiler(s) produce steam. Often sulphite pulp mills operate auxiliary boilers burning bark, oil or other fuels. In these boilers, knots, rejects and sludge from the effluent purification may also be burned. The steam from the boilers is lead to counter-pressure turbines where electrical power is produced.

3.1.7 Magnefite process

The magnefite process is using a higher pH range, pH 3 – 5, than the acid sulphite process that is operated at a pH value of 1 – 2. This result in softer cooking conditions with increased pulp strength properties and slightly higher yield compared to the acid sulphite process. In Europe, for both process the predominantly base that is used is magnesium. There are two major technical differences to consider. In the magnefite process in the white liquor preparation a pH value of 4 can be achieved without SO₂-reinforcement measures. The operation of a pressure storage tank for sulphur dioxid is therefore not necessary. The SO₂ in the white liquor occurs in the bisulphite form. Then the other steps of pulp production are similar to the acid sulphite process. The kappa numbers of unbleached pulp after magnefite cooking are higher than after

acid cooking. With the magnefite process kappa numbers from 21 to 26 for paper pulp are achievable. Against that kappa numbers of 12 to 16 can be reached with the acid sulphite process (e.g. Hallein and Neusiedler, AU; Ahlfeld, Stockstadt and Ehingen, DE). As a consequence, the pulp bleachability of magnefite pulp is not as good as with acid sulphite pulp. Longer bleaching sequences are therefore necessary in order to achieve high brightness. This causes slightly higher loads of COD and BOD in the effluents from the bleaching stages. The magnefite process is operated in four paper pulp mills in Europe (Nymölla and Utansjö, SE; until 1999 Hundsfos, NO; Gratkorn, AU).

3.1.8 Neutral Sulphite Semi-Chemical Pulp

The most common type of semi-chemical pulp is the Neutral-Sulphite Semi Chemical (NSSC) pulp. The process is a combination of chemical and mechanical pulping and has a high yield. The pulp is mainly used to produce fluting, the inner part of corrugated board. The yield is about 80% for fluting. Wood can be used without prior debarking. In the process wood chips are partially digested to weaken the bonds between fibres. The chips are then mechanically treated in a refiner. Some of the stand alone plants have no chemical recovery. Cross recovery is used by very few mills in Europe.

3.1.9 Dissolving Sulphite Pulp

In Europe, there are very few companies manufacturing dissolving sulphite pulp. In principle, the process is very similar to the manufacturing of sulphite pulp used for paper manufacturing. The same chemicals are used as in the common magnesium-bisulfite process. Therefore, the chemicals and energy recovery system is very similar. The major differences can be found in cooking and bleaching. The aim of cooking in dissolving sulphite pulp manufacturing is to achieve a low viscosity i.e. a low length of the molecule chain of the cellulose. This is adjusted in the cooking plant. The similarities and differences are discussed in the following by use of an example.

In one of the European dissolving sulphite pulp mills (Austria, manufacturing of viscose fibres) the delignification of hardwood (beech) is brought down to a kappa number of 4 – 7 before bleaching. There are no effluents before the pulp enters the bleach plant. The bleaching sequence of the plant is carried out in three stages: OPE – Z – P (TCF bleaching).

In the first bleaching stage consisting of oxygen and peroxide delignification and alkaline extraction the kappa number is decreased to 2 and a α -cellulose content of 91% is achieved. Around 50 kg NaOH/t of pulp (oven dry) is used. The releases of this bleaching stage (COD load ca. 85 kg/t) are treated in an evaporation plant. The concentrates are incinerated in a so-called soda boiler. This eliminates the bulk of the pollution load from the bleach plant.

The second bleaching stage is using ozone as bleaching agent. The last bleaching stage is using peroxide which brings the kappa down to 0,5 (>90% ISO, α -cellulose content > 91%). The COD load from the second and third bleaching stage is 15 kg COD/t before treatment and is purified in a biological wastewater treatment (reduction rate > 90%).

Besides the bleach plant, the major source of water pollution is the condensates from the evaporation plant. The pulp mill of our example is extracting acetic acid and furfural as valuable products from the evaporator condensates thus reducing the COD load of the condensates by 75%. The remaining pollution load is 30 kg COD/t which is treated in the biological wastewater treatment (reduction rate > 90%) together with the other partial wastewater streams.

The initial pollution load of the wastewater from dissolving sulphite pulp mills depends on the amount of so-called α -cellulose to be achieved and on the applied internal measures for reduction of emissions. Higher α -cellulose content corresponds to higher product qualities. Higher α -cellulose content of the pulp means a higher dosage of NaOH. This result in lower

yields and higher pollution loads in water. For instance, the use of 90-100 kg NaOH/t of pulp to produce pulp with α -cellulose content of 92.5% would double the organic load in the effluents as mentioned above (and reduce the yield by 5%).

The manufacturing of dissolving sulphite pulp is a combination of delignification and finishing.

3.2 Present Consumption/Emission Level

3.2.1 Overview of input/output

An overview of the raw material and energy input as well as the output of products, by-products and the major releases (emissions, waste etc.) of the production of sulphite pulp is presented in Figure 3.3.

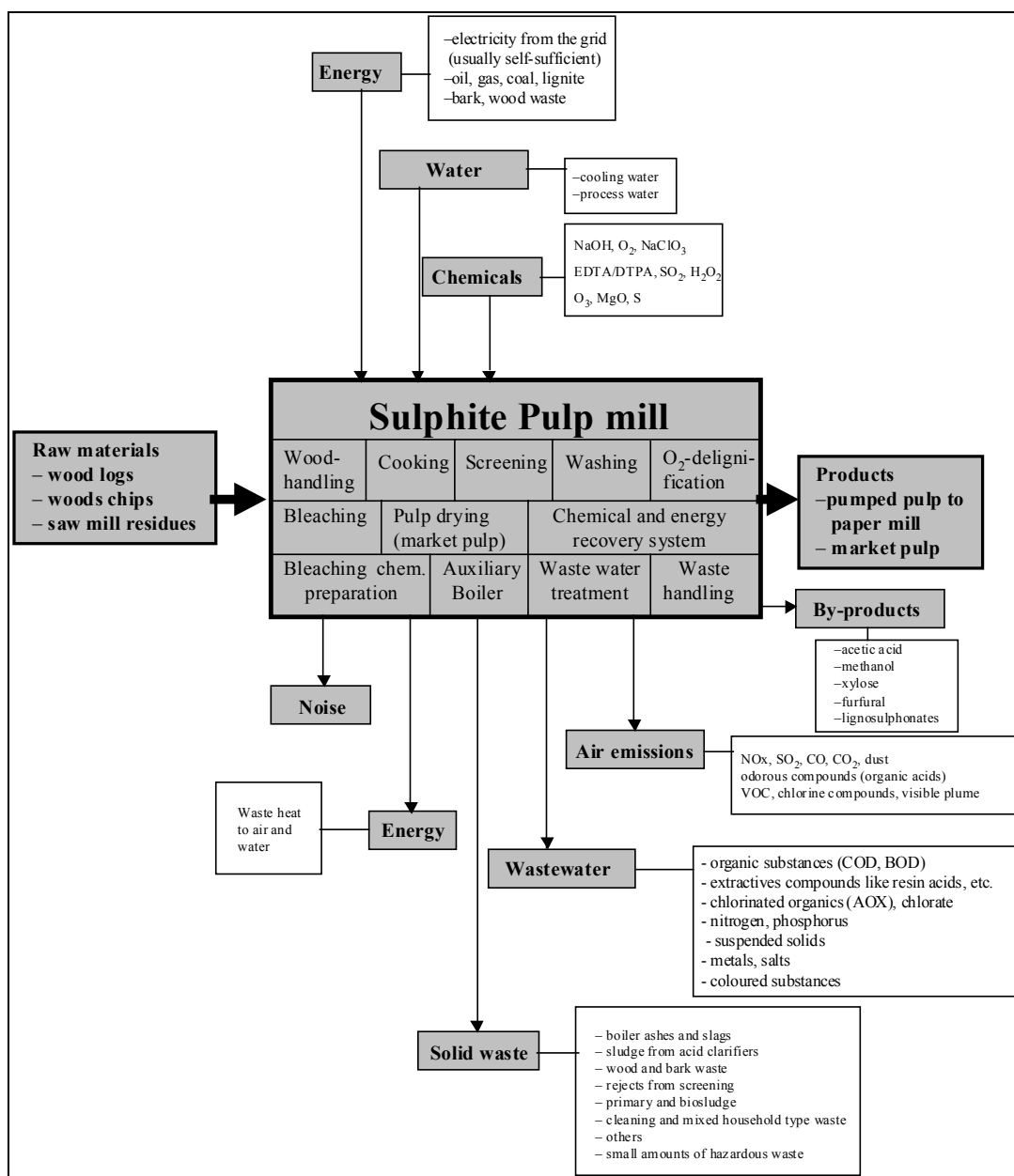


Figure 3.3: Mass stream overview of a sulphite pulp mill

The presence of some substances depend on the way of delignification and bleaching

The subsequent sections present specific consumption data, as well as specific emission data for individual operational steps associated with sulphite pulp manufacturing.

Using the mass stream overview, specific raw material consumption and specific emission per tonne of product can be calculated.

Table 3.3 shows yearly averages from six sulphite pulp mills in Germany. The data represent therefore not the whole range of emission levels. However, they can give an overview over the consumption and emission levels of present sulphite mills.

Input			Output		
Raw materials	Value	Unit	Product	Value	Unit
Wood (oven dry)	2	t/ADt	Bleached pulp	1	ADt
SO ₂ as S	32	kg/ADt			
MgO	24	kg/ADt	Emissions		
NaOH	27	kg/ADt	CO ₂	No data	kg/ADt
O ₂	13	kg/ADt	CO _{2, regenerative}	No data	kg/ADt
H ₂ O ₂	26	kg/ADt	NO _x	2.4	kg/ADt
DTPA	3	kg/ADt	CO	No data	kg/ADt
Energy			SO ₂ -S	1.75	kg/ADt
Oil	No data	MJ/t	Dust	No data	kg/ADt
Coal	No data	MJ/t	COD	34	kg/ADt
Natural gas	No data	MJ/t	BOD ₅	1.7	kg/ADt
Purchased electricity	No data	kWh/t	Suspended solids	No data	kg/ADt
Total primary energy ¹⁾	No data	kWh/t	AOX	<0.01	kg/ADt
			N _{anorg}	0.4	kg/ADt
			Total Phosphor	0.06	kg/ADt
			Wastewater flow	70	m ³ /ADt
Water demand			Residues		
Raw-/fresh water	70	m ³ /ADt	Sludge (90% dry solids)	37	kg/ADt
			Other waste	No data	kg/ADt

Notes:
1) Air emission from purchased electricity is not included.

Table 3.3: Annual average specific input/output data from six integrated sulphite pulp and paper mills (different paper grades are produced) manufacturing about 850000 ADt/a (1996)

The data refer only to the pulp production i.e. paper production is not included. The data to emission to water represent the situation after biological treatment. The air emission data refer to situation after abatement. The data set is not complete.

3.2.2 Consumption and emission levels arising from process units

In sulphite pulping the wastewater effluents and the emissions to air are the centres of interest but in the next years waste might also become an environmental issue of concern. The most relevant consumption of raw materials and emissions to water, air and soil (waste) as well as energy aspects are discussed below covering the following aspects:

- Wood consumption
- Water consumption and wastewater emissions from different process steps
 - Woodhandling
 - Condensates from evaporators
 - Spillages
 - Washing losses
 - Bleaching
 - Discharges of nutrients
 - Discharges of metals
- Consumption of chemicals
- Energy demand
- Emissions to the atmosphere

- from the recovery boiler
- from auxiliary boilers
- Odorous gases
- Chlorine compounds from bleaching and bleaching chemical preparation (only for ECF)
- Solid waste generation
- Noise

Where data are available emissions to water, air or soil (waste) are given before and after external treatment.

As for the reported emission and consumption figures, it should be borne in mind that, due to the use of some different measurement methods in the various Member States, data are not always strictly comparable from country to country. (See Annex III for more information on this issue but the different methods used do not alter the conclusions drawn in this document).

3.2.2.1 Wood consumption

Soft wood mainly spruce and hardwood (mainly beech) can be used as raw material in the sulphite pulping process. Logging and sawmill residues can also be used. The use of wood and the yield for production of bleached pulp is dependent on the selectivity in delignification and bleaching. The wood required for manufacturing 1 tonne of bleached sulphite pulp is normally between 4.2 and 5.2 m³ unbarbed wood/ADt.

3.2.2.2 Water consumption and emissions

Figure 3.4 gives an overview about the main processes involved in sulphite pulping and the major sources of emissions (to water and air). The emissions to water originate from different process mainly washing losses, effluents from the bleach plant and condensates from the evaporation plant. They also include accidental spills.

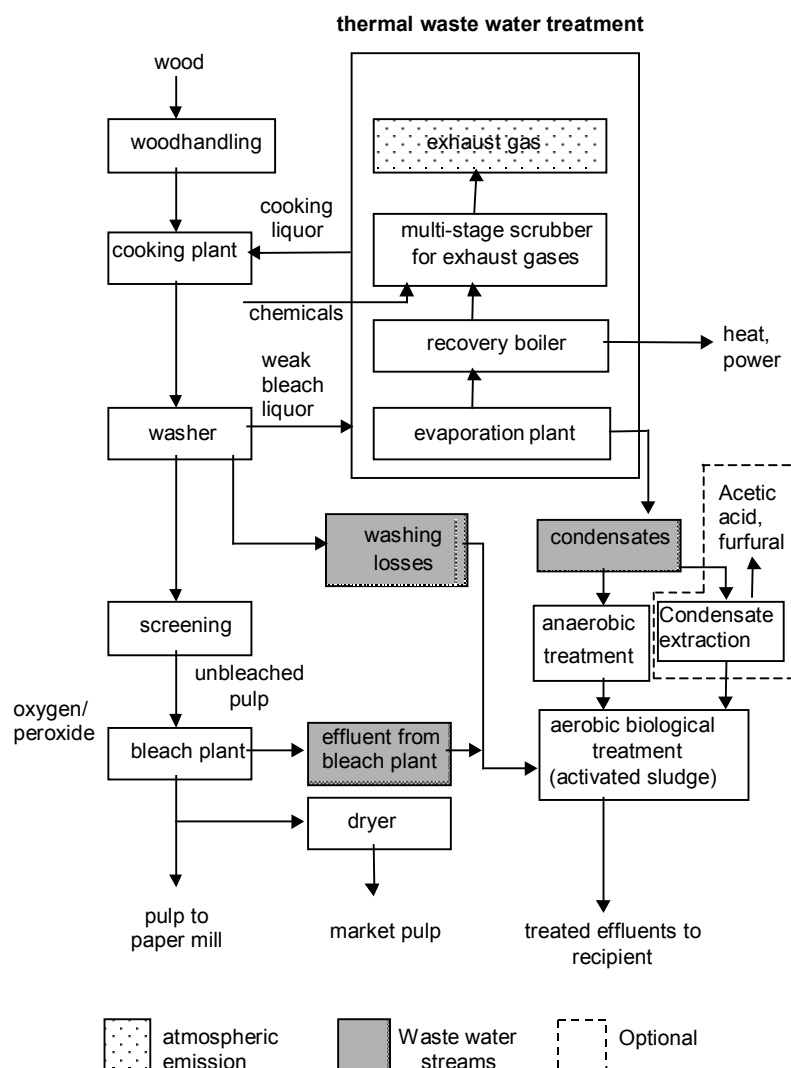


Figure 3.4: Main emissions to water and air from sulphite pulping

In the cook the delignification is brought down to a kappa number of about 14-22 for softwood and 10-20 for hardwood. The yield in the cook is somewhat higher than for kraft pulping. As a consequence the amount of wood, mainly hemicelluloses, dissolved out in the open part of the process (after brown stock washing) is comparatively high in alkaline bleaching stages and can amount up to 40-50 kg COD/t. The specific wastewater volume of the bleach plant in better performing mills is in the range of 15 - 25 m³/ADt.

It is important to neutralise sulphite liquor before evaporation. Otherwise acetic acid will be evaporated and turn up in the condensates instead of being led to the recovery boiler. The COD load in condensates is normally much higher at sulphite pulp mills compared to kraft mills as stripping is not a normal practice. The total load in condensates is up to 60 - 70 kg of COD/t. The differences between softwood and hardwood are quite small. Stripping and anaerobic treatment are possible options. As for kraft pulping most of the contaminants are readily degraded in a biological treatment plant.

Generally, the data available for sulphite pulping are much more limited than on kraft pulping. However, from available information it can be derived that total emissions of organic substances (measured as COD) before treatment vary between 80 and 200 kg/t. Available data

indicate that the total effluents from modernised sulphite pulp mills are 50 - 100 % higher than the one from modernised kraft pulp mills due to less closed processes.

Discharges after treatment are very different within Europe ranging for example from 10 up to 190 kg COD/ADT.

Sulphite pulp	Flow m³/ADt	BOD₅ kg/ADt	COD kg/ADt	AOX kg/ADt	tot-P g/ADt	tot-N kg/ADt	TSS kg/ADt
Bleached and unbleached	40-100	0.5 - 75	10 - 190	0 - 1	15 - 150	0.18 - 1	1.7 - 10

Table 3.4: Reported spans in annual average discharges in kg/ADt from Mg-sulphite pulp mills after treatment within Europe

Typical values for water consumption for magnesium bi-sulphite pulping are in the range of 40 - 100 m³ water per ADt of pulp.

A dissolving sulphite pulp mill (Lenzing AG, Austria, production of dissolving pulp for viscose fibres) reported the pollution loads before and after treatment as shown in Table 3.5.

COD load before biological treatment	Emissions to water after biological treatment
Woodyard : ca. 1 kg/t	COD: 4 –5 kg/t
Bleaching (1 st & 2 nd stage): ca. 15 kg/t	BOD ₅ : not detectable
Evaporator condensates: ca. 30 kg/t	TSS: 0.4 – 0.5 kg/t
Total load: ca. 46 kg/t	AOX: < 0.01 kg/t
Total flow: ca. 40 m ³ /t	Total P: < 0.1 kg/t
	Total N: < 0.2 kg/t
Explanatory notes: The example stands for a mill that has carried out possible process-integrated measures as described in Section 3.1.9 in order to reduce the releases to water. The wastewater from the first bleaching stage is evaporated and incinerated, acetic acid and furfural are extracted from the evaporator condensates. The remaining wastewater is treated in an activated sludge plant followed by a filtration step in order to reduce suspended solids, P and N.	

Table 3.5: Specific emissions to water of an integrated dissolving sulphite pulp mill (and viscose fibre) before and after biological treatment [personnel communication, 1998]

Table 3.6 shows the discharge of metals to the recipient. The results are based on sampling (random sampling once per day) during a 5-day period in September 1996. The random samples were mixed in proportion to the flows to give a combined sample which was analysed with regard to cadmium, chromium, copper, nickel, lead and zinc. The analysis of the metals was made by plasma mass-spectrometry (ICP-MS). Compared with 1995 the amount of cadmium, chromium, copper, nickel and lead are ca. 50 % higher. The amount of zinc is ca. 10 % higher.

Metal	Concentration [mg/m ³]	Specific load [g/t]
Cadmium	1.37	1
Chromium	5.5	4.4
Copper	9.3	7.4
Nickel	12	9.6
Lead	9.4	7.5
Zinc	144	115.2

Table 3.6: Discharge of metals from a Swedish partly integrated sulphite pulp mill in 1996 (Analysis of a combined sample consisting of 5 random samples taken during five days, 1 random sample/day); water flow about 80 m³/t

3.2.2.3 Consumption of chemicals

Consumption of chemicals varies from mill to mill and is to a certain extent regarded as confidential. However, the consumption of main chemicals is reported as typically being as follows.

Chemicals used for bleached Mg-sulphite pulp production	Amount [kgADt]
NaOH	10-40
O ₂	5-15
H ₂ O ₂ (100%)	10-40
EDTA or DTPA	0-3
O ₃ ¹	0-5
S (some mills use either S or SO ₂)	20-40
SO ₂ (some mills use either S or SO ₂)	0-70
MgO	15-25
Note: 1) Normally not used in sulphite pulp mills. However, in Europe one mill that is manufacturing dissolving sulphite pulp has implemented an ozone bleaching stage	

Table 3.7: Consumption of main chemicals in sulphite pulp production

A Swedish magnesite pulp mill producing bleached pulp for fine paper manufacturing reported a chemical consumption per tonne of pulp as sodium hydroxide 50 kg, oxygen 14 kg, EDTA 1.76 kg and hydrogen peroxide 37 kg. The bleaching sequence is (E + O) Q (E + O + P). The kappa number after cooking was on average for hardwood pulp 22 and for softwood pulp 22.

A German acid sulphite mill reported a consumption of make-up cooking chemicals of 30 kg SO₂/ADt and 15 - 20 kg MgO/ADt supposing SO₂ - losses of 2- 3 kg/ADT via the stack. The same mill uses for the two-stage peroxide bleaching of 1 tonne of air dry pulp 20 - 25 kg peroxide and 25 - 35 kg sodium hydroxide.

Most of the chelating agents used are washed out of the pulp and are discharged to wastewater. Because in most mills the Q-stages are led to wastewater treatment (to a minor extent partial streams are sent to the recovery boiler) most of this chemicals will end up in the recipient.

3.2.2.4 Emissions to the atmosphere

Sulphur emission levels from existing sulphite mills and the potential of further reductions are highly mill dependent. Due to differences between different sulphite process the values might show higher variations than in kraft pulp mills. But of course, they also depend significantly on the collection and abatement systems used for treatment of gaseous emissions. Depending on local conditions the following devices and systems can be found in sulphite pulp mills for collecting and purifying emissions to the atmosphere:

- Cyclone for chip blowing
- The gases from the continuous pressure control relief of the digesters are led to combustion in the recovery boiler.
- Collecting system for aerating gases from digesters, blow tanks, knot screens, washing filters, all weak and thick liquor tanks and fibre filters. These gases are led to combustion in the recovery boiler
- Scrubbers for the absorption of sulphur dioxide in aerating gases from the bleach plant.
- Non-condensable gases from the evaporation are led to combustion in the recovery boiler.
- Absorption of SO₂ in the flue gases leaving the recovery boilers in the acid preparation plant (venturi-scrubber system).
- Collection system for ventilation gases from the boiler house's liquor and condensate tanks, weak liquor filter and mix tank. The gases are led to combustion in the recovery boiler.
- Dust separation from flue gases from the auxiliary-boiler (burning bark, oil or other fuels) with electrofilter (ESP) and wet scrubber.
- NO_x-reduction in the bark boiler by injection of urea.

In a magnesium sulphite mill the main source for sulphur oxide emissions is the recovery boiler. After the recovery boiler, magnesium oxide ash is collected from the flue gas in electrostatic precipitators and washed with water forming magnesium hydroxide. This liquid is used in venturi scrubbers to absorb SO₂ and SO₃ from the recovery boiler (and in a few mills also from the digesters, washers and evaporators). The absorption system is made up with a number of scrubbers, normally three, four or five. Emissions are about 4 - 6 kg SO₂ per tonne of pulp when three scrubbers are used and 2 - 3 kg/t when four are used. Each scrubber reduces the concentration by about 70%.

There are also less concentrated SO₂ emissions from the bleach plant, the digesters, washing and the auxiliary boilers.

Emissions of NO_x from sulphite pulp mill recovery boilers are generally higher than those from kraft pulp mills because of the higher temperature in the recovery boiler. NO_x emissions range normally from 100 - 200 mg/MJ or about 1.5 - 3 kg/t of pulp. Table 3.8 summarises typical ranges for SO₂ and NO_x from recovery boilers.

Unit	S	NO _x
kg/t	0.5 - 3	1.0 - 3
(mg/m ³)	(100 - 400)	(200 - 500)

Table 3.8: Emissions from sulphite pulp recovery boilers in kg/t and corresponding concentrations in brackets (mg/m³) at a gas flow of about 6000 - 7000 m³/t (NTP, dry gas)

Besides the recovery boiler there are emissions to air from other combustion processes for steam and power generation. Different types of fuels may be used for steam generation. Usually sulphite mills are operating a bark boiler where bark, rejects, knots, fibre and bio-sludge is incinerated as well.

Emissions of malodorous gases in sulphite pulping are normally limited compared to kraft pulping. However, emissions of furfural mercaptanes and H₂S might cause odour and emissions of gaseous sulphur may also cause annoyance. At some mills emissions of malodorous gases are collected and burnt in the recovery boiler.

The reported ranges of total emissions to the atmosphere from European sulphite pulp mills are shown in Table 3.9.

	Total gaseous S [kg/ADt]	NO_x [kg/ADt]
Recovery boiler	0.5-5	1-3
Bark boiler	0.02-0.06*	0.1-1*
Total emissions from mills	0.55-5*	1.2-4.2*
* For the bark boiler estimated figure. Any use of fossil fuel in the bark boiler is not included		

Table 3.9: Atmospheric emissions from European sulphite pulp mills as yearly average

Emissions of VOC from the process are about 0.2 kg/t of sulphite pulp. The chip-heaps also contribute to emissions of VOC.

3.2.2.5 Solid waste generation

The production of sulphite pulping is related to the generation of different types of manufacturing specific wastes from which most can be utilised. The wastes arise from different stages of the production process such as debarking, chipping, screening, clarification of the cooking liquor, maintenance as well as from treatment of raw and wastewater. A German sulphite pulp mill reported the following main fractions of waste including some options for further treatment. The latter depend usually strongly on the local conditions.

Waste from the production of sulphite pulp				
EWC-Code ³	Description	Originate	Amount	Possible disposal route
17 04 05	Scrap (steel tapes, part of equipment etc.)	Packaging of logs, maintenance of installations	2.8 kg/t	Utilisation as material
03 03 01	Bark	Debarking plant	90 kg/t	Utilisation as fuel
-	Sawdust	Woodhandling	30-50 kg/t	Production of chip boards
-	Rejects from coarse screening	Screening	23 kg/t	Utilisation as fuel
-	Rejects from fine screening (chips, knots, bark, fibres, sand)	Screening (0.5-1% losses)	8 kg/t ¹	Utilisation as fuel, brickwork's
03 03 06	Sludge from pulp production	Mechanical and biological treatment of process water, recovery of chemicals	80 kg/t	Recultivation of landfills, brickwork's
20 03 01	Mixed municipal waste	Operation of installations	0.4 kg/t	Sorting, utilisation as material or fuel
13 02 02	Oil waste	Maintenance	0.03 kg/t	Utilisation as material or fuel
Note:				
1 The reference did not qualify the dry solid content. It seems that the figure above includes more than 50% of water. Normally, a value between 20-25 kg/ADt dry solids for primary and secondary sludges seems reasonable, when activated sludge is applied.				

Table 3.10: Example for waste generated in production of sulphite pulp [German mill, reference year: 1996]

Beyond that, the following types of waste have to be considered: Ash and cinder from energy extraction (combined burning of bio-fuel and fossil fuel); wood-room waste (sand etc.); ash and cinder from the recovery boilers; sand from fluidised bed boiler (if operated); in case of integrated pulp mills residues from the paper mill. Wood waste as bark, chips, sawdust, knots etc. is often burned on-site. Ashes from recovery boiler and bark boilers are partly used for other purposes. Furthermore sludge from clarification of the cooking liquors and base tanks is generated.

In Sweden by order of the Government the National Board of Forestry trials with addition of lime and vitalising agent in the forest are running. The purpose is to develop and test different additive and working methods in co-operation with the industry concerning the use of bark ash as vitalising agent. In the future it might be necessary to add vitalising agent in a more extended way to the forest in order to neutralise the acid rain.

A German sulphite mill using surface water reported significant amount of sludge from raw water treatment (flocculation) amounting to 50 kg/ADt.

The spans of waste from sulphite pulping to landfill in Europe are about 30 - 50 kg organic waste in DS/t of pulp and 30-60 kg inorganic waste in DS/t of pulp. Organic waste consist of wood residues, bark, pulping rejects and wastewater sludge [J. Pöyry, 1997]. If the organic waste is incinerated in dedicated incinerators there is virtually no organic waste to be landfilled. In an integrated sulphite pulp mill that is incinerating all organic residues on-site (bark, wood waste, sludge from biological treatment) the amount of waste is reported as 3.5 kg DS/Adt (100%DS). The ash from the incineration process can be utilised in different manners as e.g. in cement industry (reference: Gratkorn, AU).

³ The EWC is a harmonised, non-exhaustive list of wastes, that is to say, a list which will be periodically reviewed and if necessary revised in accordance with the Committee procedure. However, the inclusion of a material in the EWC does not mean that the given material is a waste in all circumstances. The entry is only relevant when the definition of waste has been satisfied [IPTS, 1997].

3.3 Techniques to consider in the determination of BAT

In this paragraph all **relevant** techniques currently commercially available for prevention or reduction of emissions/waste and reducing consumption of energy and raw materials, both for new and existing installations are given. This list of techniques is not exhaustive and may be continued when reviewing this document. These techniques cover in-process measures and end-of-pipe technology as well and stands for possibilities for improvement to achieve integrated prevention and control of pollution.

In Table 3.11 an overview of techniques for reduction of emissions from sulphite pulping is given. In the rows the single available techniques are compiled.

It was tried to give possible cross-media effects of every technique in the same table. It can be concluded that it is not an easy task to describe cross-media effects in a way that would not cause any dispute. There are a lot of "grey-zones" in the assessment of cross-media effects. Furthermore, they may depend on other techniques, which may be linked to a given measure, the reference to which a technique is compared with and the system boundary taken into account as well. Therefore, the qualitative assessment of cross-media effects should only be taken as help for operators or inspectors which side-effects a measure may possibly occur and is not much more than a starting-point when considering possible shifts of pollution. The results of the assessment should not be considered as imperative. Furthermore, prevention and control measures can avoid some of them. Besides other things, the cross-media effect will also depend on the specific conditions of every mill. Therefore, a general statement can hardly be given. However, the table may indicate at which environmental media (water, air, waste, energy) a measure is aiming at. The corresponding paragraphs under the detailed discussion of every technique give further explanations.

In the columns the tendency of effects caused by different techniques on emissions, raw material consumption and the mill performance are indicated qualitatively by using arrows up "↑" and down "↓". The arrows down "↓" indicate savings of raw materials or energy and a reduction of emissions into the different media water, air and soil. Arrows up "↑" indicate an increase of emissions, consumption and impacts on the production process. Some of the measures for pollution prevention and control presented in this section concern more than one environmental medium (as water, air or soil) at a time. Some techniques may have a positive and/or negative impact on other environmental media or on raw material and energy consumption (cross-media-effects). The given effects will be noted by using the arrows. An arrow in brackets "(↑)" means only a slight - often negligible - increase of energy consumption, raw material use or emission to environment when implementing a certain measure. The economic aspects (investments, operational costs) are not included in the table but are explained in the text. Data on economics can only give a rough picture and indicate the levels of costs. They will vary with the design of the whole plant and depend among others on the size of the mill and how a measure fits together with other mill equipment.

Techniques to consider in the determination of BAT	Effects on the consumption and emission level (cross-media effects)				
	Chemical consumption	Energy consumption	Emission to water	Emission to air	Solid waste
Dry debarking (see kraft)	O	↑ in debarking	↓ COD, ↓ TSS, ↓ flow	O	O
Extended cooking to a low kappa Continuous (a) or batch (b)	↑ in cooking ↓ in bleaching	(↑/↓) in cooking ↑ evaporation	↓ COD	O	O
Oxygen delignification	↑ in O ₂ -stage ↓ in bleaching	↑ in O ₂ -stage ↓ in bleaching	↓ COD	O	O
Closed screening (see kraft)	O	O	↓ COD	O	O
Efficient washing and process control (see kraft)	↓ in bleaching ↓ in cooking	↑ washing (elec.)	↓	O	O
Collection of almost all spillages (see kraft)	O	↑ evaporation	↓	O	O
TCF bleaching (vs. ECF) (at the same incoming low kappa)	↓	(↑/↓)	(↓ COD), ↓ AOX, ↑ N chel. agent	↓	O
Partly closure of the bleach plant + increased evaporation	↑ in bleaching	↑ evaporation	↓	O	O
Closure of the bleach plant in sodium s. mills	↓	↓	↓	O	O
Neutralising of weak liquor before evaporation	↑	O	(↑/↓)	↓	O
Separate treatment of the condensates or re-use in the process	O	↓	↓	O	O
Buffer tanks for concentrated liquids (see kraft)	O	O	↓	O	O
Biological wastewater treatment (see kraft)	↑	↑	↓	(↑/↓) odour	Sludge burning ?
Installation of ESP and multi-stage scrubbers on the recovery boiler	↓	↓	O	↓	O
Collection and incineration of odorous gases in the recovery boiler and/or in a venturi-washer	O	↑	O	↓	O
Emission optimised recovery boiler	O	O	O	↓	O
Low NO _x auxiliary boilers (see kraft)	O	O	O	↓ NO _x	O
SNCR on bark boilers (see kraft)	↑ urea	↑ handling system	O	↓ NO _x	O
ESP on bark boiler (see kraft)	O	↑ electricity	O	↓ dust	O
Emission optimised incineration of residues with energy recovery (see kraft)	O	↓ heat recovery	O	(↑/↓)	↓
Notes: ↑ = increase; ↓ = decrease; 0 = no (or negligible) effect. (↑/↓) = may or may not have an effect/little impact depending on the conditions;					

Table 3.11: Overview of available techniques in sulphite pulping and their impact on the environment and the mill performance respectively

The techniques for prevention and abatement emission from kraft pulp mills are similar to the available measures that can be applied in sulphite pulp mills. Therefore, for sulphite pulp mills the presentation of the techniques to consider in the determination of BAT are divided into four different groups of techniques in order to avoid repetition.

Group 1: Because of the similarities between sulphite and kraft pulping a number of the measures for kraft pulping are valid in most respects for sulphite pulping, too. This is considered to be the case concerning the techniques listed below. For them it is just referred to the respective sections in kraft pulping.

- Dry debarking (see Section 2.3.1)
- Closed screening (see Section 2.3.3)
- Collection of almost all spillages (see Section 2.3.9)
- Efficient washing and process control (see Section 2.3.10)
- Installation of low NO_x technology in auxiliary boilers (bark, coal, oil) (see Section 2.3.20)
- Electrostatic precipitator for dust reduction in bark boilers (see Section 2.3.24 regarding bark boilers)
- Use of sufficiently large buffer tanks for storage of concentrated or hot liquids from the process (see Section 2.3.12)
- Aerobic biological treatment of the effluents (see Section 2.3.13)
- Tertiary treatment by use of chemical precipitation (see Section 2.3.14)

Group 2: There are particular differences between kraft and sulphite technologies concerning the following techniques:

- Extended modified cooking to a low kappa (batch or continuous) (see Section 2.3.2)
- Oxygen delignification (see Section 2.3.4)
- TCF bleaching technique (see Section 2.3.7)
- Partly closure of the bleach plant combined with increased evaporation (see Section 2.3.8)
- Stripping of most concentrated contaminated condensates and re-use of most condensates in the process (see Section 2.3.11)
- Increase in the dry solids content of black liquor (see Section 2.3.15)
- Installation of scrubbers on the recovery boiler (see Section 2.3.16)
- Collection of weak gases for incineration in the recovery boiler (see Section 2.3.17)
- Ozone bleaching (see Section 2.3.5)

Although the principles are very similar, there are relevant differences between kraft and sulphite pulp mills. The differences concern mainly detailed technical solutions, achievable kappa-numbers reflecting residual lignin content, bleaching sequences and their chemical consumption, volatile organic compounds in contaminated condensates etc. For this group less data were provided.

Group 3: Some techniques of kraft pulping are not valid at all for sulphite pulp mills such as:

- Collection and incineration of odorous gases in the lime kiln (see Section 2.3.18)
- Installation of improved washing of lime mud in recausticizing (see Section 2.3.23)
- ECF bleaching technique (see Section 2.3.6)
- Electrostatic precipitator for dust reduction in the lime kiln (see Section 2.3.24 regarding the lime kiln)
- Incineration of odorous gases in a separate furnace including a scrubber (see Section 2.3.19)

Group 4: Finally there are a few additional techniques to be mentioned which are only applicable to sulphite pulp mills and which are not valid at all for kraft mills.

- Neutralising of weak liquor before evaporation followed by re-use of most condensates in the process or anaerobic treatment
- Reduction of SO₂ emissions from the recovery boiler by installing electrostatic precipitators and multi-stage scrubbers

Information on BAT for sulphite pulp mills is generally weaker than for kraft pulp mills. Most Sections would need to be completed and assessed in more detail. However, using the information provided and available data from other sources some techniques can be described below. The description however does not have the same level of detail than the corresponding Section on Kraft pulping. Generally, concerning sulphite pulp mills no data on costs are available.

3.3.1 Extended cooking to a low kappa

No further information received than those presented in Section 3.1.2.

3.3.2 Oxygen delignification

No further information received than those presented in Section 3.1.4.

3.3.3 TCF bleaching

Description of the technique: Since the beginning of the 90's TCF bleaching became the predominantly used bleaching method in European sulphite pulp mills. In Europe, there is no sulphite pulp mill that still applies chlorine as bleaching agent and most of ECF pulp production is replaced by TCF bleaching sequences. Existing bleach plants were converted by reorganising and upgrading equipment. Bleaching sequences with chlorine application such as e.g. C/D-E-D(E-D) were converted stepwise to TCF sequences. First molecular chlorine bleaching steps were dropped and ECF pulp produced. Then the processes were converted to TCF bleaching (e.g. EOP-Q-EOP(-EP)) by further developing the process. The use of complexing agents in peroxide stages and the increase of consistency in the bleaching tower made it possible to manufacture high quality TCF paper pulp. Further prerequisites for TCF bleaching such as extended and even cooking, high efficient washing processes and increase of evaporation capacities were implemented.

An example for the process conditions of a typical TCF bleaching sequence for sulphite pulp are shown in Table 3.12.

Parameter	O- or EOP-stage	Acid washing	EP or EOP stage(s)
Temperature	65 – 75 °C	50 – 70 °C	65 – 80 °C
Pressure	1 – 4 bar	-	1 – 2.5 bar
Consistency	10 - 14	3 - 5	14 - 40
Kappa	21 – 24 → 11-13	-	→ 3 - 5
NaOH	15 -25	-	5 - 15
O ₂	5 - 15	-	0 –7
H ₂ O ₂	2 -10	-	10 – 25
EDTA	-	0.5 – 1.5	

Table 3.12: Example for bleaching sequences for TCF sulphite pulping

Applicability and characterisation of the measure: Process integrated measure. Applicable to both new and existing mills (conversion).

Main achieved environmental performance: The releases of chlorinated organic substances (measured as AOX) to water are significantly reduced from formerly 4-8 (up to 12) kg AOX/Adt of chlorine bleached pulp down to well below 0.1 kg/t (no formation in bleaching). Releases of purgeable or volatile chlorinated organic substances (POX) to air are reduced from about 20 mg POX/Adt down to zero. The TCF pulp produced does not contain organically bound chlorine that might be released when it is repulped in paper mills. The specific fresh water demand in the bleach plant could be reduced in TCF mills from about 25-35 m³/Adt down to 10-15 m³/Adt by increased closure of the water circuits. Increased process water closure results in lower hydraulic loads and in a few cases also in reduced organic loads. TCF bleaching leads to less emission of coloured substances with waste water and the degradability of the waste water in the biological treatment plant is enhanced. Moreover, savings of energy

are achieved by TCF bleaching. The steam demand in the bleach plant can be reduced from 0.5-1 tonnes of steam/tonne of pulp down to 0-0.2 t of steam per tonne of pulp. The power demand can be reduced by 20-30%.

Finally, no risk can occur with the storage of chlorine and the preparation of chlorine dioxide.

Cross-media effects: The numerous positive effects are mentioned in the paragraph above (mainly achieved environmental performance). As drawbacks the following aspects can be noted: Releases of complexing agents such as EDTA (0.2 – 1 kg/t) if they are applied in bleaching stages that discharge the washing liquids via waste water treatment plant. However, by optimising the dosage of complexing agents the amount of EDTA can be reduced. There are experiences that the sedimentability of the biosludge in the sedimentation tank can be deteriorated to a certain extent. In other mills this effect does not occur. Because of possible risks, peroxide should be handled with care.

Operational experiences: Nowadays, for all qualities of TCF bleached sulphite pulp sufficient experiences have been gained. There are no operational problems reported.

Economics: The investment cost for conversion to TCF bleaching and the upgrading of the existing bleach plant amounts to about 20 – 50 MEuro for a sulphite pulp mill with a daily production capacity of 700 Adt per day. However, these figures depend to a certain extent on the pulp qualities to be achieved. On the other hand, the TCF conversion results in savings concerning operating costs (chemicals, energy). The savings depend on the price of chemicals and energy in the given country.

Driving force for implementing this technique: Requirements concerning protection of the environment (reduction of discharges of chlorinated organic matters and other toxic substances) and occupational safety. Decrease of operating costs for bleaching and market demands of environmentally aware customers were other important drivers.

Example plants: Most sulphite pulp mills in Europe.

3.3.4 Partial closure of the bleach plant

No further information received than those presented in Section 3.1.4.

3.3.5 Pre-treatment of wastewater from the oxygen stages in an ultrafiltration plant followed by aerobic treatment of the total effluent

Description of the technique: The wastewater from oxygen stages can be treated in an ultrafiltration plant. This technique is applied in only one sulphite pulp mill in Europe (SE). In this case, the separated concentrate is burnt in the boiler house and the permeate is led to the external biological treatment. Detailed information on operational experiences, design parameters for layout, maintenance, availability and utilization of the concentrate are not yet sufficient to draw conclusions on BAT for this technique.

3.3.6 Anaerobic pre-treatment of the condensate followed by aerobic treatment of the total effluent

Description of the technique: Condensates from evaporation of weak liquor from sulphite mills contain relatively high concentrations of readily biodegradable organic substances. They can be efficiently treated in a separate anaerobic treatment. Effluents from the bleach plant

(filtrates), other wastewater streams from the mill as washing losses, rinsing waters, leakage and spillage can then be treated together in an aerobic activated sludge system as shown in Figure 3.5.

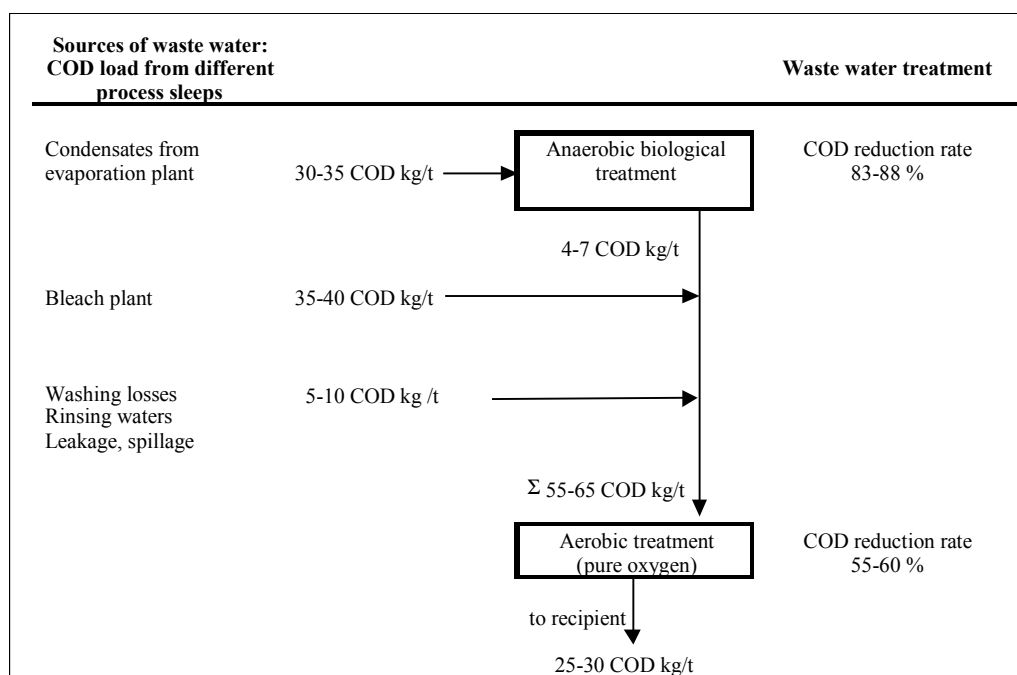


Figure 3.5: Wastewater load from acid sulphite pulping and treatment systems including reduction efficiency. Example of organic loads before and after treatment from a German sulphite pulp mill

All effluents containing particulate matters are led first to pre-sedimentation tanks for mechanical purification and then to the activated sludge plant. To the activated sludge plant may also be led different leaching water (if existing), rainwater run-off and cooling water. Fibre sludge from the pre-sedimentation tank and biosludge (surplus sludge) from the activated sludge plant is thickened in separate thickening tanks. Dewatering can take place using screw presses with a pre-concentrator. The dewatered sludge is often mixed with bark and burned in the bark boiler.

Applicability and characterisation of the measure: Can be installed in both existing and new mills.

Main achieved environmental performance: Condensates from evaporation of weak liquor from sulphite mills contain relatively high concentrations of readily biodegradable organic substances. They can be efficiently treated in a separate anaerobic treatment. COD removal efficiencies amount to about 85%. The treatment efficiency for the aerobic treatment of the rest of the wastewaters from the mill achieve about 55% to 60% COD-reduction. Depending on the process integrated measures before the effluent treatment and the specific lay out of delignification and bleaching stages final effluent loads of 25 - 30 kg COD/t can be achieved.

Cross media effects: Anaerobic treatment of concentrated wastewater streams generates energy containing biogas, which can be used as a fuel. Less excess sludge is generated. Aerobic biological treatment as a second stage consumes energy for pumps and aerators. Excess sludge has to be de-watered and further treated for instance in suitable bark boilers or fluidised bed incinerators.

Operational experiences: This technique is operating in some mills and good availability is normally reported.

Economics: No data available.

Reference plants: Several mills in Germany and Austria have applied this technique.

Literature: Not available

3.3.7 Biological wastewater treatment

Description of the technique: Biological treatment utilises the natural biological process, where micro-organisms use dissolved organic material in the water as a source of energy. In biological treatment the biodegradable dissolved and colloidal material in the water are transformed partly into a solid cell substance and partly into carbon dioxide and water. The biosludge is separated before the water is discharged.

The micro-organisms need nitrogen and phosphorus for proper growth. In pulp and paper mill effluents the amount of nutrients is low compared with the amount of organic substances. It is, therefore, often necessary to add phosphorus and nitrogen to the wastewater to achieve efficient treatment. However, it is recommendable to assess whether the initial nutrient supply in the wastewater is sufficient. Sometimes wastewater from bleached sulphite pulp mills contain enough phosphorus and in integrated pulp and paper mills sometimes only very little of additional nitrogen is needed. Therefore, overdosing of nutrients should be avoided by monitoring the concentration of the nutrients in the outlet.

The temperature of the wastewater influences the functioning of the biology. The temperature must not exceed 30-35°C in aerobic processes and cooling can become necessary. The effluent temperature of sulphite pulp mills is normally between 29 and 35°C.

Lignin, which is dissolved during pulping and is, to some extent, present in the effluent, is only partially degraded in biological treatment. The remaining lignin fractions give the treated water a brown colour.

A simplified process scheme for activated sludge treatment is shown in Figure 3.6.

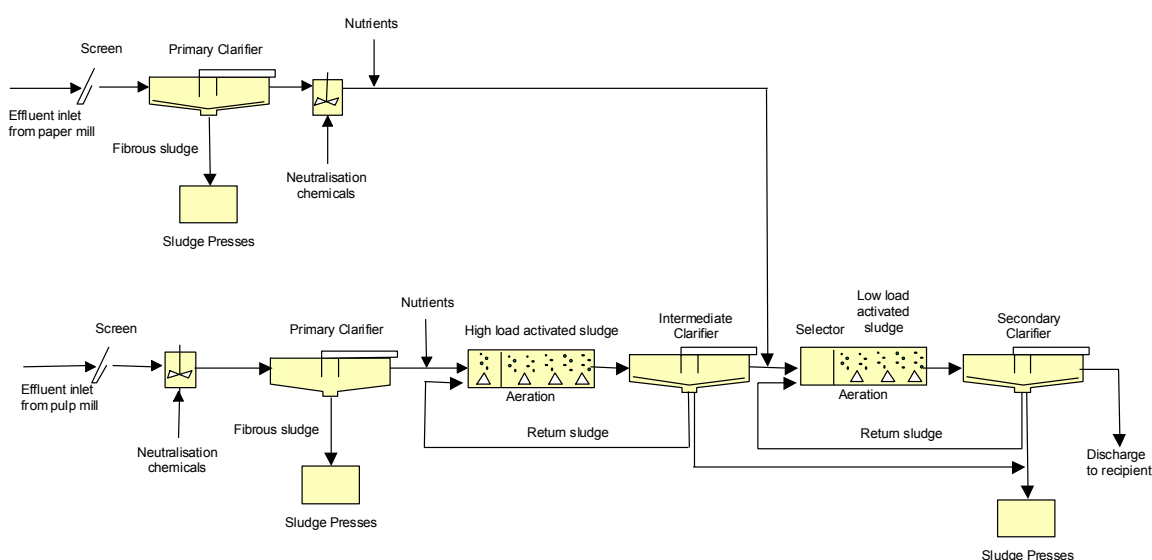


Figure 3.6: Process diagram of the effluent treatment plant for a sulphite pulp mill. Example from an Austrian mill [Neusiedler AG, Austria]

Applicability and characterisation of the measure: End-of-pipe technique. The process can be applied to both new and existing mills.

Main achieved environmental performance: The efficiency of the treatment varies, depending on the type of effluents treated. In Table 3.13 the achieved outlet concentration of the effluent treatment shown in Figure 3.6 is compiled. The values are derived from daily average samplings of COD, BOD₅ and total suspended solids. In 1998, the annual production of the integrated mill amounts to about 45000 tonnes of pulp and about 80000 tonnes of fine paper. The COD load of the paper mill contributes to about 10% to the total COD load of the effluent inlet.

Days in August '98	Influent COD load pulp mill [kg/d]	Influent COD load paper mill [kg/d]	Measured daily average concentration after biological treatment		
			COD [mg/l]	BOD ₅ [mg/l]	TSS [mg/l]
1	16922	1601	520	21	32
2	16785	1614	521	19	32
3	15809	1685	524	22	32
4	15984	2149	465	21	26
5	13042	2478	524	25	24
6	13380	1291	507	25	20
7	15978	856	483	19	18
8	13966	449	428	23	20
9	12740	1515	389	17	36
10	13017	1069	410	24	22
11	10888	1769	395	22	18
12	14574	1809	364	19	18
13	13230	2039	412	21	18
14	13754	1485	409	16	24
15	14345	2307	408	25	24
16	14547	2126	466	22	32
17	13862	1505	501	17	44
18	15612	1307	537	17	48
19	11278	2723	499	24	48
20	14695	2079	433	23	52
21	14713	1833	400	19	38
22	13294	2231	411	22	26
23	13525	1549	474	25	30
24	15590	1498	483	23	20
25	13908	881	534	18	24
26	12928	1738	493	17	20
27	13724	1767	424	25	32
28	16763	2034	510	19	20
29	15673	1403	476	19	22
30	16385	923	458	24	24
31	16230	2102	527	16	18
Mean value	14424	1671	465	21	28
Maximum	16922	2723	537	25	52
Minimum	10888	449	364	16	18
Explanatory notes:					
1) The wastewater flow of the paper department is about 15 m ³ per tonne					
2) The wastewater flow of the pulp department is about 55 m ³ per tonne					
3) Total phosphorus is measured only once a week and is normally below 1 mg/l with a few peak values up to 2 mg/l					
4) Inorganic nitrogen is normally below 7 mg/l					

Table 3.13: Discharge into water from an integrated sulphite pulp mill after biological treatment [Data are derived from a mill visit in 1998]

Cross media effects: Aerobic biological treatment consumes energy. The consumption of electrical energy in activated sludge treatment is in the range of 1.2-2 kWh/kg of reduced BOD (aeration and pumping). The sludge generation in activated sludge treatment is in the range of 0.4-0.7 kg DS/kg BOD-reduced [Finnish BAT report, 1997].

The fibrous sludge from the primary clarifier of the example plant described above is incinerated as substitute raw material in the brick industry. The excess biosludge is de-watered, washed with evaporator condensate, de-watered again, and finally incinerated in the recovery boiler together with thick liquor. This option for biosludge treatment has been chosen because the mill does not operate a bark boiler. The wood chips are supplied by nearby saw mills. Other sulphite pulp mills normally burn the de-watered sludge in the bark boiler.

Operational experiences: Aerobic biological treatment such as activated sludge treatment for effluents from sulphite pulp mills has been successfully used for over 10 years.

The concept of the effluent treatment as shown in Figure 3.6 above tries to separate influents and peak flows to achieve a smooth operation. If concentration peaks of COD or unusual variations in temperature and hydraulic load in the inlet effluent are assessed, the given partial wastewater stream is led to an emergency basin where it is intermediately stored and discharged stepwise to the major wastewater flow. This concept results in relatively little variations of emissions and a continuous high performance of the treatment plant.

Economics: The total investment costs of the whole effluent treatment system including sludge de-watering as described above is reported to amount to about 20 MEuro (referring to a annual production of 45000 tonnes of pulp and about 80000 tonnes of fine paper). The costs imply a dimensioning according the maximum load. This results in higher costs but also higher security of the operation.

Example plants: Neusiedler AG, Austria; all four sulphite pulp mills in Germany have applied activated sludge treatment. However, the evaporator condensate is pre-treated by anaerobic reactors that are followed by aerobic treatment as described above; there is a number of other examples plants in Europe that operate activated sludge treatment.

Literature/Reference

[Personal communication with operators in Germany and Austria]

3.3.8 Installation of ESP and multi-stage scrubbers on the recovery boiler - chemical recovery and abatement of air emissions

Description of the technique: Besides the recovery boiler being a significant source of SO₂ and particulate emissions other potential releases of SO₂ are the digester where liquor and gas are withdrawn at certain times during the process and the blow tank (see Figure 3.7). The flows of the latter contain between 30 and 70% of the sulphur dioxide charged to the digester. They are usually recovered in tanks with different pressure levels both for economic and environmental reasons. SO₂ releases from washing and screening operations and from vents of the evaporators can be recovered by collecting the gases and introducing them in the recovery boiler as combustion air.

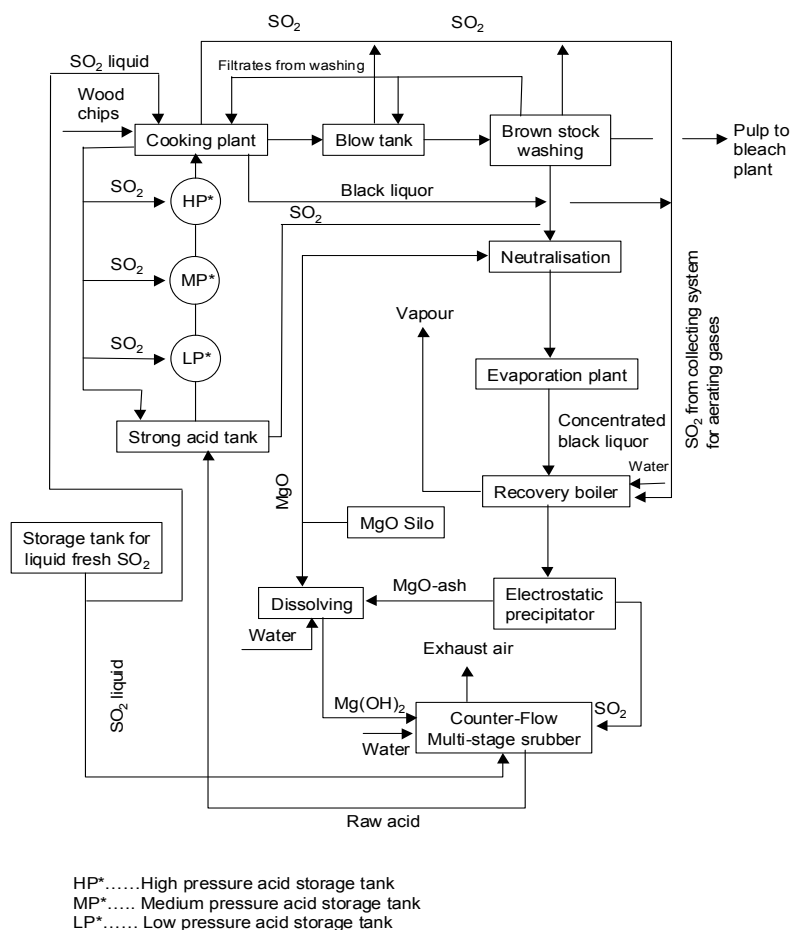


Figure 3.7: SO₂ - circuit in a sulphite pulp mill

The final sulphur dioxide emissions are closely related to the system of recovery of spent cooking liquor. The flue gas from incineration of the concentrated black liquor carries a considerable amount of SO₂ gas which varies somewhat with sulphidity of the spent liquor from the particular sulphite process used. To control these emissions proper design and operation of the furnace and auxiliary emission control devices (multi-stage scrubbers) can be applied.

The magnesium bisulphite recovery process demands controlled oxidation conditions to minimise the formation of MgSO₄ and SO₃ and temperatures between 1250 and 1400°C to generate a clean ash with maximum reactivity in contact with water. The chemicals used in the cooking plant appear in the flue gas in the form of light MgO ash and the sulphur as SO₂. These two chemicals form fresh cooking liquor when brought together in a counter-flow multi-stage scrubber.

The steps to regenerate the cooking liquor consist of a cleaning of the MgO ash by washing and slaking in water to form Mg(OH)₂. The SO₂ is scrubbed with this alkaline solution counter-currently and returning the SO₂ rich solution to the liquor preparation (see Figure 3.7).

Applicability and characterisation of the measure: The measures for SO₂ emission control can be considered as process integrated technique because the liquids used in the scrubber and the washed off SO₂ is reused in the process. The technique is applicable to both existing and new mills. Factors that influence the possibility of further reduction of sulphur emission are the type of sulphite process - type of cooking base and pH of cooking liquor - and to a certain extent the size of the mill. Due to the higher flexibility of sulphite pulping, for sulphite mills it is more difficult than for kraft mills to describe what can be considered as achievable levels associated with BAT on a sector level. Below two examples of the performance of SO₂ emission control systems in a smaller (35000 t/a) and a bigger mill (300000 t/a) are given.

Main achieved environmental performance: Various types of scrubbers for recovery of SO₂ are used in all sulphite mills applying recovery of chemicals from the cooking liquor.

A small mill (Neusiedler AG) manufacturing bleached sulphite pulp from softwood (87%ISO) is operating a flue gas cleaning system consisting of an electrostatic precipitator and a counter-flow three stage scrubber. The mill reported the following measured values in 1998:

	NO _x ⁴	SO ₂	CO	dust	Excess O ₂	Black liquor ²	Production	Gas flow ³	NO ₂ ⁴	SO ₂	CO	dust
Units	mg/Nm ³	mg/Nm ³	mg/Nm ³	mg/Nm ³	%	t/d	t/d	Nm ³ /t	kg/t	kg/t	g/t	kg/t
Limit value¹	350	300	50	40								
Jan	243	53	1	3	5	295.4	137.2	6238	1.52	0.31	6.2	0.019
Feb	251	30	2	3	6	294.6	143.4	5932	1.49	0.16	11.8	0.018
Mar	237	70	1	3	7	288.4	136.2	6152	1.46	0.40	6.1	0.018
April	223	49	1	3	8	254.5	116.3	6543	1.46	0.29	6.5	0.020
May	252	21	5	3	9	296.8	136.5	6263	1.58	0.13	31.3	0.020
June	250	35	3	3	10	301.3	141.5	6140	1.54	0.20	18.4	0.018
July	243	37	2	3	5	300.9	137.9	6280	1.53	0.22	12.5	0.019
Aug	244	49	3	3	6	300.9	130.9	6684	1.63	0.31	20	0.020
Mean value	243	43	2	3	5	291.6	135	6279	1.53	0.25	14.1	0.019

Notes:

- 1 The emission limit values and the measured values are referring to daily means and standard conditions (0°C, 1013 mbar, oxygen content (5 %) after subtraction of the water vapour content (dry gas). According to the Austrian Air Protection Law 95% of all daily means shall not exceed the established mass concentration.
- 2 The dry solid content of concentrated black liquor after evaporation amounts to 56 - 58% DS. The energy content of black liquor is about 7.8 GJ/t. As an average 2.16 t of black liquor is burned per tonne of pulp produced.
- 3 A minor amount of raw gas (36.2 MJ/Nm³) is added to the flame to support incineration and for safety reasons. The amount of raw gas varies between 4758 Nm³/d and 6742 Nm³/d that corresponds to about 39 Nm³/t or 1.4 GJ/t of pulp. The contribution of the emission from incineration of raw gas to the total emissions is negligible.
- 4 Usually the concentration of NO_x would be in the range of 350 mg/Nm³. By injection of ammonia the average concentration is lowered to about 250 mg/Nm³.

Table 3.14: Atmospheric emissions from the recovery boiler of a small Austrian sulphite pulp mill manufacturing 35000 t/a
[All data from a site visit in Oct. 98]

The variations of NO_x are very low and there are only slight fluctuations around 250 mg/Nm³. Dust emissions are not monitored continuously because they are nearly completely recovered by ESP and the three-stage scrubbers. SO₂ emissions are usually clearly below 100 mg/Nm³ but there are some peaks reaching 450 - 600 mg/Nm³. These peaks are mainly caused by acid operation applied to clean the system (2 to 3 times per month). During that time only two scrubbers are in operation.

A big Swedish magnesium based mill (Nymölla) with an annual pulp capacity of 300000 t reported SO₂ emissions from the process in the range of 1.0 - 1.5 kg S/ADt. In the recovery system absorption of SO₂ from flue gases from the recovery boiler takes place in five venturi scrubbers. A system for collection of various vent gases is installed. Vent gases from the cooking, washing and evaporation departments are collected and introduced in the recovery boiler as combustion air.

Monitoring of emissions: Automatic SO₂- and NO_x-analysers

Cross media effects: No negative cross-media effects to be expected

Operational experiences: Variations of the described SO₂ control systems are applied in all magnesium based sulphite mills. However, different reduction efficiencies for SO₂ removal are reported from European mills.

Economics: No data available

Driving force for implementing this technique: The recovery of SO₂ from incineration of spent liquor is inherent for the preparation of cooking liquor and carried out for both economical and environmental reasons. However, better performing systems are usually implemented for further reduction of the acidification potential of SO₂. Better performing systems are characterised by an additional scrubber stage for SO₂ absorption and collection systems for vent gases from the cooking, washing and evaporation departments.

Reference plants: Numerous plants in Europe use similar systems

Literature:

[SEPA-report 4008, 1992], [data from a site visit, 1998]

3.3.9 Reduction of odorous gases

No further information received than those presented in Section 3.2.2.4.

3.3.10 Emission optimised recovery boiler by controlling the firing conditions

No sufficient information received.

3.3.11 Measures to prevent uncontrolled development of normal operation and to reduce the consequences of accidents

As an example how to prevent uncontrolled development of normal operation in sulphite pulp mills the security measures for SO₂ supply and storage are described.

Description of the technique: In order to compensate losses, "make up" sulphur dioxide is necessary in the chemical circuit of a sulphite pulp plant. This demand is generally satisfied by the supply of SO₂ liquid. In general, it is stored in adequate storage tanks. The whole plant for refilling, storage and maybe liquefaction of sulphur dioxide including the piping for the SO₂-liquid has a security analysis, which is updated regularly and when changes have been made. For further areas, in which SO₂ is used, there exists an investigation of security (e.g. installation for treatment of odorous gases, digester house, container field and exhaust gas desulfurization plant). Possible risks of the train transport of liquid-SO₂ are checked in a security control as well. Via an information script the public is informed of the dangers of sulphur dioxide and the right behaviour during an uncontrolled development of normal operation.

The following technical equipment belongs to the installation for SO₂-supply and storage:

- double-walled piping
- secure electricity supply
- environmentally sound treatment of SO₂ in case of a failure of the normal operation (suction and treatment or reserve storage)

Besides the technical equipment the following organisational measures are implemented:

- regular checking and maintenance
- alarm plan including reasonable measures to be taken in case of uncontrolled development
- qualified staff n in charge of major accidents
- training of employees
- information of the public

Applicability and characterisation of the measure: Applicable to both existing and new mills.

Main achieved environmental performance: An immediate limitation of emissions is not going to be achieved with these measures. The probability of a major accident as well as the effects of the operation of the plant as directed, are however limited considerably.

Monitoring of emissions: Automatic SO₂-analysers

Cross media effects: No cross-media effects to be expected

Operational experiences: The described security system for SO₂ supply and storage is for instance applied at Sappi, fine paper Europe, mill Ahlfeld (Germany) with success.

Economics: no data available

Driving force for implementing this technique: Consequent intention to operate the pulp mill with less risk to environment and adjacent neighbourhood.

Reference plants: Numerous plants in Europe use similar security systems

Literature: not available

3.4 Best Available Techniques

3.4.1 Introduction

In understanding this chapter and its contents, the attention of the reader is drawn back to the preface of this document and in particular the fifth section of the preface: “How to understand and use this document”. The techniques and associated emission and/or consumption levels, or ranges of levels, presented in this chapter have been assessed through an iterative process involving the following steps:

- identification of the key environmental issues for the sector; for integrated sulphite pulp and paper mills the major concerns are water use, wastewater discharge (COD, BOD, suspended solids, N, P), energy consumption (steam and electricity), solid waste such as rejects, sludge and ash, air emissions from energy generation (SO₂, NO_x, CO₂, dust), noise, waste heat to water and sometimes odour; the latter three stand for local impacts;
- examination of the techniques most relevant to address those key issues;
- identification of the best environmental performance levels, on the basis of the available data in the European Union and world-wide;
- examination of the conditions under which these performance levels were achieved; such as costs, cross-media effects, main driving forces involved in implementation of this techniques;
- selection of the best available techniques (BAT) and the associated emission and/or consumption levels for this sector in a general sense all according to Article 2(11) and Annex IV of the Directive.

Expert judgement by the European IPPC Bureau and the relevant Technical Working Group (TWG) has played a key role in each of these steps and in the way in which the information is presented here.

On the basis of this assessment, techniques, and as far as possible emission and consumption levels associated with the use of BAT, are presented in this chapter that are considered to be appropriate to the sector as a whole and in many cases reflect current performance of some installations within the sector. Where emission or consumption levels “associated with best available techniques” are presented, this is to be understood as meaning that those levels represent the environmental performance that could be anticipated as a result of the application, in this sector, of the techniques described, bearing in mind the balance of costs and advantages inherent within the definition of BAT. However, they are neither emission nor consumption limit values and should not be understood as such. In some cases it may be technically possible to achieve better emission or consumption levels but due to the costs involved or cross media considerations, they are not considered to be appropriate as BAT for the sector as a whole. However, such levels may be considered to be justified in more specific cases where there are special driving forces.

The emission and consumption levels associated with the use of BAT have to be seen together with any specified reference conditions (e.g. averaging periods).

The concept of “levels associated with BAT” described above is to be distinguished from the term “achievable level” used elsewhere in this document. Where a level is described as “achievable” using a particular technique or combination of techniques, this should be understood to mean that the level may be expected to be achieved over a substantial period of time in a well maintained and operated installation or process using those techniques.

Where available, data concerning costs have been given together with the description of the techniques presented in the previous chapter. These give a rough indication about the magnitude of costs involved. However, the actual cost of applying a technique will depend

strongly on the specific situation regarding, for example, taxes, fees, and the technical characteristics of the installation concerned. It is not possible to evaluate such site-specific factors fully in this document. In the absence of data concerning costs, conclusions on economic viability of techniques are drawn from observations on existing installations.

It is intended that the general BAT in this chapter are a reference point against which to judge the current performance of an existing installation or to judge a proposal for a new installation. In this way they will assist in the determination of appropriate "BAT-based" conditions for the installation or in the establishment of general binding rules under Article 9(8). It is foreseen that new installations can be designed to perform at or even better than the general BAT levels presented here. It is also considered that existing installations could move towards the general BAT levels or do better, subject to the technical and economic applicability of the techniques in each case.

While the BREFs do not set legally binding standards, they are meant to give information for the guidance of industry, Member States and the public on achievable emission and consumption levels when using specified techniques. The appropriate limit values for any specific case will need to be determined taking into account the objectives of the IPPC Directive and the local considerations.

Manufacture of sulphite pulp is not a single process but a series of unit processes, often linked and inter-dependent. Therefore, it is always a suitable combination of techniques that constitutes BAT for sulphite pulp and paper mill. The order of priority and the selection of the techniques or combinations of techniques depend on the local circumstances.

Best available techniques given below are, if not stated otherwise, applicable to new and existing plants. In pulp and paper mills, the applicability of a technique is less driven by the fact whether a mill is new or existing. Pulp and paper mills are characterised by the fact that machinery is rebuilt rather than replaced whole-scale. The modular rebuilding and development of plants means that each site is a unique product of its location and history. On the other hand, there is a series of unit processes, which are common in all countries.

3.4.2 BAT for sulphite pulp and paper mills

Below, the techniques or combination of techniques that are considered as BAT for integrated and non-integrated sulphite pulp mills are given. The following list of BAT is not considered exhaustive and any other technique or combination of techniques achieving the same (or better) performance can also be considered; such techniques may be under development or an emerging technique or already available but not described in this document. For integrated sulphite pulp and paper mills it is refer to Section 6.4 where further details on BAT for papermaking are given. If not stated otherwise, the data refer to yearly average values.

General measures

1. Training, education and motivation of staff and operators. Pulp and paper mills are operated by people. Therefore, training of staff can be a very cost-effective way of reducing discharges of harmful substances.
2. Process control optimisation. To be able to reduce different pollutants simultaneously and to maintain low emissions, improved process control is required.
3. To maintain the efficiency of the technical units of pulp mills and the associated abatement techniques at a high level, sufficient maintenance has to be ensured.
4. Environmental management system which clearly defines the responsibilities for environmentally relevant aspects in a mill. It raises awareness and includes goals and measures, process and job instructions, check lists and other relevant documentation.

Measures for reducing of emissions to water

1. Dry debarking
2. Extended delignification in the closed part of the process. This is achieved by a combination of extended cooking and oxygen delignification. It has to be kept in mind that there is a difference in magnesium-bisulphite and magnefite-pulping concerning achievable kappa number after extended cooking.
3. Highly efficient brown stock washing and closed cycle brown stock screening. A carry-over from the washed pulp to the bleach plant of < 5 kg COD/t is achievable.
4. Effective spill monitoring, containment, and recovery system
5. Partly closing of the bleach plant when magnesium based cooking processes is being used. Up to now this technique leads to a slight loss of brightness and is therefore not generally considered as BAT. For products where brightness is crucial as fine paper this technique is not considered as BAT.
6. Closure of the bleach plant when sodium based cooking processes is being used.
7. TCF bleaching.
For bleaching of sulphite pulp the use of chlorine containing bleaching chemicals can be avoided. The application of high consistency peroxide bleaching results in short and efficient bleaching sequences.
8. Neutralising of weak liquor before evaporation
9. Re-use of most condensates in the process or separate biological treatment
10. Use of sufficiently large buffer tanks for storage of concentrated or hot liquids from the process
11. Primary treatment of wastewater
12. Biological wastewater treatment in activated sludge system or by use of other techniques achieving the same or better performance or efficiency
In addition to the process-integrated measures and primary treatment (item 1 to 10) biological treatment is considered BAT for sulphite pulp mills. Activated sludge plants consisting of equalisation basin, aeration basin, secondary clarifier and sludge handling show excellent performance for the treatment of pulp mill effluents. Low loaded activated sludge plants with a sludge load below 0.15 kg BOD/(kg MLSS*d) and typical retention times in the aeration basin of about one day are regarded as BAT. They can achieve high removal efficiencies and a stable treatment system. It should be noted that any other waste water treatment system with comparable emission levels and comparable costs can also be regarded as BAT.

When implementing suitable combinations of BAT achievable emission levels for non-integrated and integrated sulphite pulp mills are considered to be in the same range as far as the pulping side is concerned. For integrated mills, the measures related to pulp mills (Chapter 3) and additionally the measures described under the corresponding Chapter on papermaking (Chapter 6) have to be considered.

However, there are some techniques to consider that refer solely to integrated pulp mills as for example

- Effective separation of the water systems of the pulp and paper mill from each other
- Recycling of the pulp dilution water between the pulp and paper mills

Table 3.15 shows achieved emission levels of some pulp mills in Europe that have implemented a set of process-integrated BAT measures but not necessarily all and not necessarily to their full extent and biological wastewater treatment as well.

Example pulp mills	Reported achieved emission levels after biological treatment (annual averages)							Type of wastewater treatment
	COD [kg/Adt]	BOD ₅ [kg/Adt]	AOX [kg/Adt]	TSS [kg/Adt]	Total P [kg/Adt]	Total N ¹⁾ [kg/Adt]	Flow ²⁾ [m ³ /Adt]	
Gratkorn, AU Magnefite	39	2.6	-, - (TCF)	2.8	0.028	0.018	50	Anaerobic +activated sludge with pure O ₂
Mill 1, DE	22	0.9	-, - (TCF)	1.8	0.04	0.28	61	Anaerobic +activated sludge with pure O ₂
Mill 2, DE	23	0.5	-, - (TCF)	n./a.	0.04	0.3	80	Anaerobic +activated sludge
Mill 3, DE	36	1.55	-, - (TCF)	n./a.	0.015	0.085	55	Anaerobic +activated sludge (data for 1998)
Mill 4, DE	11 ³	n./a	-, - (TCF)	n./a	n./a	n./a	n./a	Flocculation of the bleach plant effluents+ trickling filter + activated sludge
Neusiedler, Kematen, AU	30	1.7	-, - (TCF)	1.7	0.047	0.053	48	Activated sludge

n/a. = no data available (TSS is no control parameter for pulp mills in DE because it is already part of the unfiltered COD)

Notes:
1) Tot N for German pulp and paper mills include only inorganic nitrogen compounds.
2) Cooling water and other clean water are discharged separately and are not included.
3) Calculated value. The mill has an integrated annual production of 26000 bleached sulphite pulp and 171170 folding boxboard. The mills produces oxygen bleached GW on site. According to mill experiences it is assumed that the wastewater treatment plant achieves a COD reduction rate of 70% for the effluents from the pulp mill.

Table 3.15: Examples of achieved emission levels to water after biological treatment of well performing existing pulp mills in Europe (reference year: 1997)

The list of mills is a selection of mills where data were available or provided and is therefore not intended to be complete. The data were provided by the TWG Members or gained from personnel communication. The method of analysis is the one used in the respective country

Assuming adequate design and capacity of the wastewater treatment plant and appropriate operation and control by skilled operators the following discharge **after** biological treatment is generally achievable:

Parameters	Units	Bleached sulphite ¹
COD	kg/ADt	20 – 30 ²
BOD	kg/ADt	1 – 2
TSS	kg/ADt	1.5 - 2.0
AOX	kg/ADt	(-)
Total P	kg/ADt	0.02 - 0.05
Total N	kg/ADt	0.15 – 0.5
Process wastewater amount ³	m ³ /ADt	40 - 55 ⁴

Notes:
1) Emission levels for non-integrated and integrated bleached sulphite pulp mills
2) Because of higher kappa number after cooking for magnefite process the BAT associated level is 35 kg COD/Adt
3) Cooling water and other clean water are discharged separately and are not included.
4) Process water from the paper mill in integrated sulphite pulp mills is not included

Table 3.16: Emission levels associated with the use of a suitable combination of best available techniques after biological treatment

For integrated sulphite pulp mills this figures refer only to the pulp produced. The emissions from papermaking have to be considered separately (see Chapter 6 papermaking). The water circuits however are linked and the water flow can not be simply be added

Table 3.16 should be read together with the following additional explanations:

- **Chemical oxygen demand (COD):** The reduction rate for COD is related to the types and amounts of effluents treated (e.g. condensates are more degradable than spills), the construction and hydraulics of the treatment plant and appropriate adjustment of the operating parameters. To be regarded as well performing plant the COD reduction rates in aerobic treatment should exceed 55%.
Consequently, emission levels of 20 - 30 kg COD/Adt can generally be achieved by bleached sulphite pulp mills. The concentration measured in effluents of these mills is in the range of 400 - 600 mg COD/l.
The most common reasons for less performing activated sludge plants are chosen design and overload.
- **Biological oxygen demand (BOD₅ or 7):** In well designed treatment plants BOD is removed almost completely (95% removal) from pulp mills wastewater when the carbon-phosphorus-nitrogen ratio and oxygen supply is maintained sufficient and well controlled. In case of disturbances or if some of the running parameters are moving away from the target level, the BOD concentration in effluents will start to increase. This calls for adjustment of the running parameters and/or analysis of the biomass. The BOD concentration in the effluent is related to the control of system and can be used as an indicator of the health of the active biomass.
The BOD concentration in treated effluents of 20 -30 mg/l is achievable. Depending on the water flow this corresponds to 1.0 kg BOD₅/Adt (at 20 mg/l and 55 m³ flow/Adt) and 1.7 kg BOD₅/Adt respectively (at 30 mg/l).
- **Total suspended solids (TSS):** Under normal operation conditions, the water from the secondary clarifier is fairly clear. The content of suspended solids is in the range of 20 to 30 mg/l. This corresponds to discharges of 0.8 - 2.0 kg TSS/Adt (at a water flow of 55 m³/Adt). The values depend on the surface load of the secondary clarifier and the characteristics of the biomass.
- **Adsorbable organic halogen (AOX):** TCF mills discharge virtually no chlorinated organics (no formation in bleaching).
- **Phosphorus and nitrogen (Tot-P and Tot-N):** Mineral nutrients are usually added to the biological treatment plant to keep the balance C : P : N which is of crucial importance for the growth of active biomass. It is necessary to find and keep a balance between incoming N- and P-compounds that are available for biomass and the amount of nutrients added which requires a certain fine-tuning of the nutrient feed. Often, pulp mills do not add phosphorus to their wastewater whereas nitrogen addition (usually as urea) is essential for pulp mills. When the system is well optimised the phosphorus discharge of below 0.5 mg tot-P/l and below 5 mg tot-N/l are achieved. The corresponding loads are 0.02 - 0.05 kg P/Adt and 0.15 - 0.5 kg N/Adt respectively (at a water flow of 50 m³/Adt).

To ensure a continuously well running wastewater treatment plant an emergency basin to protect the biomass from toxic or hot concentrated liquors and an equalisation basin to equalise load and flows can be beneficial.

Measures for reducing of emissions to air

1. Collection of concentrated SO₂ releases and recovery in tanks with different pressure levels
2. SO₂ releases from washing and screening operations and from vents of the evaporators can be recovered by collecting the gases and introducing them in the recovery boiler as combustion air.
3. Control of SO₂ emissions from the recovery boiler by use of electrostatic precipitators and multi-stage scrubbers for abatement of flue gases and collection and scrubbing of various vents.

4. Reduction of odorous gases by efficient collection systems. These gases can be either burned in the recovery boiler or washed in a separate washer (back-up system)
5. Emission optimised recovery boiler by controlling the firing conditions
6. Reducing SO₂ emissions from auxiliary boilers by using bark, gas, low sulphur oil and coal or controlling S emissions
7. Installation of low-NO_x auxiliary boilers (bark, oil, coal) and controlling combustion conditions
8. Cleaning of the auxiliary boilers (in which other biofuels and/or fossil fuels are incinerated) flue gases with efficient electrostatic precipitators to mitigate dust emissions.
9. Emission optimised incineration of residues (sludge from wastewater treatment, bark) with energy recovery

A combination of these techniques result in a range of emissions for the major source, the recovery boiler, as shown in Table 3.17. Not all examples stand for European sulphite pulp mills that are well performing in sulphur or NO_x reduction, or both. However, some of the mills have implemented a reasonable set of these techniques. In all mill cases the gaseous emissions are cleaned with modern gas cleaning equipment as electrostatic precipitators and multi-stage scrubbers (4 to 6 stages). Process related emissions cover recovery boiler and fugitive emissions as far as they are collected and burned in the recovery boiler.

It should be noted that a direct comparison of the achieved emission levels between countries is difficult due to uncertainties in the basis of data (lack of harmonisation in the methods of analysis and calculating emissions).

Reported emissions to the atmosphere from sulphite pulp mills (annual averages)			
Examples of sulphite pulp mills	Emission of gaseous sulphur from the recovery boiler (SO₂) in kg S/Adt	Emission of NO_x (sum of NO and NO₂ calculated as NO₂) from the recovery boiler in kg NO_x/Adt	Remarks
Mill 1, DE	0.95	2.7	5-stage scrubber
Mill 2, DE	0.7	2.2	
Mill 3, DE	1.5	2.8	
Mill 4, DE	0.75	1.1	
Mill 5, DE	1.1	2.2	
Neusiedler, AU	0.13	1.5	Ammonia injection
Hylte, SE	0.6	1.1	
Utansjö, SE	1.46	0.85	Use very little oil on the RB
Nymölla, SE	1	1.84	Started to use urea injection on one of the two RB (30% reduction)
Explanatory notes: n/a. = no data available; RB = Recovery boiler The emissions from auxiliary boilers are not included in the figures "total from process"			

Table 3.17: Examples of achieved emission levels to air of some existing pulp mills in Europe (reference year: 1997 for the German mills and 1998 for Austrian and Swedish mills)

The total emissions do not include the auxiliary boilers. The list of mills is a selection of mills where data were available or provided and is therefore not intended to be complete. It contains rather mills from different pulping countries in Europe. The method of analysing is the one used in the respective country

Depending on the type of the specific process-integrated measures implemented and the technical character of the mill the following atmospheric process emissions associated with the use of BAT can be generally achieved:

Parameters	Units	Bleached sulphite pulp mills
TSP	kg/ADt	0.02-0.15
SO ₂ as S	kg/ADt	0.5-1.0
NO _x as NO ₂	kg/ADt	1.0-2.0

Table 3.18: Emission levels from the pulping process (recovery boiler and fugitive emissions) associated with the use of a suitable combination of best available techniques (emissions from any auxiliary boiler are not included)

Table 3.18 should be read together with the following additional explanations. As far as concentrations of emissions are given they refer to daily averages and standard conditions of 273 K, 101.3 kPa and dry gas. The reference oxygen content is 5% for recovery boilers.

Dust emissions: In sulphite pulp mills, emission of particulates is controlled by electrostatic precipitators and multi-stage scrubbers. Dust emissions for recovery boilers between 5 - 20 mg/Nm³ or 0.02 - 0.15 kg TSP/ADt (with a gas flow of 6000 - 7000 m³/ADt) can generally be achieved by use of ESP and scrubbers.

SO₂ emissions: Reduction of SO₂ emission from flue gases by absorption in alkaline liquid is considered BAT. A removal efficiency for SO₂ of 95 + % is achievable. From recovery boilers equipped with multi-stage scrubber SO₂ emissions between 50 - 150 mg S/Nm³ or 0.3 - 1.0 kg S/ADt are achievable.

NO_x emissions: The emission of nitrogen oxides can be controlled by burner design (low NO_x burners) and modified combustion conditions (primary methods). The design of the recovery boiler (staged air feed systems) can result in relatively low NO_x concentrations. Achievable emission levels are in the range of 200 - 300 mg NO_x/Nm³ or 1.0 - 2.0 kg NO_x/ADt respectively.

Secondary methods as selective non-catalytic reduction (SNCR) are usually not in operation. However, there are available.

Odorous gases: Pulp mill odorous gases are collected and incinerated in the recovery boiler. A back-up system is considered as BAT.

Auxiliary boilers

Depending on the actual energy balance of the mill, the type of external fuels used and the fate of possible biofuels as bark and wood-waste additionally there are atmospheric emissions from auxiliary boilers to consider. Emission levels associated with BAT from auxiliary boilers incinerating own biofuels and different fossil fuels are given in Table 3.19. The total releases to air are very site specific (e.g. type of fuel, integrated or market pulp mill, production of electricity).

It has to be noted that auxiliary boilers within the pulp and paper industry are of a very variable size (from 10 to above 200 MW). For the smaller only the use of low-S fuel and combustion techniques can be applied at reasonable costs while for the larger also control measures. This difference is reflected in Table 3.19. The higher range is considered BAT for smaller installations and is achieved when only quality of fuel and internal measures are applied; the lower levels (in brackets) are associated with additional control measures like SNCR and scrubbers and are regarded as BAT for larger installations.

Released substances	Coal	Heavy fuel oil	Gas oil	Gas	Biofuel (e.g. bark)
mg S/MJ fuel input	100 - 200 ¹ (50 - 100) ⁵	100 - 200 ¹ (50-100) ⁵	25-50	<5	< 15
mg NO _x /MJ fuel input	80 - 110 ² (50-80 SNCR) ³	80 - 110 ² (50-80 SNCR) ³	45-60 ²	30 -60 ²	60 -100 ² (40-70 SNCR) ³
mg dust/Nm ³	10 - 30 ⁴ at 6% O ₂	10 - 40 ⁴ at 3 % O ₂	10-30 3% O ₂	< 5 3% O ₂	10 - 30 ⁴ at 6% O ₂
Notes:					
1) Sulphur emissions of oil or coal fired boilers depend on the availability of low-S oil and coal. Certain reduction of sulphur could be achieved with injection of calcium carbonate.					
2) Only combustion technology is applied					
3) Secondary measures as SNCR are also applied; only larger installations					
4) Achieved values when electrostatic precipitators are used					
5) When a scrubber is used; only applied to larger installations					

Table 3.19: Emission levels associated with the use of BAT for auxiliary boilers using different fuels

In a modern non-integrated mill the heat generated from black liquor and incineration of bark exceeds the energy required for the entire production process. However, fuel oil will be needed at certain occasions like start-ups.

Solid waste

1. Minimisation the generation of solid waste and recover, re-cycle and re-use these materials as far as possible.
2. Separate collection of waste fractions at source and, if necessary, intermediate storage of residuals/waste to make possible an appropriate handling of remaining waste products (e.g. utilisation outside the plant)
3. Incinerating all non-hazardous organic material (bark, wood waste, effluent sludge, etc.) in an auxiliary boiler, specially designed for burning of moist, low calorific value fuels (as e.g. fluidised bed boilers)
4. External utilisation of residuals/waste as substitutes in forestry, agriculture or other industries, if possible

It should be noted that there is little detailed and reliable information available on achievable amounts of solid wastes. There is a lack of statistical data and various terms for different waste fractions are used in Europe. Some countries report only those solid waste - primarily inorganic solid wastes - which no longer can be recycled or reused, but have to be disposed off to landfill. This implies that all the organic wastes, which have a reasonable heating value and/or which can be incinerated without the risk of hazardous emissions in the auxiliary boiler of a mill are already excluded from the given solid waste amounts (bark and wood waste, primary and biosludge from wastewater treatment). Hence, the solid waste disposed of at landfill comprises mainly boiler ashes, sludge, some wood and bark waste, rejects and miscellaneous cleaning and mixed household-type wastes. Other mills burn all organic waste fraction including the sludge in a on-site waste incinerator. Those mills have very low amounts of waste to be land-filled, if any.

Because of the lack of sufficient information on that matter it is not possible to present achievable values on the amount of non-hazardous solid waste to be land-filled. To give an indication about the amount of solid waste that might be expected at sulphite pulp mills that apply BAT the example of an Austrian integrated bleached sulphite pulp mill operating an on-site waste incinerator can be mentioned. In this case, the remaining solid waste after incineration is 3.2 kg DS/Adt (100% DS) that can be further utilized. It is assumed that bark and other wood residues as well as the mixed sludge from wastewater treatment are burned. Energy (steam) is recovered for the pulp production.

A small amount of hazardous waste is generated in all mills. Such waste include oil and grease residues, used hydraulic and transformer oils, waste batteries and other scrap electrical equipment, solvents, paints, biocide and chemical residues, etc. Normally they amount to about 0.05-0.1 kg/t of product.

Energy saving measures

In order to reduce the consumption of fresh steam and electric power, and to increase the generation of steam and electric power internally, a number of measures are available.

1. Measures for reducing heat losses and for low heat consumption:
 - High dry solids content of bark
 - High efficiency of steam boilers, e.g. low flue gas temperatures
 - Effective secondary heating system e.g. hot water about 85 °C
 - Well closed-up water system
 - Relatively well closed-up bleaching plant
 - High pulp concentration (MC-or HC technique)
 - Use of secondary heat to heat buildings
 - Good process control
2. Measures for low consumption of electric power
 - As high pulp consistency as possible in screening and cleaning
 - Speed control of various large motors
 - Efficient vacuum pumps
 - Proper sizing of pipes, pumps and fans
3. Measures for a high generation of electric power
 - High boiler pressure
 - Outlet steam pressure in the back-pressure turbine as low as technically feasible
 - Condensing turbine for power production from excess steam
 - High turbine efficiency
 - Preheating of air and fuel charged to boilers

The effect of this energy saving measures can often not be easily been shown in form of values because improvements depend on the situation of the mill before the measures were implemented.

In many European countries, information on energy balances of whole pulp and paper mills is poorly available in public. In Europe, different reporting schemes are used. Energy balances also depend to a certain extent on local conditions. Therefore the ranges of energy consumption of pulp mills shown in Table 3.20 should only be taken as an indication about the approximate need of process heat and power at energy efficient sulphite pulp mills. Further examples of energy efficient sulphite pulp mills including the specific conditions might be possible to add in a reviewed version of the BREF.

Type of mill	Process heat consumption (net) in GJ/ADt	Power consumption (net) in MWh/ADt	Remarks
Non-integrated bleached sulphite pulp	16 – 18	0.7 - 0.8	
Integrated bleached sulphite pulp and coated fine paper	17 – 23	1.5 - 1.75	Paper drying is more energy consuming than pulp drying
Integrated bleached sulphite pulp and uncoated fine paper	18 - 24	1.2 - 1.5	Fillers and surface size 10 - 30%
Notes: The units can be converted from MWh to GJ according to 1 MWh = 3.6 GJ and 1 GJ = 0.277 MWh			

Table 3.20: Energy consumption associated with the use of BAT for different types of production per tonne of product [data from Jaakko Pöyry, 1998]

Chemical usage

1. Availability of a database for all used chemicals and additives containing information on the chemical composition of the substances, degradability, their toxicity for men and environment and potential of bioaccumulation.
2. The principle of substitution is applied i.e. less hazardous products are used when available.
3. Prevention of inputs of hazardous substances into soil and groundwater
4. Measures to prevent uncontrolled development of normal operation and to reduce the consequences of accidents

3.5 Emerging Techniques

No emerging techniques identified. The short description of new pulping processes using organic solvents (organosolv pulping), which are described under Section 2.5 may also be considered by sulphite pulp mills. However, since none of the proposed organosolv processes have been implemented successfully in full scale, it is too early to make a conclusive judgement on that process alternative.

4 MECHANICAL PULPING AND CHEMI-MECHANICAL PULPING

In mechanical pulping the wood fibres are separated from each other by mechanical energy applied to the wood matrix causing the bonds between the fibres to break gradually and fibre bundles, single fibres and fibre fragments to be released. It is the mixture of fibres and fibre fragments that gives mechanical pulp its favourable printing properties. In the mechanical pulping the objective is to maintain the main part of the lignin in order to achieve high yield with acceptable strength properties and brightness. Mechanical pulps have a low resistance to ageing which results in a tendency to discolour.

The main processes and techniques are Stone Groundwood Pulping (SGW), Pressure Groundwood Pulping (PGW), Thermo-Mechanical Pulping (TMP) or Chemo-Thermo-Mechanical Pulping (CTMP). The main raw materials, yields on wood and end-uses of pulps are summarised in Table 4.1.

Pulping Process	Raw materials	Yield on wood	Typical end-uses
Groundwood pulp	Spruce and fir (softwood)	95-97 %	Printing & writing papers and newsprint
TMP	Spruce and fir (softwood)	93-95 %	Printing & writing papers and newsprint
CTMP	Dominantly spruce, but also aspen and beech, NaOH, SO ₂ and H ₂ O ₂	90-94 %	Printing & writing papers, tissue and packaging boards

Table 4.1: Main raw materials, yields and end-uses of mechanical pulps

Figure 4.1 gives an overview over the main steps in mechanical pulping

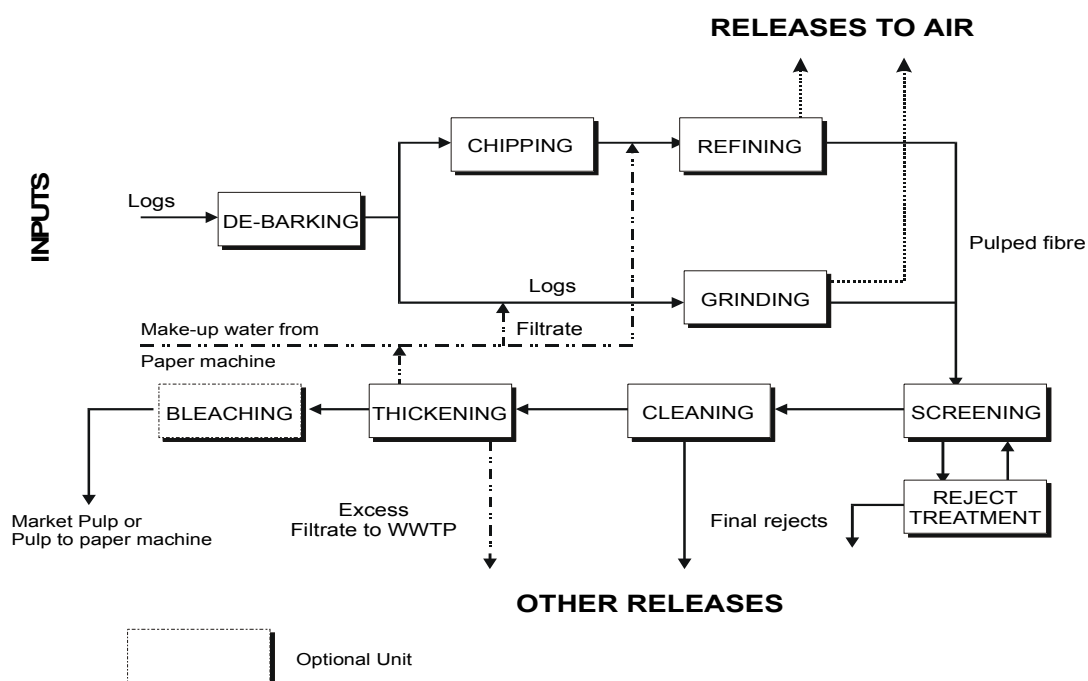


Figure 4.1: Main steps in Mechanical Pulping
[Guidance Note IPR 6/9]

There are two main processes used for the manufacturing of mechanical pulping. In the stone ground wood process (SGW) or in the pressurised ground wood process (PGW) logs are pressed against a rotating grinder stone with simultaneous addition of water. Refiner Mechanical Pulps (RMP, Thermo-Mechanical Pulps = TMP) are produced by defiberizing wood chips between disc refiners. The elements causing the mechanical action - grits on a pulp stone in the grinder and bar edges on a steel disc in the refiner - will give the resulting pulps a typical blend of fibres and fibre fragments. Groundwood pulp has a higher proportion of fine material and damaged fibres giving the pulp good optical and paper-surface properties. The more gentle treatment in the refiners produces a higher yield of intact long fibres which gives the pulp higher strength, which is valuable in furnishes for products with a high requirement on runnability.

The characteristics of the pulp can be affected by increasing the processing temperature and, in the case of refining, by the chemical treatment of the chips. Both steps will increase the energy consumption as well as the pollutant level because of a lower pulping yield. The chemi-thermo-mechanical-pulping process (CTMP), in which the wood is pre-softened with chemicals, is generally considered to be a mechanical pulping technique since the chemicals principally soften the lignin prior to the mechanical stage rather than fully dissolve it out as in true chemical pulping processes.

Most mechanical pulping is integrated with paper manufacture. Mechanical pulp is typically included in a paper furnish to increase the opacity of the paper product.

4.1 Applied Processes and Techniques

4.1.1 Groundwood Pulping

Groundwood pulping consists of a fibre line, reject handling and auxiliary systems. The latter are e.g. storage of chemicals and auxiliary steam and power generation.

The main unit processes of manufacturing of groundwood pulp are shown in Figure 4.2 [CEPI, 1997b]. Groundwood pulp mills are in practice always integrated with a paper mill and therefore the pulp is normally not dried with a drying machine.

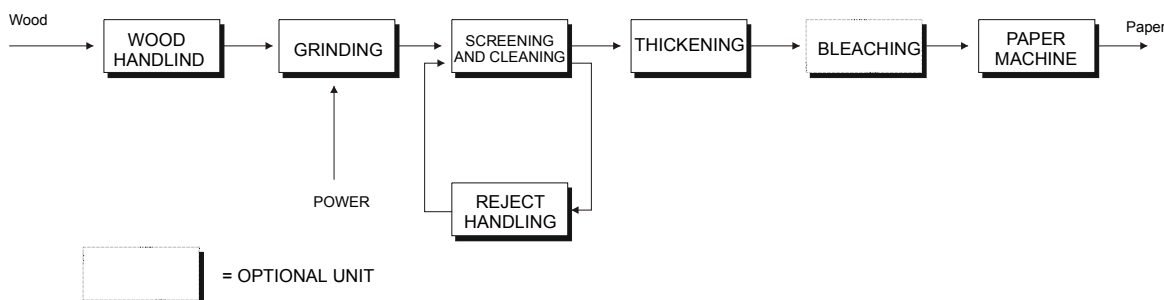


Figure 4.2: Groundwood pulping process

4.1.1.1 Wood Handling

The logs required for the groundwood process are obtained by thinning out forests and are usually 10-20 cm in diameter. If the wood for mechanical pulping is stored, drying should be prevented, e.g. through storage in water or sprinkling of log piles. This may require water collection systems in the wood yard in order to avoid discharge of organic substances collectively characterised as COD and toxicity. The bark has to be removed before the logs are processed. In debarking of pulpwood debarking takes usually place in drums where the contact

between rolling logs and water debarks them. Water is used in debarking often for de-icing and washing of wood in the debarking drum.

4.1.1.2 Grinding

The initial defibration takes place in grinders by forcing logs against special rotating grinding stones with the wood fibres parallel to the axis of a stone, producing a pulp at around 2% consistency. The grinder stones used are as a rule of the ceramic-bound type and have to be resharpened periodically.

Most of the energy put into the grinding process is transformed into heat. Wood is warmed and by presence of enough water lignin bonds are softened and fibres are released from the grinding surface. Grinding stones are cooled with shower water that is used also for disintegration of fibres and transportation to the next process stages. Therefore, for this process the availability of water is of basic importance (heat dissipation and friction reduction of the fibres).

The specific energy requirement (kWh/t) for groundwood production is an important process parameter e.g. an increase in the specific energy requirement is always linked with better strength properties, but also with a lower drainage capacity (freeness).

The superior strength properties of refiner mechanical pulps, especially for TMP, forced further development of the conventional grinding process for competitiveness reasons. The Pressure Grinding Process (PGW) was developed where the grinding process takes place at overpressure (up to around 3 bar). That allows the process to be operated with white water temperatures of 95°C and grinder pit temperatures of 125°C. The more intensive softening of lignin associated with this temperatures results in improved groundwood qualities (higher strength) but the technical and financial requirements are considerably higher. Subsequently low-pressure steam is generated when the pulp is de-pressurised. The recovered low-pressure steam is mainly used for the production of warm process water. Another, relatively inexpensive method to improve the quality of groundwood is the thermogrinding process (TGW). In this process the heat losses which result from evaporation in the grinding zone are reduced and the process temperature is optimised without using over-pressure but stability controllers.

4.1.1.3 Screening and Cleaning

All mechanical pulps contain undesired components such as large, insufficiently pulped fragments (e.g. coarse rejects) and the shives that consist of many fibre bundles. The shives have to be removed because they reduce the strength and the printing quality of the paper.

A screening installation consists of various stages in order to reduce the strain on subsequent installations and to save most of the acceptable components contained in the rejects. The screening out of the coarse rejects is easy to perform, but the removal of the shives requires a more elaborated technique. The shive content of unscreened mechanical pulp may be as high as 5% depending on the process used. The purpose of screening is to remove the shives to a large extent and, at the same time, to keep the simultaneous screening out of valuable long fibres as low as possible.

The coarse rejects are removed from the main pulp stream by vibrating flat screens equipped with perforated plates. Hammer mills or pulpers are used for the reduction of the coarse rejects. The retained coarse shives are usually added to the rejects of the fine screening system for further processing by means of filtration through pressure screens which retain shives above a certain size depending on the type of paper required.

The screening process is carried out at high dilutions (below 1 % dry content). The fine screening is followed by a centrifugal separation of fibres and other particles with different specific weights (centricleaners). Separated rejects of the last stage are thickened and treated with special reject handling equipment like reject refiners and are then recycled to the screening process (secondary screens and centricleaners). Accepted pulp from reject handling stages can be recirculated back to the main fibre line. Final rejects are discharged from the process as solid wastes. Depending on the reject handling concept the dry solids content of these wastes may vary between 5-30 % [CEPI, 1997b]. The screening reject rate may be as high as 30% of the inflow and in case of groundwood the energy requirement for screening, thickening and refining the screen rejects are significant (accounting for about 25% of the total energy).

The screened and cleaned mechanical pulp is thickened by use of disc filters or thickening drums and then stored in tanks and storage towers.

4.1.2 Refiner Mechanical Pulps

The objective of the refiner process is the same as that of groundwood manufacturing, i.e. the softening of lignin bonds and fibrillation of the wood fibres.

In refiner mechanical pulping, chips are ground between steel discs with bar patterns in a refiner. Depending on the quality, the refining can be repeated in a second-stage and sometimes even a third-stage refiner. The forces from the impact of the bars cause the chips to break down into fibre bundles, individual fibres and fibre fragments. With the progressing treatment the impact also modifies the walls of the individual fibres. Most of the applied energy (friction work) transforms into heat, which flashes part of the moisture in the chips. To prevent the wood from burning in the refining zone, cooling (dilution) water has to be added. The refiners normally operate at a high discharge consistency (25-50%). The large quantity of steam released in the refining process is normally captured in a heat recovery system for further use.

In the original refiner pulping process (RMP), which is hardly used today, chips were refined at atmospheric pressure. Because of the low temperature the process produced a high amount of damaged fibres but the optical properties of the RMP pulp were relatively good. To improve the pulp quality, process modifications aiming at increased softness of the wood in the refining zone have been applied. These included the preheating of chips (TRMP and TNP) or pressurisation of the refiner (PRMP). These processes produce pulps of slightly higher strength and reduced shive level at almost unchanged optical properties.

A more dramatic strength improvement and shive reduction is gained in the TMP process (4.1.2.1), where the chips are heated under pressurised conditions and the refining is also pressurised.

Mild chemical pre-treatment of the chips also enhances the softening of the wood and improves the properties of pulp produced by refining at atmospheric pressure (CRMP) or pressurised refining (CTMP, 4.1.2.2).

With stronger chemical treatment and refining at atmospheric pressure, pulps with high-strength properties can be produced from both softwood and hardwood. These mechanical pulps (CMP) are comparable to semi-chemical pulps.

4.1.2.1 Thermomechanical Pulping (TMP)

Thermomechanical pulping consists of a fibre line and auxiliary systems. The latter are e.g. reject handling, storage of some chemicals and auxiliary power generation. The main unit processes of manufacturing of TMP are shown in Figure 4.3.

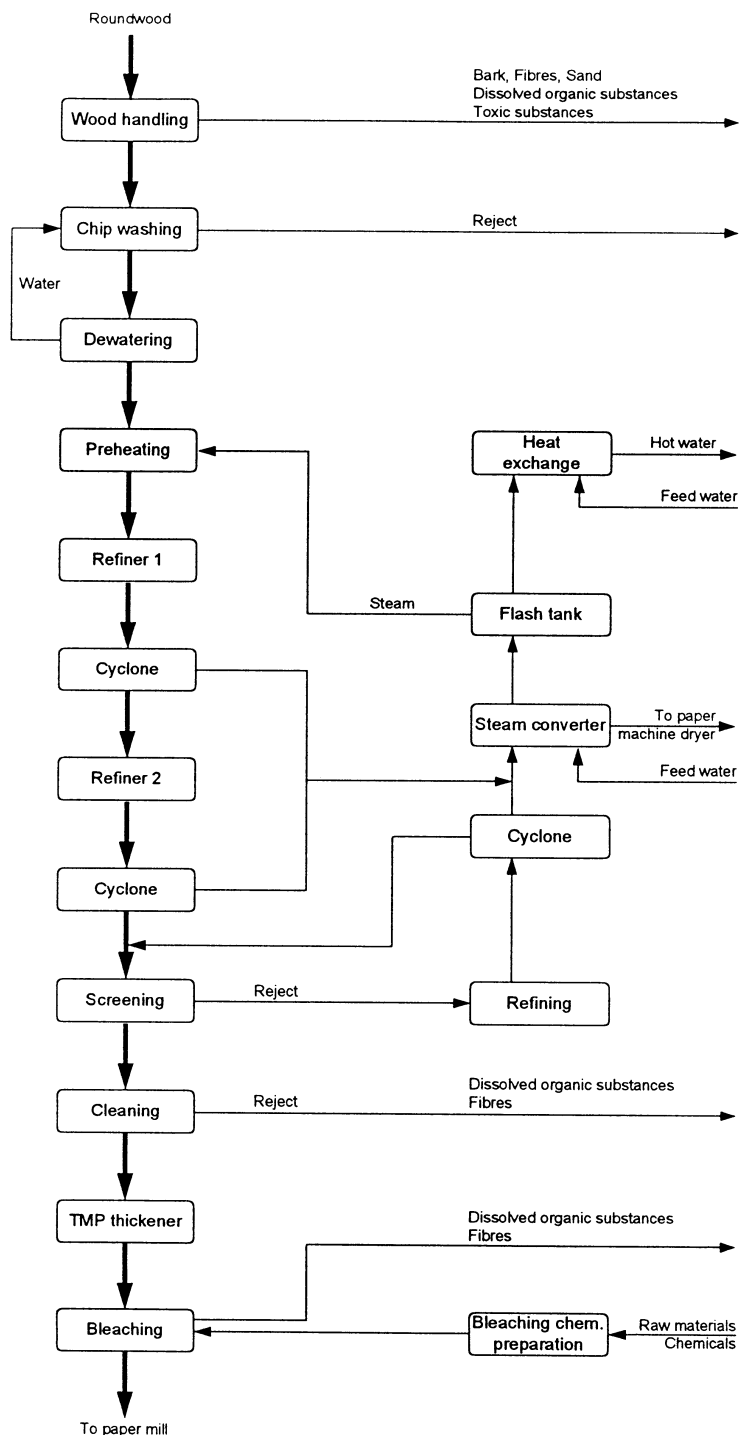


Figure 4.3: Schematic of the TMP process and emissions
[SEPA Report 4713-2, 1997]

In the following only the TMP process itself i.e. the main unit processes that have to be distinguished from groundwood pulping from an environmental point-of-view are described in more detail. For screening and cleaning, reject handling, thickening and bleaching of mechanical pulps it is referred to the corresponding paragraphs of Section 4.1.1 and 4.1.3.

In the thermo-mechanical pulping (TMP) process washed and screened wood chips are subjected to thermal pretreatment, and the disintegration and defibration process is carried out in a series of disc refiners at overpressure.

A certain amount of wood can be delivered as woodchips from sawmills. Sawmill and other off-site chips require only screening and storage in the woodhandling. If barked roundwood is used wood is first debarked and chipped. Chips for mechanical pulping must not contain stones, sand, scrap metal or other hard contraries that may cause wear or damage to the refiner plates. In most chips refining processes the chips are therefore washed to remove contraries before refining. This results in a reject from the chip washer as water effluent.

After chipping and washing, the raw material is preheated with steam and then refined either in a single stage at an elevated temperature and pressure or in a two-stage refining system in which the first stage is followed by a second refining stage under pressure or at atmospheric pressure. The pulping of screen rejects is often carried out in the second stage refiner. Part of the organic substances of the wood is dissolved in water and discharged from the process either from the mechanical pulp plant or from the paper machine side.

A large share of the comparatively high amount of electric energy required in refiner mechanical pulping is converted into heat as steam that is evaporated from wood moisture and dilution water in the refiners. Because of the pressurised conditions (excess pressures of up to 5 bar), in many mills, a significant amount of the steam generated may be recovered, cleaned through heat-exchanger to produce clean process steam, e. g. for the use in paper drying. A part of the energy of the released steam may also be recovered as hot water. After refining, the pulp is discharged and diluted, screened and cleaned. After screening follows dewatering and storage in a big pulp tower at high consistency. The application of more mechanical energy instead of chemical dissolution results in more pronounced fibre fragmentation and formation of fine material. The significance of water in the mechanical pulping processes implies that fresh wood is to be preferred as raw material. If the wood for mechanical pulping is stored, drying should be prevented, e. g. through storage in water or sprinkling of log piles. This may require water collection systems in the wood yard in order to avoid discharge of organic substances collectively characterised as COD and toxicity. The use of chips makes refiner-based pulping somewhat more versatile with regard to the supply of the raw material.

Since the wood loss during the TMP manufacturing is very low and most of the wood material is converted into pulp, the heat value of the wastewater in a TMP mill is too low to be recovered in the same way as in a chemical pulp mill (black liquor). This implies that external effluent treatment of the wastewater is normally necessary in a TMP mill.

TMP is nearly almost always produced in connection to a paper mill due to the possibility of reuse the heat from refiners for production of steam and better energy efficiency. Therefore, TMP is not normally dried with a drying machine.

4.1.2.2 Chemi-mechanical Pulping

The addition of chemicals in the refiner process has become important because wood chips can be impregnated very easily. The mild chemical pre-treatment of the chips enhances the softening of the wood and improves the properties of pulp produced by refining at atmospheric pressure (CRMP) or pressurised refining (CTMP). The latter combines the TMP process with a sulfonation of the wood chips. In most cases chemical pre-treatment increases release of pollutants as a consequence of the yield loss caused by the chemical treatment. Different kinds

of treatment are used for different wood species and the properties of the CTMP can be varied to a great extent by changing the amount and the nature of the chemicals. The chemi-mechanical pulping methods produce clean pulps of sufficient strength and acceptable optical properties and can be used as the main fibrous component in printing paper, packaging board and hygienic paper furnishes.

Chemi-mechanical pulping consists of a fibre line and auxiliary systems. The latter are e.g. reject handling, storage of some chemicals and auxiliary power generation. The main unit processes of manufacturing of CTMP can be seen in Figure 4.4.

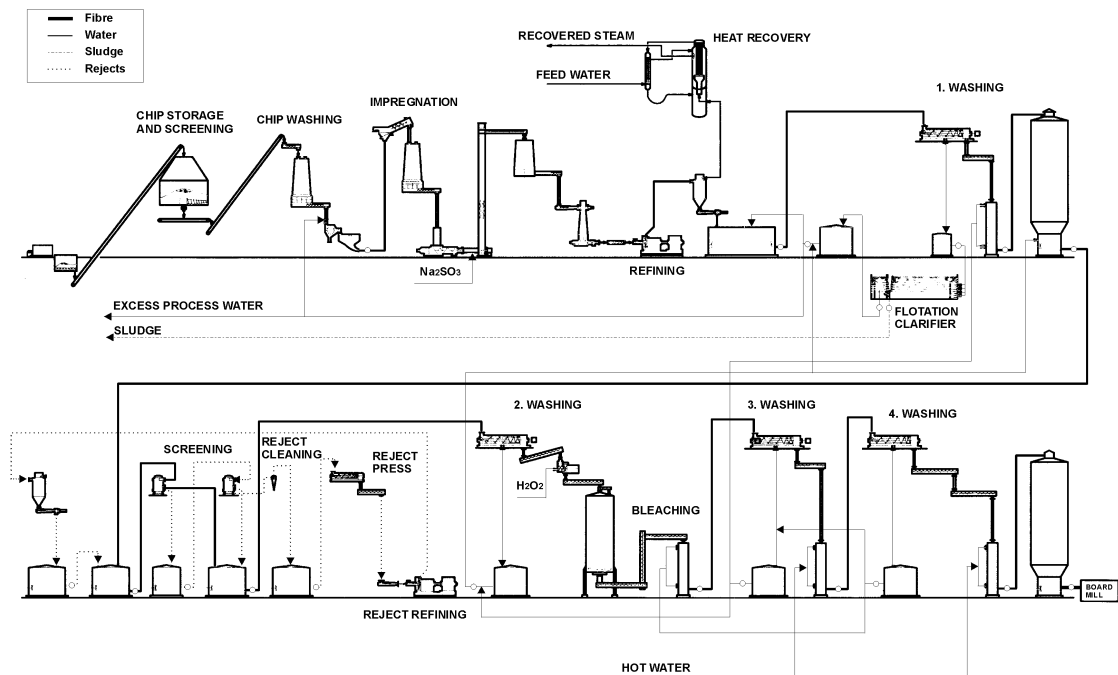


Figure 4.4: Schematic of the CTMP process
[By courtesy of a Finnish mill, 1998]

The CTMP process combines the TMP process with a chemical impregnation of the wood chips. In the following only the CTMP pulping process itself is described i.e. only the main unit processes that has to be distinguished from TMP pulping. For screening and cleaning, reject handling, thickening and bleaching of mechanical pulps it is referred to the corresponding paragraphs of Section 4.1.1 and 4.1.3.

After debarking, chipping, chip washing and screening the wood chips are first impregnated in an impregnation tower where the chips are immersed in an alkaline chemical solution. Sodium sulphite (Na_2SO_3) is mostly used for softwoods, and lately alkaline peroxide has been predominantly used for hardwoods. After chemical impregnation the chips are pre-warmed and their temperature increases further in the 1-2 stages refining machines (rotating refining plates) resulting in softening of lignin bonds and fibres are released. The manufactured CTMP is mixed with recycled process water, which is used also for disintegration of fibres and transportation to the next process stages.

A further development of the CTMP process is the CMP process. With stronger chemical treatment and refining at atmospheric pressure pulps with high strength properties can be produced from both softwood and hardwood. After chemical impregnation the chips are cooked in a temperature ranging from 70-170 °C. The cooking time depends from the process and can vary

between 15 minutes to a couple of hours. Different kinds of treatment are used for different wood species. Optical properties are drastically reduced and the yield can fall below 90%.

Both the increase in the refining temperature and the use of chemicals (alkaline treatment) increase the generation of pollutants as a consequence of the yield loss in refiner mechanical pulping. In most cases chemical pre-treatment increases the energy consumption. Optical properties are drastically reduced and CMP can only form a minor part of the furnish for printing papers.

CTMP is often produced in connection to a paper or board mill due to the possibility of reuse the heat from refiners for production of steam and better energy efficiency. However, CTMP is sometimes manufactured as market pulp and dried with a flash dryer up to 90 % dry solids content.

4.1.3 Bleaching of Mechanical Pulps

With the increased demand for high-brightness paper and board, the bleaching of mechanical pulps has become more common. The bleaching of mechanical pulp is in principle totally different than that of chemical pulps because it is based on lignin-saving methods instead of lignin-removing ones. The bleaching of mechanical pulps aims at changing chromophoric groups of lignin polymers into a colourless form. Thus, the bleaching of pulp increases primarily the brightness of pulp with minimum losses of dry solids and overall yield from wood. The effect is not permanent and the paper yellows to an extent with time. As it does not result in permanent brightness gain bleached mechanical pulp is more suitable for newsprint and magazine paper than for books or archive papers. The lignin-saving bleaching is carried out in 1-2 stages depending on the final brightness requirements of the pulp. The bleaching stages are distinguished according to the bleaching agent applied

Reductive bleaching uses sodium dithionite ($\text{Na}_2\text{S}_2\text{O}_3$)

In dithionite bleaching (symbolic shorthand: S) organic material is not dissolved from the pulp. Typically using 8 to 12 kg dithionite per tonne of pulp this technique results in a minimal yield loss and brightness can be increased by up to 12 units from an initial brightness level of 58-70 ISO to about 70 - 76% ISO [Finnish BAT Report, 1997]. A suitable pH value is 5.6 to 6.5 and a temperature up to 70°C accelerates the bleaching process. Residual dithionite in the pulp can cause corrosion with metallic components downstream in the process. In most mills a metal chelating agent (e.g. EDTA, DTPA) is used to prevent degradation of the dithionite. The consistency in conventional hydrosulphite bleaching is 3-5%. Medium consistency (MC) pumping has made it possible to bleach at 10-12% consistency with increased efficiency.

Oxidative bleaching using peroxide (H_2O_2)

The yield drop in peroxide bleaching (symbolic shorthand: P) is approximately 2%, mainly due to the alkalinity during the bleaching that results in an increasing dissolving of organic substances out of the wood (and in an increase of pollution load).

Peroxide bleaching influences the pulp properties - in addition to increased brightness, the strength of the pulp improves, the content of extractives is reduced and the water uptake capacity improves. When applying the maximum economical amount of peroxide an increase in brightness of up to 20 units to 78 - 84% ISO can be achieved [Finnish BAT Report, 1997]. The bleaching process results in lower brightness in the presence of heavy metal ions. Therefore, chelating agents (e.g. EDTA, DTPA) are added before bleaching to form complexes with heavy metals (Fe, Mn, Cu, Cr), which prevents the pulp from discolouring and the peroxide from decomposing. EDTA and DTPA contain nitrogen, which will show up in the wastewater. Introduction of a washing stage between pulping and bleaching is effective in reducing the

problematic metals and can thus reduce the amount of chelating agent needed and improve the effectiveness of the applied peroxide. The bleached pulp is finally acidified with sulphuric acid or sulphur dioxide to a pH of 5 - 6. Modern peroxide bleaching is conducted at a consistency level of 25 - 35%.

The two bleaching processes are also used as a combination of the two. A higher final brightness can be reached with peroxide bleaching than with dithionite bleaching but with reduced opacity. The achievable pulp brightness is dependent on the initial pulp brightness that in turn is feedstock and process related. In particular it is not only the wood species but also the degree of decay of the pulpwood, which is important.

4.2 Present Consumption/Emission Levels

4.2.1 Overview of input/output

An overview of raw material and energy input and the output of products, residues for further utilisation and major releases (emissions, waste etc.) of mechanical pulp and paper mills is presented in Figure 4.5.

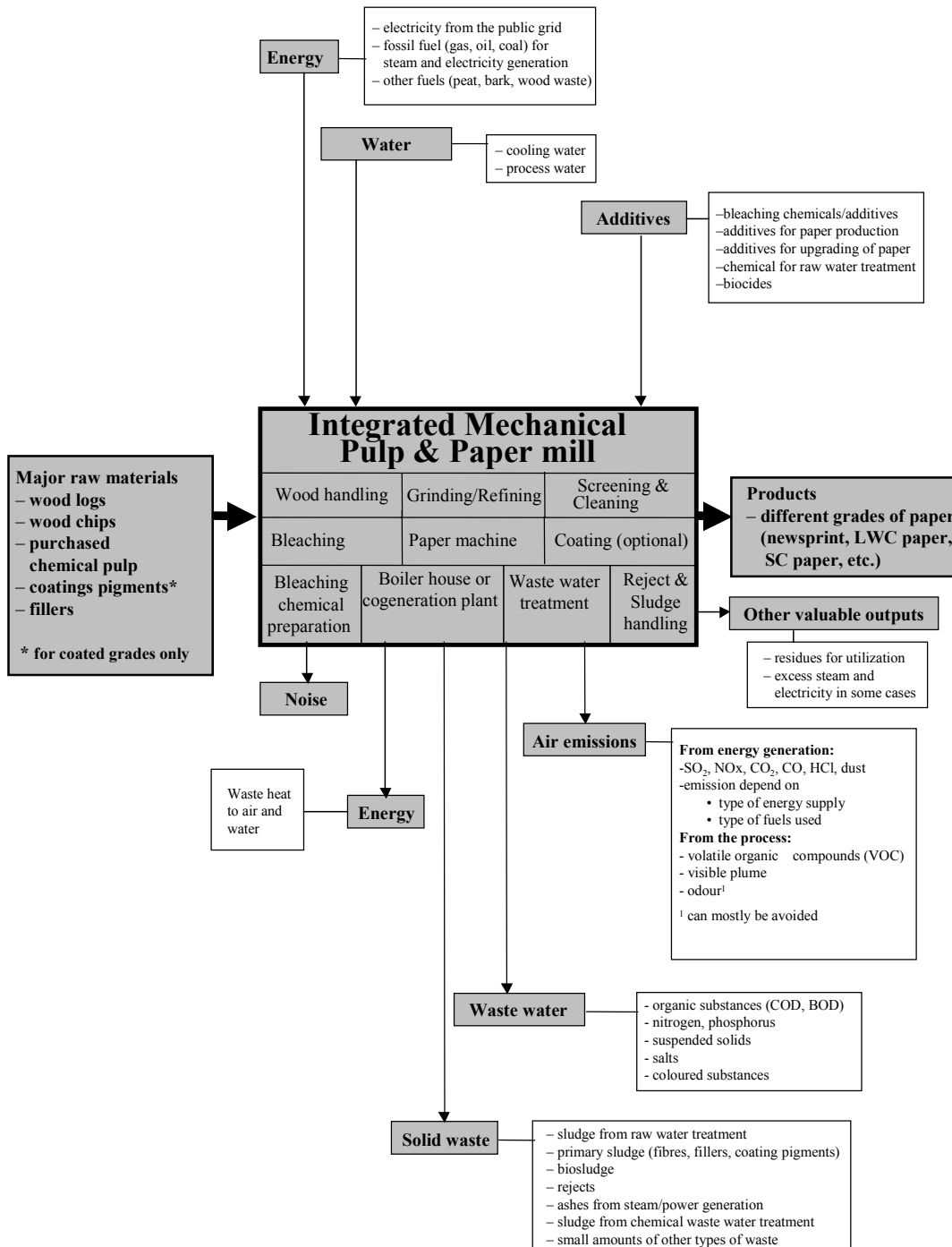


Figure 4.5: Mass stream overview of an integrated mechanical pulp and paper mill
The presence of some of the substances depend mainly on the paper grade and paper properties to be achieved and the type of energy supply

Consumption and emission levels for raw materials used and emissions generated from a whole mill are compiled below. Mechanical pulp mills are mostly integrated with paper production. Furthermore, very often different fibre sources are mixed for the manufacturing of a given paper as for instance chemical pulp, mechanical pulp and de-inked pulp may be mixed and in case of printing papers a relatively high amount of fillers and coatings are used.

Therefore, typical consumption and emission levels for whole mills given in Table 4.2 and Table 4.3 are related to integrated mechanical pulp and paper mills. They are presented to give a quick overview about the materials used and to provide guidance about the environmental impact to be expected. They are not representative in a sense that the given values cover the whole range of observed values in Europe but represent rather case studies of this type of mills.

The overall consumption and emission levels of an integrated wood-containing paper mill manufacturing coated printing paper (ULWC, LWC and HWC) from TMP are given in Table 4.2. This mill uses a mix of raw materials as fibre materials consisting of 60% TMP manufactured on site and 40 % purchased pulp (bleached kraft pulp and in a minor quantity de-inked pulp).

Input			Output		
Raw materials	Value	Unit	Product	Value	Unit
Wood chips from sawmills ¹⁾	361	kg/t	Printing paper	1000	kg/t
Purchased pulp ¹⁾	259	kg/t	Excess energy	132	kWh/t
Pigments (kaolin, talc, CaCO ₃) ¹⁾	343.5	kg/t	Emissions		
Bleaching chemicals/additives ²⁾	27	kg/t	CO ₂ ³⁾		kg/t
Additives for paper production ²⁾	4.6	kg/t	CO _{2, regenerative} ³⁾		kg/t
Additives for upgrading of paper ²⁾	57.3	kg/t	NOx ³⁾		g/t
Chemicals for raw water treatment	4.2	kg/t	CO ³⁾		g/t
Biocides	No data	kg/t	SO ₂ ³⁾		g/t
			Dust ³⁾		g/t
Energy			COD	2.7	kg/t
Natural gas	294	kWh/t	BOD ₅	0.17	kg/t
Fuel oil	ca. 3.2	kWh/t	Suspended solids		g/t
Purchased electricity	1852	kWh/t	AOX	< 0.4	g/t
Purchased steam	1140	kWh/t	Nitrogen	24	g/t
			Phosphate	4.3	g/t
Water demand			Wastewater flow	14.1	m ³ /t
Surface water	22	m ³ /t	Cooling water	12	m ³ /t
Well-water	4.4	m ³ /t	Residues		
Drinking water (sanitary facilities)	0.2	m ³ /t	Rejects and sludge (dried to 75 % moisture)	46	kg/t
			Saw dust	8.8	kg/t
			Metal scrap	2.5	kg/t
			Hazardous waste (e.g. used oils, mixtures of solvents)	0.3	kg/t
Explanatory notes:					
1) The fibrous material is referred to t absolute dry, i.e. without moisture. In fact, the average moisture content of the raw material used is 50 % for wood chips, 9 % for purchased kraft pulp, 45 % for DIP and 0.2 % for pigments. The moisture content of the final product is about 4 - 5 %.					
2) Additives are expressed as commercial solutions containing various amounts of water. As bleaching chemicals are used: 30 kg/t H ₂ O ₂ , 15 kg/t NaOH, 15 kg/t sodium silicate and 3 kg/t DTPA. As additives are used: 43 kg/t synthetic binders (latex), < 8 kg/t starch, 1 kg/t retention agent (polyacrylamide), fixing agents, poly DADMAC, hardness stabilisers, various biocides					
3) Emissions to air could be calculated from the emissions generated at the external power plant (principle of combined heat and power) that supplies power and steam to the paper mill. The whole electricity required for the TMP plant and 75% of heat needed for the whole site is based on external supply. Natural gas is used for infrared drying. Fuel oil is only used for heating of the buildings.					

Table 4.2: Yearly average values (reference year: 1997) of consumption and emission levels from a German mill for the manufacturing of wood-containing printing paper (LWC, ULWC, HWC) based on oxidative bleached TMP (60 % of the fibrous material)

Total production of the mill: 370000 t/a printing paper; The effluents are treated in a two-stage biological treatment (activated sludge)

The overall typical consumption and emission levels of a CTMP mill are given in Table 4.3.

Input			Output		
Raw materials	Value	Unit	Product	Value	Unit
Wood	1090	kg/t	CTMP pulp	1000	kg/t
Na ₂ SO ₃	25 (20 - 30)	kg/t	Excess energy	600 - 1200 ¹⁾	kWh/t
DTPA	2 (1 - 2.5)	kg/t	Emissions		
Bleaching chemicals (H ₂ O ₂)	10 - 40	kg/t	NOx	250	g/t
Chemicals for raw water treatment	0 - 2	kg/t	SO ₂	240	g/t
Sodium silicate	8 - 30	kg/t	Dust	50	g/t
			COD	15 (12 - 25)	kg/t
			BOD ₅	1 (0.5 - 2)	kg/t
			Suspended solids	0.5 (0.1 - 2)	kg/t
			AOX	0	g/t
Energy			Tot-N	400 (300-500)	g/t
Wood residuals	600	kWh/t	Tot-P	10 (5 - 50)	g/t
Fuel oil	200	kWh/t	Wastewater	20 (10-30)	m ³ /t
Purchased electricity	1800 (1500-3000)	kWh/t	Cooling water	0 - 20	m ³ /t
			Residues		
Water demand			Rejects and sludge	30 (15 - 40)	kg/t
Surface water	20 (10 - 30)	m ³ /t	Ashes	7	kg/t
			Hazardous waste (e.g. used oils, mixtures of solvents)	10	kg/t
Note:					
1) The figures refer to the case that no drying is applied i.e. integrated pulp and paper production. The heat energy may be used in the paper machine.					

Table 4.3: Yearly average values of consumption and emission levels from Finnish CTMP mills
The values refer to a non-integrated mill built in 1985 with some modernised equipment; production capacity: 110000 t/a bleached CTMP (CSF 400) for hygiene papers. The values in brackets reflect typical levels from CTMP mills. The effluents are treated in a biological treatment plant (activated sludge)

4.2.2 Consumption and emission levels arising from process units

In mechanical and chemi-mechanical pulping the wastewater effluents, the relatively high consumption of energy that is often generated on site and rejects and sludge from different parts of the manufacturing process and above all from the wastewater treatment plant are centres of environmental concern.

The most relevant consumption of raw materials and emissions to water, air and soil (waste) as well as energy aspects are discussed below covering the following aspects:

- Wood consumption
- Water use
- Wastewater emissions
- Emissions to the atmosphere from: refiners, energy generation and bark boilers.
- Solid waste generation
- Consumption of chemicals
- Use of energy
- Noise

As for the reported emission and consumption figures, it should be borne in mind that, due to the use of some different measurement methods in the various Member States, data are not

always strictly comparable from country to country. (See Annex III for more information on this issue but the different methods used do not alter the conclusions drawn in this document).

4.2.2.1 Wood consumption

In the production of groundwood pulps wood has to be delivered as logs due to the construction of grinding machines. In TMP and CTMP pulping processes wood is used as chips and therefore both processes can use roundwood or chips from sawmills, woodpanel or particleboard industries.

High yields are characteristic for mechanical pulping where the losses occurring during the process, mainly in the form of dissolved ligneous substances, are low. The use of wood is normally between 2.4 m³/ADt and 2.6 m³/ADt for groundwood, 2.3 m³/ADt and 2.8 m³/ADt for TMP and 2.8 m³/ADt and 3.0 m³/ADt of chemithermomechanical pulp [CEPI, 1997b].

4.2.2.2 Water use

In mechanical pulping processes the water systems are usually quite closed in order to maintain high process temperatures. Fresh water is only be used for sealing and cooling as surplus clarified waters from the paper machine are usually used to compensate for the water leaving the circuit with the pulp (5-10 m³/tonne of pulp) and the rejects. For a TMP mill sources of emissions to water are wood handling, cleaning and bleaching (see Figure 4.3).

Most of the mechanical pulp mills are integrated mills i.e. their water and energy management is closely linked to the paper mill that manufactures different coated or uncoated paper grades. Typical ranges of overall water consumption for GW, TMP and CTMP processes are shown in Table 4.4.

Pulping process	m ³ /ADt of pulp
Groundwood	5 - 15
TMP	4 - 10
CTMP	15 - 50

Table 4.4: Water consumption in mechanical pulping
The water consumption of the paper mill is not included

In Figure 4.6 the sources of emissions to water and main substances of concern from a CTMP mill are shown. Strict counter-current water system is applied i.e. clean wash water is used for the last wash press and led towards the fibre flow. The high-polluted filtrate from the first press is send to effluent treatment. The liquid stream after separation of the fibres may be treated by flotation to take out solids from water before sending them to wastewater treatment plant as well. Sealing and cooling waters are collected and used as process water. If the volume of the white water tank is sufficient i.e. no addition of fresh water is needed to keep the tank levels a consumption of about 10 m³ fresh water per tonne of pulp is required. If the properties of the final product require a low content of extractives (in case of board pulp or fluff pulp) or fines (in case of fluff pulp) some more fresh water may be needed. On the other hand an internal treatment of the white water from the first washing stage by use of a flocculation/ flotation unit results in water consumption below 10 m³/t. The flocculation-flotation unit removes extractives and fines and about 40 - 50 % of the COD.

4.2.2.3 Wastewater emissions

Figure 4.6 gives an overview about the emissions to water from CTMP mills.

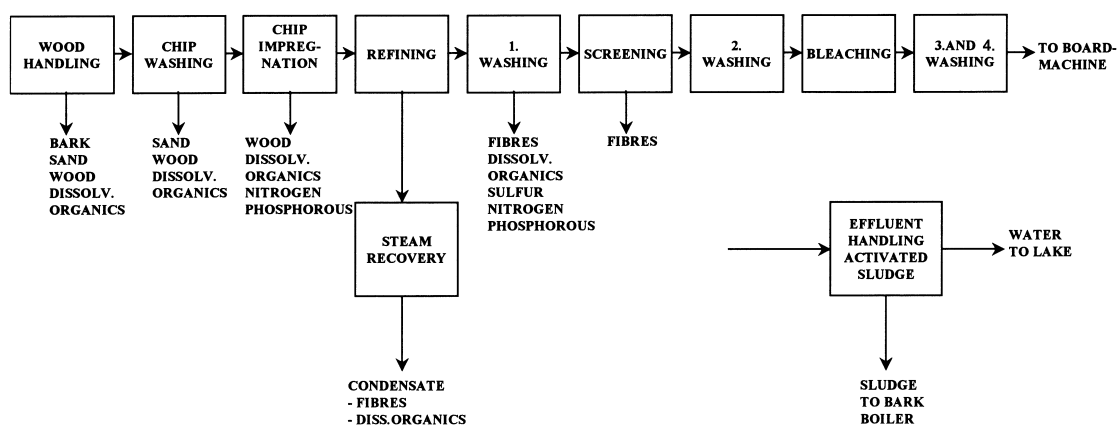


Figure 4.6: Emissions to water from a CTMP mill

Emissions to water are dominated by oxygen consuming organic substances that are lost in the water phase in the form of dissolved and dispersed organic substances. A yield of 92-97 % means that 30-80 kg /tonne of the wood in form of solid and dissolved substances are lost during processing. The yield is dependent on the energy input and the temperature in the process and on the use of chemicals. Wood species, seasonal variations and storage conditions of the wood also influence the amount of dissolved solids. During mechanical pulping, the stability of the cellulose and the lignin is not affected, but simple carbohydrates, hemicelluloses, lignins, extractives (e.g. fatty and resin acids), proteins and inorganic substances including nitrogen and phosphorus are dissolved and dispersed in the process water. With a decreasing yield and increasing temperature the organic load of the water from pulping increases.

Typical specific loads measured such as BOD₅, COD and nutrients (phosphorus and nitrogen) for different pulps are listed below.

Pulping process	Yield [%]	BOD ₅ [kg/t]	COD [kg/t]	Nitrogen [g/t]	Phosphorus [g/t]
GW	96-97	8.5-10	20-30	80-100	20-25
PGW	95-96	10-13	30-50	90-110	20-30
PGW-S	95-96	11-14	45-55		
RMP	95-96	10-15	40-60	90-110	20-30
TMP	94-95	13-22	50-80	100-130	30-40
CTMP (bleached CTMP)	92-94 (91-93)	17-30 (25-50)	60-100 (80-130)	110-140 (130-400)	35-45 (50-60)

Table 4.5: Typical specific loads such as BOD₅, COD and nutrients in water from the mechanical pulping of Norwegian spruce (*Picea abies*) before external treatment [Finnish BAT Report, 1997 and figures in brackets based on personal information from Finnish CTMP mills]. BOD₇ has been converted into BOD₅ by use of the formula $BOD_7/1.16 = BOD_5$ proposed within the same report

If mechanical pulp is bleached in an alkaline peroxide step the releases of organic pollutants increase significantly due to the alkalinity during the bleaching. The yield loss in connection with peroxide bleaching is 15-30 kg/tonne corresponding to an additional load of approximately 10-30 kg O₂/tonne measured as COD respectively. The upper values of the table above are related to peroxide bleached mechanical pulps. Whereas in TMP mills using only hydrosulphite as bleaching chemical COD levels of 2500 - 3000 mg O₂/l have been measured referring to a water flow from the TMP mill of 3-4 m³/t (paper machine not included). A groundwood mill has reported COD concentrations before treatment between 1700 and 2000 mg O₂/l.

The discharge of nitrogen in mechanical pulping originates from the wood and chelating agents (e.g. EDTA; DTPA) used in bleaching. A dosage of 2-3 kg EDTA/tonne of pulp results in an additional discharge of 150-220 g nitrogen/tonne of pulp. The discharge of phosphorus depends on the wood. Emissions of nutrients (nitrogen and phosphorous) are low but may have a negative impact due to eutrophication.

About 20-30% of the bark (referred to dry bark) is water-soluble of which 50-60 % consists of phenolic substances and about 25% soluble carbohydrates. Depending on the storage of wood carboxylic acids and alcohols might also be found in effluent from the debarking plant. Some compounds discharged from mills show toxic effects on aquatic organisms before treatment as e.g. some of the extractive components like resin acids that may be leached from bark in the wood handling. The wastewater from debarking is usually treated together with other wastewater streams in external treatment plants.

Additives used for papermaking may cause a measurable part of the organic discharge after treatment because some substances are heavily degradable. Emissions of coloured substances may affect the living species in the recipient negatively, since the water transparency is decreased.

The releases after treatment from the mills depend mainly on the design and operation of the processes that cause the major part of discharges and the wastewater treatment plant applied. The efficiency of biological wastewater treatment at mechanical pulp mills resembles that of chemical pulp mills. The COD reduction is however normally higher at levels between 70 and 90%. Moreover, at several plants tertiary treatment is employed which polishes the effluent thereby reducing discharges further. This is particular true for pollutants associated with TSS.

Pulping process	Flow m ³ /t	BOD ₅ kg/t	COD kg/t	tot-P g/t	tot-N g/t	TSS kg/t
CTMP	8-40	0.5-9	12-30	5-50	200-500	0.1-12
TMP	15-25	0.2-1.7	2- 8	5-15	60-160	0.5-1.5

Table 4.6: Emissions achieved with activated sludge treatment at mechanical pulp mills
[Comments from Swedish EPA and information from Finnish CTMP mills]

Much higher values are reported elsewhere for mills employing less effective effluent treatment.

For CTMP plants there are a few alternatives how to treat the wastewaters: the activated sludge treatment in one or two stages with or without a chemical treatment; internal treatment of the first stage white water plus activated sludge treatment for other effluents; evaporation and burning of the most contaminated wastewater and activated sludge treatment of the rest; a combination of anaerobic and aerobic treatment of wastewater. Today the activated sludge treatment is the most common technique and if properly designed a BOD-reduction of 98% and a COD-reduction of 85% is easily reached. The reason why the anaerobic treatment is not used more commonly for CTMP mill effluents is that anaerobic systems are relatively sensitive to disturbances.

There are an increasing number of paper mills in Europe that manufacture and use not only one single type of pulp but different types of pulps at one site. For instance, a paper mill manufacturing mainly newsprint and SC printing papers may use a combination of raw materials like mechanical pulp (groundwood and TMP), de-inked pulp from recycled papers and a certain amount of purchased chemical pulp. In this type of mills the water system is closely linked between the different processes. A German paper mill that manufactures newsprint and SC papers from 45000 t TMP/a, 85000 t/a groundwood, 220000 t/a DIP, 45000 purchased kraft pulp and 93000 pigments has reported organic pollutants before treatment as 14 kg COD/t and 6.3 kg BOD₅/t respectively. After biological treatment in an activated sludge system the following values have been measured: COD: 3.4 kg/t, BOD₅: 0.1 kg/t, total water flow: 12 -13 m³/t; nitrogen: 0.2-4.2 mg/l, phosphate: 0.3-1.3 mg/l, AOX: 0.11 mg/l.

4.2.2.4 Emissions to the atmosphere

Volatile Organic Carbons (VOC)

Atmospheric emissions from mechanical pulping are mainly linked to emissions of VOC. Sources of VOC emissions are evacuation of air from chests from wood-chips washing and other chests and from sparkling washer where steam released in mechanical pulping processes contaminated with volatile wood components is condensed.

The concentrations of volatile organic compounds depend on the quality and freshness of the raw material (wood) and the techniques applied. The emitted substances include acetic acids, formic acids, ethanol, pinenes and turpenes. A German TMP mill has reported the following concentrations of organic substances **before** external treatment:

Process stage	Emission of organic substances
Sparkling washer	- total organic C: 6000 mg/m ³ (highest individual value: 9600 mg/m ³) - pinenes ¹⁾ : 13000 mg/m ³
Washing of wood-chips	- total organic C: 300 mg/m ³ - pinenes ¹⁾ : 500 mg/m ³
Evacuation of air from other chests	- total organic C: 150 mg/m ³ - pinenes ¹⁾ : 50 mg/m ³
1) Mostly pinenes (C ₁₀ H ₁₆) but also including other volatile organic substances of class III of the German Technical Instructions on Air Quality Control; if the total mass flow is > 3 kg/h the mass concentration shall not exceed 150 mg/m ³	

Table 4.7: Emissions of volatile organic compounds from a German TMP mill before treatment
A CTMP mill reported 200 g terpenes per tonne of pulp before treatment

There are different options to reduce the VOC emission. Recovery of turpenes from those contaminated condensates that contain mainly turpenes or incineration of the exhaust gas in the on-site power plant or a separate furnace are available alternatives. In that case, about 1 kg VOC/t of pulp is emitted from the process. Some VOCs may be released from wastewater treatment and unquantified emissions also occur from chip heaps.

An overview of the emissions to the atmosphere from a CTMP mill is shown in Figure 4.7.

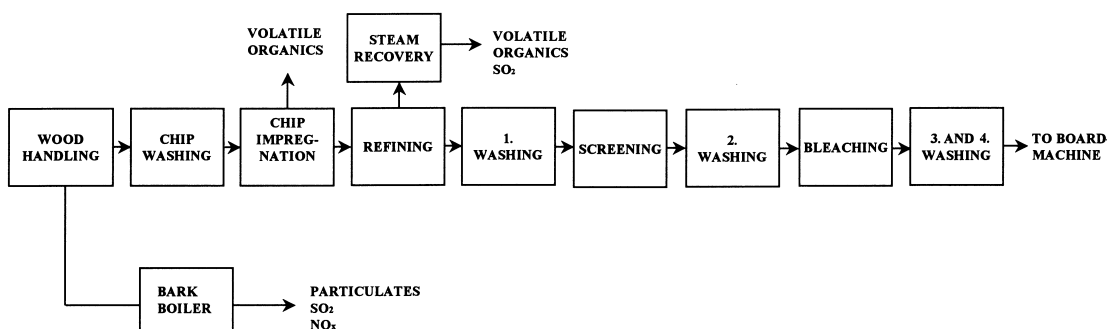


Figure 4.7: Emissions to the atmosphere from CTMP mills

The atmospheric emissions originate mainly from chip impregnation and steam recovery (VOCs) and the bark boilers where wood residuals are burned (particulates, SO₂, NO_x).

Emissions from energy generation

Like in other pulp and paper mills, mechanical pulping generates emissions to the air that are not process-related but mainly related to energy generation by combustion of different types of fossil fuels or renewable wood residuals. The fossil fuels used are coal, bark, oil and natural gas. In a typical integrated paper mill that uses mechanical pulp high-pressure steam is generated in a power plant. The energy is partially transformed into electricity in a back pressure turbo-generator and the rest is used in paper drying. The power plants burning solid fuels have electrostatic precipitators for the removal of particulates from the flue gases. The emission of sulphur dioxide is limited by using selected fuels. Depending on the local conditions there are paper mills in Europe using different amounts of energy from external supply.

Emissions from bark boilers

For refiner mechanical pulps the removed bark is usually burned in bark boilers. Together with the bark parts of the rejects and sludge might be incinerated. There are some mechanical pulp mills that use no roundwood as raw material but wood chips from sawmills.

4.2.2.5 Solid waste generation

The solid waste removed from the mechanical pulping processes consists of bark and wood residues from the debarking, washing and screening of chips (about 1.5 % reject), fibre rejects (primary sludge), ash from energy production and excess sludge from external biological wastewater treatment. The wood-containing residues are usually burned in the bark boiler. Ashes are usually disposed off or used in the building material industry.

The biggest waste fraction consists of different types of sludge mainly fibre containing primary sludge and excess sludge from biological wastewater treatment. The amount of waste for disposal can be reduced by increase of the de-watering performance of the sludge press. If the sludge has to be transported for further treatment e.g. incineration it is reasonable to dry the sludge with excess heat from the process (e.g. hot air) up to 75 % dry solid content.

The options for further use depend on the quantities and qualities of the sludge produced. Primary sludge may be used as additional material in the brick industry or may be incinerated on or off site. For suitable solutions for further treatment of sludge and rejects it is reasonable to held different types of sludge separately.

A chemical analysis of primary and secondary sludge from a German mechanical pulp and paper mill showed the following results:

Parameter	Unit	Primary sludge	Excess sludge
Dry solid content	%	47.9	31.7
Volatile solids	% DS	33.2	48.3
TOC	% DS	19	23
Arsenic	mg/kg DS	1.6	2.3
Lead	mg/kg DS	41	22
Cadmium	mg/kg DS	< 0.67	<0.67
Chromium _{total}	mg/kg DS	24	17
Copper	mg/kg DS	238	71
Nickel	mg/kg DS	5.7	7.5
Mercury	mg/kg DS	0.08	0.09
Zinc	mg/kg DS	141	135

**Table 4.8: Composition of primary sludge from sedimentation tanks and composition of excess sludge from the activated sludge plant
Report from a German mechanical pulp mill (GW & TMP)**

4.2.2.6 Consumption of chemicals

The main chemicals used for mechanical pulping are bleaching chemicals and in case of CTMP the chemicals used for impregnation of the wood chips.

If dithionite bleaching is applied (NaHSO_3) a maximum charge of dithionite of about 8 to 12 kg per tonne of pulp is mixed to the pulp. In most mills a metal chelating agent (e.g. EDTA, DTPA) is added.

Oxidative bleaching with peroxide (H_2O_2) is carried out in the pH range of 10-10.5. The pH has to be adjusted with sodium hydroxide (NaOH). The maximum economical amount of peroxide is 3 - 4% (50% solution) of the amount of pulp. Sodium silicate is added (1.5 - 4 % of the amount of pulp) to buffer the pH and stabilise the peroxide. Chelating agents (e.g. EDTA, DTPA) are used to form complexes with heavy metals (Fe, Mn, Cu, Cr), which prevents the pulp from discolouring and the peroxide from decomposing. The dosage of chelating agents is about 5 kg per tonne of pulp. EDTA and DTPA are heavily degradable and contain nitrogen, which will show up in the wastewater. The bleached pulp is finally acidified with sulphuric acid or sulphur dioxide to a pH of 5-6.

The ranges of chemicals used vary largely because they depend on the main process used for bleaching of the mechanical pulp. For instance, if reductive dithionite bleaching is used H_2O_2 , NaOH , NaSiO_3 , $\text{H}_2\text{SO}_4/\text{SO}_2$ are not used at all ("0"). Furthermore, the quality of the wood is an important factor. The pulping of chips from shavings from saw mills result in a lower initial pulp brightness (5 - 6 points lower) than the pulping of wood chips from fresh round-wood. Therefore, the latter needs less bleaching chemicals to achieve a comparable brightness. For fresh pulpwood less polluting reductive bleaching might be sufficient.

Substances	Amount of chemicals used for GWP [kg/t]	Amount of chemicals used for TMP [kg/t]	Amount of chemicals used for CTMP [kg/t]
NaHSO_3	0 - 12	0 - 12	-
H_2O_2	0 - 30	0 - 40	0 - 40
NaOH	?	0 - 20	0 - 25
NaSiO_3	0 - 40	0 - 40	0 - 40
EDTA/DTPA	0 - 5	0 - 5	0 - 5
$\text{H}_2\text{SO}_4/\text{SO}_2$	-	-	0 - 10
Na_2SO_3	-	-	25 - 30

Table 4.9: Consumption of main chemicals in kg/t for bleached grades of mechanical pulp
All chemical consumption are expressed as commercial solutions containing various amounts of water

In integrated mechanical pulp mills a lot of other additives may be used depending on the final paper product (further information on the use of additives can be found in ANNEX I).

4.2.2.7 Energy use

The specific energy consumption in mechanical pulping is dependent on the particular pulping process, the properties of the raw material and, to a large extent, the quality demands on the pulp set by the end product. The freeness value (Canadian Standard Freeness = CSF) characterises the drainage properties of the pulp and is usually used for specifying the quality of the pulp. A low freeness value indicates a slow draining pulp with a high degree of fibrillation. For the manufacturing of a pulp with lower freeness (better strength) the energy input in the grinding or refining is increased. Besides the drainage properties, the distribution between long fibres and fine material in a specific pulp and the softness of the fibres is controlled by the energy input. The type of paper and board in which mechanical pulp is used determine the requirements for freeness, brightness and other properties. Wood containing printing paper, e.g. LWC, SC magazine paper (freeness 20-60 ml CSF) and newsprint (freeness 80-150 ml CSF) are the most common products. The pulps are also used in paper board (freeness 450-750 ml CSF), tissue (300 ml CSF) and fluff (700 ml CSF).

Only a portion of the mechanical work put into the grinder or refiner is used to liberate the fibres in the wood. The rest of the applied energy is converted through friction into heat and some of this can be recovered as hot water or steam that can be used for drying of the final product. The greatest potential for energy recovery from mechanical pulping is limited to that part of the process carried out under pressure. The amount of recoverable energy is not a constant percentage of the total energy input over the range of freeness because e.g. lower freeness pulp involves more secondary or tertiary refining at atmospheric pressure. Typical ranges of energy consumption and recovery rates are shown in Table 4.10.

Mechanical pulp and freeness, ml CSF	Energy consumption (kWh/t of pulp)	Recoverable energy	
		as hot water [%]	as steam [%]
GW 350-30	1100-2200	20	
PGW 350-30	1100- 2200	30	20
PGW-S 350-30	1100-2300	30	20
RMP 350-30	1600-3000	30	20
TMP 400-30	1800-3600	20	40-45
CTMP 700-30	1000-4300	20	40-45

Table 4.10: Energy consumption and recovery of energy in mechanical pulping [TEKES, 1997]. Energy consumption refers to oven dry (100%) pulp. These figures are only average numbers, which may deviate $\pm 10\%$, due to local mill circumstances and also due to measuring inaccuracies

Thus, for instance for groundwood, the energy consumption ranges from about 1100 kWh/t at CSF 350 to about 2000 kWh/t at CSF 40 with no energy recovery. The PGW variant consumes from about 1300 kWh/t at CSF 300 to about 2300 kWh/t at CSF 40 but up to 30% of the gross energy input may be recovered as hot water by exchanging against the hot pulp. Up to 30% of the energy may be recovered as hot water with RMP and up to a total of 60-65% for TMP as hot water and steam. With TMP operating at about 6 bar pressure the process produces up to 2 tonnes of steam per tonne of pulp or about one tonne of steam per MWh of the refiner. Generally, the amount of recovered steam depends on the specific energy consumed and is some 2 tonnes per tonne of pulp at a pressure of 2 to 4 bar.

Generally TMP consumes more energy than groundwood pulping. For instance, groundwood pulp used for SC paper and newsprint production consumes in total about 2200 kWh/t and 1600 kWh/t respectively, whereas TMP consumes about 3600 kWh/t and 2500 kWh/t respectively.

Table 4.11 shows the energy consumption in the form of heat and electric power in a Swedish TMP mill with a production of 500000 t/a newsprint and Table 4.12 shows the energy balance for the same mill.

Department	Process heat [MJ/t]	Electric power [kWh/t]
Wood handling	150	50
Refining	0	2110 ¹⁾
Washing and screening	0	50
Bleaching	0	75
Bleach chemical preparation	0	5
Bleached stock screening	0	35
Power boiler	0	25
Total pulp mill	150	2350
Stock preparation	0	235
Paper machine	5300 ¹⁾²⁾	350
Total paper mill	5300	585
Effluent treatment	0	39
Total per tonne of paper	5450	2974
Notes:		
1) From a Finnish integrated TMP mill higher electricity consumption in the range of 2400 kWh/t was reported for the refining stage (including reject refining) and a lower value of 4800 MJ/t process heat consumption for the paper machine respectively [Finnish comments].		
2) A Swedish newsprint mill reports a heat demand of about 4 GJ/t for drying paper, a need that will be reduced by about 10% with a future shoe-press installation.		

Table 4.11: Energy consumption in an integrated mill with a production capacity of 500000 t/a newsprint from TMP
[SEPA Report 4712-4, 1997]

A modern Finnish integrated CTMP mill reported the following figures for electric power consumption: wood handling 20 - 30 kWh/Adt, refining (CSF 450) 1600 - 1900 kWh/Adt, bleaching and screening about 500 kWh/Adt. In total about 2100 - 2400 kWh/Adt are required.

Department	Heat [MJ/t]	Electric power [kWh/t]
Pulp mill		
Recovered steam, only for process use ¹⁾	+1500	
Power boiler, process steam (only own bark)	+1500	
Turbine generator		+100
External supply	0	+2289
Consumption	-150	-2350
Effluent treatment	0	-39
Excess energy from pulp mill	+2850	0
Paper mill		
Consumption	-5300	-585
External supply ¹⁾	+2450	+585
Total external supply	2450	2874
Notes:		
1) From the Finnish paper maker point of view the heat recovery of TMP process is significantly higher. For an integrated 250000 t/a newsprint mill based on TMP a heat recovery value (recovered steam) of 3450 MJ/t was reported. Thus, in this case there is no need for external supply of heat [Finnish comments]		

Table 4.12: Energy balance for an integrated Swedish mill manufacturing 500000 t/a of newsprint from TMP
[SEPA Report 4712-4, 1997]

The energy balance and the degree of heat recovery depend amongst other things on the energy prices in the given country. If the energy from the public grid is relatively cheap mills may only run a small power plant for steam production (e.g. a bark boiler) that is needed for the paper machine and the TMP mill will be operated with purchased electricity. The recovered energy from the refiners will be sufficient to produce the heat needed for a second paper machine. Countries with comparatively higher prices for electricity tend to install bigger power plants for power generation on site resulting in generating a surplus of heat (less heat recovery).

In Table 4.13 the values for energy consumption of a Finnish non-integrated CTMP mill are compiled.

Department	Heat [MJ/t]	Electric power [kWh/t]
Pulp mill		
Recovered steam, only for process use	+ 2700	
External supply	0	+1650
Consumption	0	-1600
Effluent treatment	0	-50
Excess energy from pulp mill	+2700	0
Pulp dryer		
Consumption	-5600	- 150
Steam boiler (wood residuals & fuel oil)	+2900	+ 150
Total external supply	2900	1800

Table 4.13: Energy balance for a non-integrated Finnish CTMP mill (CSF 400 ml)

4.2.2.8 Noise (local)

The debarking plant and to less extent the paper machine and the refiners generates noise that can be controlled by carefully insulating the debarking house. Trucks and other vehicles used to transport the huge amounts of raw materials and products respectively can cause noise in the vicinity of the mill.

4.3 Techniques to consider in the determination of BAT

In this paragraph all **relevant** techniques currently commercially available for prevention or reduction of emissions/waste and reducing consumption of energy and raw materials, both for new and existing installations are given. This list of techniques is not exhaustive and may be continued when reviewing this document. The techniques cover in-process measures and end-of-pipe technology as well and stands for possibilities for improvement to achieve integrated prevention and control of pollution.

In Table 4.14 an overview of techniques for reduction of emissions from mechanical and chemical pulping are given. In the rows the single available techniques are compiled.

It was tried to give possible cross-media effects of every measure in the same table. It can be concluded that it is not an easy task to describe cross-media effects in a way that would not cause any dispute. There are a lot of "grey-zones" in the assessment of cross-media effects. Furthermore, they may depend on other techniques, which may be linked to a given measure, the reference to which a technique is compared with and the system boundary taken into account. Therefore, the qualitative assessment of cross-media effects should only be taken as help for operators or inspectors in order to give them an indication, which side-effects of a measure might possibly occur. It is not much more than a starting-point when considering possible shifts of pollution. The results of the assessment should not be considered as imperative. Furthermore, prevention and control measures can avoid some of the cross-media effects. The cross-media effect will also depend on the specific conditions of every mill. Therefore, a general statement can hardly be given.

However, the table may indicate at which environmental media (water, air, waste, energy) a measure is aiming at. The corresponding paragraphs under the detailed discussion of every technique give further explanations.

Mechanical pulp mills are, with very few exceptions, integrated with a paper mill. Therefore, there is a certain overlapping between mechanical pulping and stock preparation on the one hand and papermaking and associated processes on the other. In these cases cross references to the respective chapters will be given. This especially true for water use and circulation respectively. They can not be described separately from the paper mill.

Finally, some of the measures and principles for improvement environmental performance can be applied to paper mills using mechanical pulp as furnish as well as to other paper mills. These points will be noted with cross references as well to avoid unnecessary repetition and to show similarities and differences between the production of different paper grades.

In the columns the tendency of effects caused by different techniques on emissions, raw material consumption and the mill performance are indicated qualitatively by using arrows up "↑" and down "↓". The arrows down "↓" indicate savings of raw materials or energy and a reduction of emissions into the different media water, air and soil. Arrows up "↑" indicate an increase of emissions, consumption and impacts on the production process. Some of the measures for pollution prevention and control presented in this section concern more than one environmental medium (as water, air or soil) at a time. Some techniques may have a positive and/or negative impact on other environmental media or on raw material and energy consumption (cross-media-effects). The given effects will be noted by using the arrows. An arrow in brackets "(↑)" means only a slight - often negligible - increase of energy consumption, raw material use or emission to environment when implementing a certain measure. The economic aspects (investments, operational costs) are not included in the table but are explained in the text. Data on economics can only give a rough picture and indicate the levels of costs. They will vary with the design of the whole plant and depend among others on the size of the mill and how a measure fits together with other mill equipment.

Each technique is provided with a reference mark, which helps to identify the according section in the text where each single technique is discussed in detail.

Techniques to consider in the determination of BAT	Effects on the consumption and emission levels (cross-media effects)					
	Chemical consumption	Energy (E) & water (W) consumption	Emission to water	Emission to air	Solid waste	Remarks
4.3.1 Emission control from the wood yard	0	0	↓	0	0	
4.3.2 Dry debarking	0	E ↑ in debarking W ↓	↓ COD, ↓ TSS, ↓ flow	0	0	
4.3.3 Minimisation of reject losses	0	E ↓	↓	0	↓	
4.3.4 Minimisation of disposal of rejects	0	E ↓ incineration E ↑ dewatering	0	(↑)	↓	
4.3.5 Efficient washing and process control	↓ bleaching	(↑)washing (electr.)	↓	0	0	mainly CTMP
4.3.6 Water recirculation in pulp and paper mill	0	W ↓	↓	0	0	
4.3.7 CTMP mill effluent treatment. Closing up the water circuits by use of evaporation and burning the concentrates	0	↓ (W), ↑ (E)	↓	(↑)	↓	Only CTMP
4.3.8 Installation of Co-generation of heat and power	0	E ↓	0	↓	0	
4.3.9 Heat recovery from refiners	0	E ↓	0	↓	0	
4.3.10 Abatement of VOC emissions from steam releases	0	0	0	↓	0	
4.3.11 Emission optimised incineration of solid waste and energy recovery	0	E ↓	0	(↑)	↓	
4.3.12 Use of sufficiently large puffer tanks for storage of concentrated or hot liquids	0	0	↓	0	0	Mainly CTMP
4.3.13 Biological wastewater treatment	↑	E ↑	↓	↓ odour	(↑)	Solid waste can be burned
4.3.14 Tertiary wastewater treatment	↑	E ↑	↓	0	(↑)	Solid waste can be burned
Notes: ↑ = increase; ↓ = decrease; 0 = no (or negligible) effect; (↑) or (↓) = low influence depending on the conditions						

Table 4.14: Overview of available techniques in mechanical and chemi-mechanical pulping mills and their impact on the environment and the mill performance respectively

4.3.1 Emission control from the wood yard

No data yet received.

This technique is considered to be relevant for mechanical pulping because wood for mechanical pulping needs to be kept fresh so that it doesn't dry. Often the wood logs are sprinkled with water to avoid drying out.

4.3.2 Dry debarking

Refer to 2.3.1

4.3.3 Minimisation of reject losses by using efficient reject handling stages

Description of the technique:

There are basically two methods available for separation of contaminants from the pulp:

- centrifugal cleaners or centricleaners, where particles heavier than fibres are separated
- pressure screens equipped with holes or slots, where oversized material is separated.

The rejects from both centricleaners and pressure screens also contain a large amount of fibre material. This material is recovered by adding several screens or centricleaners in series. With this arrangement considerable amounts of raw material can be saved and in the suspended solids load to the effluent treatment reduced.

Pulp Screening and Cleaning

The screening process in mechanical pulping has another objective than in chemical pulping, where the reject can be withdrawn from the fibre line. The purpose is instead mainly to separate the material and after proper treatment return it back to the main fibre line. The reject treatment is mill specific and many solutions are possible. Often the screening and cleaning systems are based on cascading principles. These systems have the disadvantage of being less controllable than feed forward systems.

The pulp is cleaned and screened with pressure screens and centricleaners. Screening is carried out with holes (diameter 1-2 mm) or slots (0.15-0.35 mm wide) at a concentration of 1.3 % or higher. The operating at 3 % accepts consistency has in some cases resulted in reduced shives content of 60 % compared to conventional low consistency screening technology.

Centricleaners are often used as supplement to screens. The rejected material is different from the screening reject, being stiff particles with small specific surface. The main drawback with centricleaners is the low pulp consistency (0.5-0.7 %) which corresponds to water volumes of 150 -200 m³/ADt. But most of this water can be recirculated and used for other purposes in the pulp mill. Many mills today reconsider centricleaners in the pulp line and consider as an alternative centricleaners in the paper mills.

Reject refining

In order to return screened and cleaned rejects to the main fibre line, they are usually refined in 1-2 stages between rotating refining plates. The initial break-up of the coarse fibre bundles in the refiner take place in the breaker-bar zone, where the oversize material is turned into single fibres. The fibres pass into a thin gap by the centrifugal forces and are intensively treated at high pulp consistency (30-45 %).

The reject amount can be in the range of 20-30 % and the energy consumption about 10-40 % of the overall specific energy demand in the mechanical pulping. If efficient reject recovery and recycling is required, TMP-lines can be designed for e.g. 20 % reject refining calculated from the capacity of the fibre line.

Final screening and cleaning rejects that cannot be returned to the fibre line are discharged from the process as solid wastes or incinerated in a boiler.

An important issue is how the rejects from a screen are brought back to the main fibre line. In cascade coupling after separation the rejects are recycled to a point ahead of the withdrawal (counter-currently). This will produce a high volume of circulating waters, especially in systems with high reject flows. The advantage with cascade coupling is that the risk of too high shive content in the accept flow is minimised.

Applicability and characterisation of the measure: Addition of cleaning stages and reject refining can be applied at both new and existing mills.

Main achieved environmental performance: Reduction of fibre losses and decrease of waste generation by some percent. The reduction rate depends on the stage of raw material use efficiency before measures for improvement were taken.

Cross-media effect: Reject refining increase power consumption. The steam from a reject refiner is normally not recovered. On the other hand, rejects have already passed the very energy intensive first refining stage so that in total energy will be saved when reducing the reject losses. Therefore the net energy balance of this measure is positive. Residues from the process are decreased.

Economics: Investment costs for 700 ADt/d pulp capacity are typically 0.8 - 1.1 MEuros and operating costs 0.3 - 0.5 MEuros/a.

Driving force for implementing the technique: The driving force to adopt this measure is to increase raw material and energy efficiency. Secondly, TSS load to the effluent treatment plant that is usually recovered in the sedimentation tank is reduced.

Reference plants: Numerous plants in Europe.

Literature

[CEPI, 1997b]

4.3.4 Minimisation of disposal of rejects to landfill by incineration with energy recovery

Description of the technique: Rejects and sludge that is generated during pulp manufacturing and water treatment must be de-watered before final disposal or further treatment. Dewatering is carried out by means of wire presses or screw presses. Dewatering aims at removing water from the sludge as far as possible. Different types of mechanical equipment are available for this operation.

- Belt presses (Twin wire presses)
- Screw presses
- Decanter centrifuges

Most new installations during the last 10-15 years have been belt presses, which have a reliable function and produce fairly high dry solid values, 40-50 % with fibre sludge and 25-40 % with mixed fibre/biological/(chemical) sludge.

Screw presses can be used in two ways, either to increase the dry solid content after belt press dewatering, when approximately 10 % dry solid increase can be obtained or direct dewatering when higher dry solid content can be obtained compared to belt-press dewatering.

After de-watering the sludge and rejects can be incinerated for further reducing the amount of wastes from mechanical pulping to landfill disposal. The following options are available:

- Incineration together with bark in bark boilers.
- Separate sludge incineration.

For co-combustion, particularly of rather low dry solid sludges, the fluidised bed boiler is presently best for new installations. This can be run with 100 % sludge, although the use of a support fuel is more common (like coal or oil). The requirement of the support fuel depends on the dry solid and the ash content of the sludge. Generally, at least 35-40 % dry solid is required for spontaneous combustion.

Separate sludge incineration with moving-grate stoker equipment has also been successfully utilised.

For detailed discussion of incineration with energy recovery it is referred to section 4.3.11.

Applicability and characterisation of the measure: The incineration in bark boilers has been tested and applied in full scale in a number of mills. The grate-type bark boilers can be converted to fluidised-bed ones, but unfortunately with substantial investment and shut-down costs.

Separate incinerators are also proven technology, but they consume usually lot of support fuel and standard sludge incinerators do not have a heat recovery part which means that no steam or electrical power can be produced.

As far as sludge dewatering is concerned, all types of presses have been used with good results. An increasing application of screw presses has been observed for some years, due to an increasing interest in sludge incineration, requiring high dry solid values, but involving also additional investment costs.

Main achieved environmental performance: Depending on the reject handling concept the wastes from rejects can be reduced significantly. Usually there are only ashes from incinerators that can either be landfilled or used for other purposes (e.g. building industry)

Cross-media effect: With incineration in bark boilers, the energy content exceeding the evaporation of water in rejects can be recovered.

In sludge dewatering, water emissions are increased through the dewatering of the sludge, which usually are led to the activated sludge system. They have to be considered when planning the effluent treatment. Energy generation is related to dry solids content of the dewatered sludge if the sludge is incinerated.

Operational experience: These processes have been used several years in modern mills. Incineration in bark boilers is more common than in separate incinerators due to the poor heat economy of the latter alternative.

Economics: Investment costs for a new sludge and reject incinerator are about 5-7 MEuros and operating costs 0.5 - 0.6 MEuros/a corresponding a pulp production of 700 ADt/d. Grate-fired boiler retrofit to a fluidised-bed boiler would cost approximately 10-15 MEuros, and operating costs would be 0.3 - 0.4 MEuros/a.

Driving force for implementing the technique: The driving force to adopt this measure is to reduce wastes to be disposed to landfill.

Reference plant: Numerous plants in Europe.

Literature:

[J. Pöyry, 1997b], [J. Pöyry, 1992]

4.3.5 Efficient washing and process control

This technique is mainly relevant with chemithermomechanical pulping (CTMP).

Description of the technique: The washing process in CTMP-pulping is in principle similar to washing in chemical pulping, but the efficiency requirements are usually less demanding. The purpose is mainly to separate the organic material dissolved in refining from fibres. The washing is often mill-specific and many alternative solutions are possible in terms of type of washing equipment etc

Washing of CTMP-pulp is, however, somewhat more difficult than the washing of chemical pulp and it requires more capacity of the washing equipment. In practise, this means more surface area with drum washers or washing presses per tonne of pulp. The washing efficiency is usually 65-70 % calculated from the recovered organic material. This corresponds typically to one washing stage, which can be carried out with drum washers, twin wire presses or screw presses.

With improved washing it is possible to increase the washing efficiency to 75-80 % by installing more washing equipment in series. The washing equipment is usually the same as the equipment of the first washing stage.

Main achieved environmental performance: With improved washing it would be possible to concentrate the organic material in the same volume of effluents and reduce the carry-over to the paper or board machine. This may be an asset, if the effluents are further treated separately from the paper or board effluents e.g. in an anaerobic treatment.

Cross-media effect: No major cross-media effects.

Operational experience: The improved washing is practised only in a few integrated mills in the world.

Economics: Investment costs are typically 3-5 MEuros at new mills and 2-3 MEuros at existing pulp mills of 700 ADt/d. No major additional operating costs are anticipated.

Driving force for implementing the technique: The improved washing may create better circumstances for an anaerobic treatment if applicable of CTMP-effluent fraction. The quality aspects of finished board and paper may also give rise to consideration of this technology.

Reference plant: A few plants in Europe and in North America.

Literature:

[CEPI, 1997b], [J. Pöyry, 1997b]

4.3.6 Water recirculation in pulp and paper mill

Description of the technique: The degree of recirculating water within the pulping process is highly dependent on the suitability of a specific water fraction for reuse and the level of contaminants that are allowed to accumulate in the process. In any case there must be bleedout points for sewerage and disposal of contaminants at an effluent treatment. Normal water makeup is done in non-integrated mills with fresh water. In integrated mills paper machine white water covers most of the process water need.

Inside the mechanical pulping process the recycle stream candidates are various filtrates, pressates or similar from chip or pulp handling and cloudy or clear white water generated by fibre save-all equipment. These streams are fed to specific uses according to their availability and suitability. Many factors influence on the suitable degree of water recycling in the pulping. Considering the accumulation of undesirable compounds into the streams, these are generated by wood or chip pretreatment, refining and bleaching and some is brought in integrated mills with the counter current flow of paper machine white water.

In the process points where dissolved materials are formed, there also must be dilution to effectively carry away the undesirable compounds from the wood material or pulp. Otherwise they are carried to the succeeding process stages with adverse effects. Additionally, in recycling and discharging of waters a trade-off may be necessary to reach an economical balance. For instance, discharging water from the pulping process by sewerage more clear instead of cloudy white water provides better capture of fibre material in the pulp, but also retains more unwanted resinous compounds in it. In general terms, the proper selection of water re-use is complicated e.g. by the colour of process water, pH, dissolved and suspended solids content including also residuals of used pulping chemicals, that can cause unwanted chemical reactions or even increased pulping chemical consumption.

Items forming the basis of water use reduction and recycling in pulping are:

- Use of counter-current water flow principle, where feasible
- Improved fibre recovery by sewerage clean instead of cloudy white water and in integrated mills by excess white water input from the paper mill
- Rebalancing of tank volumes, especially white water volumes for coping with process fluctuations, startups and shutdowns.
- High consistency thickening of pulp prior to feed to drying (or paper machine), which is effective both for non-integrated and integrated mills, though for slightly different reasons.
- Clear white water usage in equipment cleaning showers and if acceptable, as flushing water.

In Figure 4.8 main water sources and sinks in an integrated mechanical pulp and paper mill are given. As shown fresh water is introduced in the papermaking process mainly through paper machine forming section and press-section showers after which, it is fed upstream to various washing and diluting process. Water loops are clearly separated by thickening steps after which stock is diluted with some fresh water to adjust consistency and to dilute the stock with clean water before it enters the approach system.

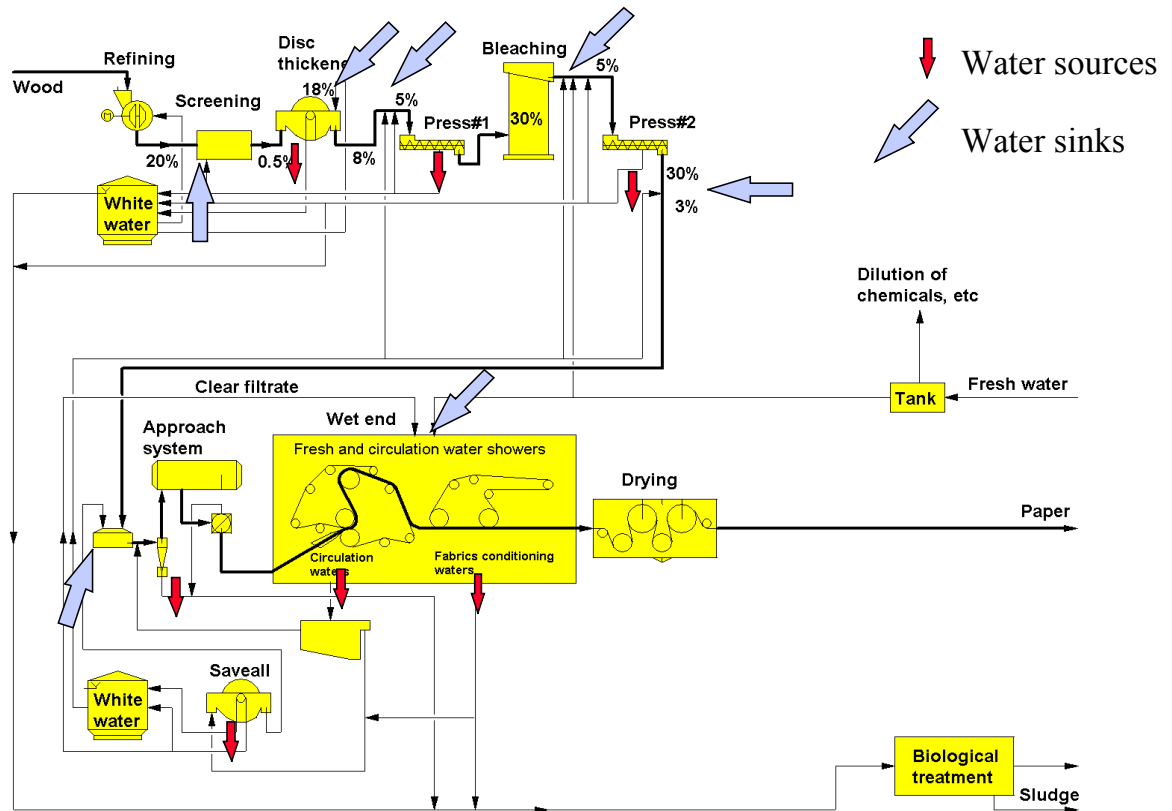


Figure 4.8: Main water sources and sinks in an integrated mechanical pulp and paper mill [Edelmann, 1997]

Applicability and characterisation of the measure: Enhanced water recirculation can be applied in existing mills, in new mills many of the described concepts are applied efficiently.

Assessment of the suitability of specific stream(s) for a specific reuse must be carried out to avoid adverse effect on the process itself and the product. Existing mills may need rebalancing their filtrate, whitewater and pulp tank capacities, in order to keep fresh water makeup and effluent bleedout to a minimum.

Because the water temperature in the pulping rises along the degree of water loop closure, in existing mills problems may evolve in pulp bleaching and the performance of supporting equipment such as centrifugal pumps. Thus also an energy balance evaluation is necessary.

Main achieved environmental performance: With efficient closure, in integrated mills meaning also the counter current re-use of paper machine white water, the effluent discharge and fibre losses to sewer are reduced. The degree of water reduction depends on the paper/board grade.

Monitoring of emissions: On-line monitoring of combined pulp mill effluent flow rate and lab monitoring of suspended and dissolved solids, pH, temperature and organic content as BOD₅ or COD is recommended. Also on-line suspended solids or turbidity meter can be used.

Cross-media effects: More dissolved or colloidal matter can be retained with pulp as a result of efficient water reuse in pulping. This must be compensated in the paper machine to avoid for instance an increase in machine breaks, changes in wet end paper web retention or sheet drainage.

Operational experiences: The principles discussed can be used with slight adverse or no impacts in the pulping process.

Economics: Because most of the mechanical pulp mills are integrated with paper production the measures to improve water reuse is typically linked to water use reduction in both pulping and papermaking.

The investment costs for an integrated mill, with 700 ADt/a production and aiming at reduction of fresh water consumption from 20 m³ to 10 m³, are about 10-12 MEuros.

Driving force for implementing this technique: Reduction of effluent hydraulic and suspended solids load is the key component to promote the implementation. More concentrated wastewater can be treated more effectively and need less investment and operating costs.

Reference plants: Numerous modern mills apply efficient water recirculation around the world. Many old mills also exist which have carried out the listed measures more selectively

Literature

[CEPI, 1997b], [Edelmann, 1997]

4.3.7 CTMP mill effluent treatment. Closing up the water circuits by use of evaporation and burning the concentrates

Description of the technique: There are a few alternatives of how to treat the wastewater from CTMP plants:

- Activated sludge treatment in one or two stages with or without chemical treatment (see 4.3.13). Today the activated sludge method is the most common one and if correctly designed very effective. A BOD reduction of 98% and a COD reduction of 85% can easily be reached. A drawback using this method is the fairly high concentrations of nutrients in the effluent. Therefore, some CTMP plants have had to complete the treatment with an additional chemical treatment (see 2.3.14).
- Internal chemical treatment of white water the first washing stage plus activated sludge treatment of the rest. There is one CTMP plant treating this white water with a chemical, which makes it possible to remove extractives and fines in a following flotation stage. At the same time a 40-50% COD reduction was reported. A drawback of this method is the fairly high chemical costs.
- Combination of an anaerobic and aerobic treatment of the wastewater. There is only one plant in Sweden (SCA, Östrand) using this technique. The reason why the anaerobic treatment is not used more commonly is that it is very sensitive to disturbances (principles see 3.3.6 and 5.3.5).
- Evaporation of the most contaminated wastewater and burning of the waste plus activated sludge treatment of the rest. For evaporation of wastewater a new evaporator (see Section 4.5.1), the Zedivap evaporator has been developed. This new evaporation technique is considered as emerging. The first one is now working at a Swedish CTMP plant and is in the optimisation phase of continually improving the situation. The concentrate will be burned in a recovery boiler of an adjacent kraft pulp mill. The evaporation alternative is most suitable in such a case, when the pulp capacity has to be increased and the biological treatment plant is becoming too small. The condensate from such an evaporation plant can be used in the CTMP plant as process water lowering the fresh water consumption considerably. Evaporation is also an alternative if tertiary treatment is regarded as necessary i.e. in such cases where the nutrient concentrations in the effluent have to be lowered.

- It is also possible to evaporate the whole effluents and incinerate the concentrates in a recovery boiler. This results in zero discharge of liquid effluents. The Millar Western Pulp (Meadow Lake) Ltd., in Saskatchewan, Canada, a 240000 t/a greenfield mill at that period, produces since 1992 bleached CTMP without having an effluent pipeline. The CTMP mill converts aspen hardwood using the Alkaline Peroxide Pulping (APP) process into finest tissue and writing grade market pulp. Their zero effluent system will be described in the following because it contains a number of innovations, which are of general interest for the sector. It has opened the door for use in other industrial applications where the receiving water body cannot effectively assimilate an industrial discharge.

The Meadow lake water recycling system consists of the six unit operations, which are shown, in Figure 4.9 and Figure 4.10.

- Suspended solids removal (Krofta clarifiers including an option to use settling ponds)
- Mechanical Vapour Recompression evaporation (1.5 times more capacity than the design flow rate to provide flexibility and catch up ability)
- Steam-driven concentration
- Concentrate incineration
- Distillate polishing for general mill usage
- Treatment of lake water make-up

As shown in Figure 4.9 the only water that needs replacing is that which is lost through evaporation and is about $2 \text{ m}^3/\text{ADt}$.

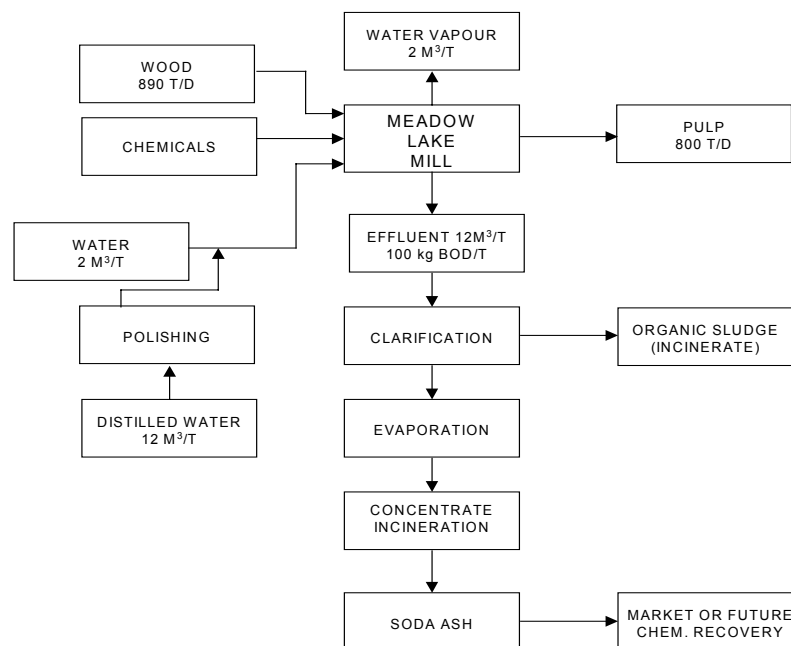


Figure 4.9: Water recycle system of the Meadow Lake CTMP mill

Evaporation technology is used to close the water loop and achieve zero effluent status [Evans, 1992]

Figure 4.10 shows the effluent process concept including major flows of the water through the various treatment steps.

All process water streams are pumped to the primary treatment, which serves to remove suspended solids. Captured solids are de-watered and incinerated. Clarified water can be stored in outside ponds that provide reserve capacity between the pulp mill and the evaporators.

Clarified water is delivered to the mechanical vapour recompression (VR) evaporators where the concentration of total solids is increased from 2.5% to 35%. The distillate from the MVR evaporators is segregated in to fractions internally to prevent contamination of the clean distillate, which account for 85% of the distillate produced. The distillate fraction which has most of the volatile organic compounds is stripped of most of those organics in a steam stripper for incineration in the recovery boiler. Most of the evaporator distillate can be used directly in the pulp mill at 65 °C. However, some demands exist for water at 20 - 30 °C. To provide this some of the distillate is cooled and the small fractions of volatile organics are removed in a biological stabilisation pond.

The solids level of the concentrate from the MVR evaporators is increased to 70% dry solids in two steam driven concentrators and incinerated in a chemical recovery boiler.

The smelt from the recovery furnace is cooled and sodified on a conveyor then deposited in a bunker.

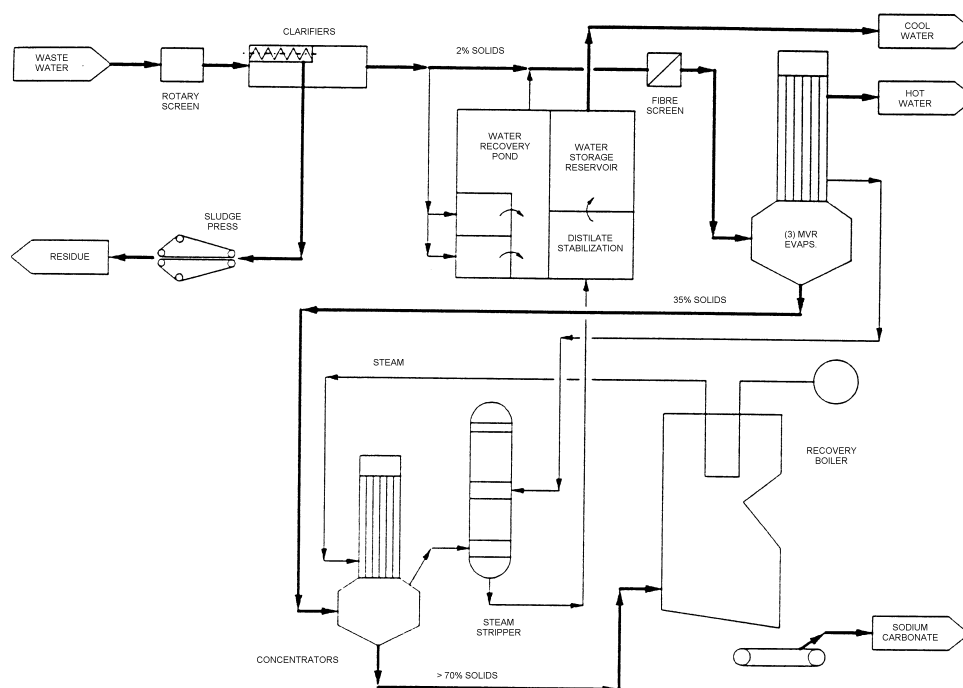


Figure 4.10: Zero liquid effluent process concept
[Ward, 1993]

Applicability and characterisation of the measure: Process integrated measure. Closing the CTMP plant is possible for both new and existing mills. Limitation is high capital cost of evaporation and possible recovery plant (as in Meadow Lake). The described concept was built for a greenfield mill and needs a lot of space, which existing mills often do not have. The solution will depend on local conditions and is often different for market CTMP-mills compared to integrated CTMP-manufacturing. When using evaporators the bleaching of CTMP has to be modified. For instance no sodium silicates can be used because of scaling.

Main achieved environmental performance: No discharges to water.

Monitoring: Monitoring of the process and equipment is of the utmost importance in a zero effluent facility. Different testing programmes were running, dynamic monitoring of fouling rates and corrosion and a quality management system certified ISO 9002. These are supplemented by an analytical lab to keep a careful watch on the facility. One example is the metals monitoring program which tracks ions in the system and permits proactive work to take place on corrosion, fouling and scaling.

Cross media effects: Information on the energy balance compared to a conventional system was not available. The solid waste loop is not yet closed but in conventional systems neither. No other cross-media effects are known.

Operational experiences: The water recycle system causes no losses in pulp production and has no negative impact on pulp quality. The company has developed some unique methods of employee involvement in management decisions. Training was crucial to the successful start-up at Meadow Lake. New employees were given a minimum of three-month instruction on their positions before start-up was attempted. Ongoing coaching for skill development has kept the work force on the leading edge of technology and work practices. Safety at all costs has led to employee commitment to this essential program that keeps moral high and insurance premiums low. Small teams are formed regularly and have the ability and authority to make changes to the process where benefit from such changes can be demonstrated.

Economics: The system has operating costs competitive with conventional bleached CTMP water and secondary effluent treatment systems. After the optimisation period the effluent treatment operating costs at Meadow Lake are now below the cost of conventional secondary treatment. However, high investment costs for over-sized evaporation and liberal sizing of the recovery plant and storage capacity for effluents (for 3 days) arose at the start-up phase. The attractiveness of the zero-liquid discharge approach is augmented by potential chemical and energy recovery that can be used to reduce cost of production and amortise capital costs. Data on specific costs are not available. Changes in aqueous effluent regulations do not effect zero effluent mills, which is an economical advantage.

Driving force for implementing this technique: The Meadow Lake site was selected primarily for its close proximity to fibre supply, infrastructure, and people. Though, water was scarce and the possible receiving water body is small and due to arid climate and severe winters in the area the river ceases to flow at times. A conventional effluent treatment system would have necessitated the drilling of wells tapping into an under ground aquifer to provide enough dilution water to thin the effluent discharge and keep the river flowing year round. This option was not acceptable to the owners of the company and the decision was made to pursue zero effluent technology. It can be stated that marketing a zero-liquid discharge pulp to environmentally conscious consumers has certain advantages.

Reference plants: Examples are Meadow Lake and Chetwynd in Canada. Stora Fors, Sweden, has started an evaporation plant for a part of the whole wastewater.

Literature:

[Ward, 1993], [Evans, 1991], [Evans, 1992], [Evans, 1993], [Fromson, 1993], [Sweet, 1993]

4.3.8 Application of Co-generation of Heat and Power (CHP)

Refer to 5.3.9 Whether or not co-generation is BAT, depends on the energy balance of the mill and how electricity from the grid has been produced. The difficulty might be to compare hydroelectric, nuclear power, coal, oil, gas or biofuel power.

4.3.9 Heat recovery from refiners

No information yet received.

4.3.10 Abatement of VOC emissions from steam releases

No information yet received.

4.3.11 Emission optimised incineration of solid waste and energy recovery

Description of the technique: In mechanical paper mills, mostly integrated also with paper mills, there is a variety of solid wastes - bark, wood residues, pulp waste sludge and screening rejects - that must be disposed of. The bark is readily used as fuel in the mill auxiliary boiler but sludges traditionally have been landfilled. A viable alternative to landfilling, which is becoming an expensive and more limited exercise for the mills, is incineration of these sludge wastes. In such incineration it is necessary to apply environmentally sound incineration techniques to minimise particulate, SO₂ and NO_x emissions.

Because sludges represent waste that often has a lower heat value than true solid fuels, such as bark or wood, their incineration in a boiler designated solely for sludge is rare.

In practice mills that use bark, wood, peat or coal as fuel for steam and power generation obtain cost-efficiency by burning the pulping and paper sludges in the same boiler with solid fuels of high heat value. This is also emphasised by the fact that sludges, unless at over 50 % consistency and low in ash, would require in any case support fuel to dispose of them properly by burning.

The environmentally sound technology most suitable for pulp sludge and reject incineration is the same than for wood, bark and peat. However, certain specific features in preparation of sludge or burning can differ.

The boilers are used to provide steam to be used directly as process steam for heating and drying, but in an increasing number of cases also for electric power production. However, when the boiler is small and its main purpose is to dispose of sludge with a minimum amount of support fuel, the boilers cannot economically produce anything else but low pressure steam for heating in the process or buildings.

In the incineration of pulp and paper mill sludges the environmental ends can be met by application of proper boiler and, as sometimes needed, a series of fuel pre-treatments.

In paper and reject sludge incineration both conventional grate-fired boilers and fluidised bed boilers can be used. The fluidised bed technology, however, is more versatile with its better flexibility, higher efficiency and low emissions.

The heating value of bark from wet debarking or peat at 40 - 60% moisture is 4.5-10.5 MJ/kg. In contrast, the mechanically dewatered pulp sludges have a lower heat value amounting to 2.5-6.0 MJ/kg due to their often higher moisture and ash content. The heat value of dry pulp waste can reach over 20 MJ/kg. The higher the humidity of the fuel the lower the overall economy of the boiler and also the more difficult is the operability unless efficient technology is applied. A fluidised bed boiler is less sensitive to fuel humidity than a grate-fired boiler. Because some paper sludges often reach 20-30 % ash content, and at worst with deinking waste 60 %, operational problems such as grate plugging due to ash is very likely in grate fired boilers. High

amounts of ash may cause also deterioration of fluidised bed system efficiency, but in much lesser amount. The burning improves the smaller is the proportionate amount of ash or sludge.

The main difference of grate-firing and fluidised bed technology is in the heat transfer method. In grate-firing the fuel particles are heated mainly by radiation. This makes the combustion temperature and burning time very important and the system performance can easily drop when fuel humidity increases. Variations in sludge dryness at the grate-fired boiler entrance cause problems to maintain efficient burning because of temperature drops. In the fluidised bed boilers the main heat transfer method is by conduction, which by the aid of a fluidised sand bed inside the boiler, stabilises the system heat capacity and makes it less sensitive to fuel humidity and heating value fluctuations.

The burning in a fluidised bed boiler takes place at a lower temperature, typically in the 750-950 °C range, than required in grate firing. This is beneficial in reduction of gaseous emissions. In addition, the heat transfer per unit area is a little higher with fluidised bed systems.

There are two main types of fluidised bed systems: Bubbling (BFBC) and circulating (CFBC) fluidised bed boilers.

In BFBC the sand bed inside the boiler is fluidised and kept in the lower part of the boiler, except for a small part escaping the bed. This escaped fraction and possible semi-burnt fuel is recovered in a cyclone and returned to the bed. In CFBC the sand bed extends up beyond the first heat exchange part, after which the sand is separated from the flue gases in a large cyclone and returned back to the bottom of the bed.

On the efficiency point of view both fluidised bed technologies are good. However, if the fuel is high in coal content, the circulating bed type is better in preventing excessive concentration of heat, generated by coal burning in the bed.

The sludge heat value and the overall burning results can be improved by applying improved dewatering such as screw press. The aimed dryness target should be 45 %, when ash content is below 30 %, otherwise higher and reaching for instance 65-70 % at 50 % ash content. When the amount of sludge is high and the proportionate amount of all the fuels over 30 % shredding of sludge followed by palletising or briquetting can be economical in increasing its bulk density sufficiently to render combustion easier. The sludge and other solid fuels can be fed alternately or in addition through a pre-heating treatment. Indirect drying utilises low or medium pressure steam, generated at the mill, which at best could still be used elsewhere as lower pressure steam. The direct drying method uses the flue gases as heat source.

The improvement of the overall combustion is case-specific. It can be achieved by adding efficient fuel pre-demoisturization for certain solid fuels, by mechanical dewatering of the combustion materials or by drying them with heat. In general, when the fuel initial moisture has been in 45-50 % range, a 10-15 % improvement in heat economy has been recorded by increasing the dryness to 55-60 %. Necessarily, the higher the fuel moisture entering the boiler, the higher is the flue gas flow.

The emissions from fluidised bed boilers can better meet stringent demands than the grate-fired boilers. The fluidised bed systems provide in-situ SO₂ and NO_x emission control in addition to being simpler and more effective than the grate-fired ones.

For SO₂ control the boiler ash contains already some calcium that binds sulphur present in the fuel. Additional SO₂ reduction is obtained by lime injection to the boiler, by providing Calcium:Sulphur ratio in the range of 1-3. A high calcium surplus provides up to 80-95 % sulphur removal to boiler ash, being higher with CFBC. Optimum sulphur capture takes place around 850 °C burning temperature. The drawback of lime injection is the increased ash amount.

In grate-fired boilers there is no efficient internal means of controlling SO₂ emissions.

External sulphur and SO₂ removal methods can also be applied. Either wet or semi-wet methods, which both apply alkaline washing liquid to bind sulphur, or dry methods are available. Dry methods are less efficient than enhanced control of fluidised bed burning, lime injection into the boiler or the external wet methods.

The lower NO_x emission of fluidised bed boilers is first of all because of lower burning temperature involved. Low NO_x burners can obtain further decrease of NO_x.

Some trade-off between SO₂ and NO_x reduction may be necessary. This is for instance because the NO_x emissions tend to rise, the higher is the calcium surplus in the boiler after lime injection. Additionally the minimum NO_x formation in burning takes place at around 960 °C, when the optimum SO₂ removal with lime injection is reached at lower temperatures.

CO and hydrocarbon emissions are kept negligible by avoiding running the boiler at overload and maintaining oxygen excess in burning.

The boiler particulate emissions are controlled efficiently by an electrostatic precipitator, providing with good design almost a total capture.

Applicability and characterisation of the measure: The implementation or improvement of fluidised bed boilers for burning of wood residues or solids disposal can be applied both in existing and new mills. The controllability of the burning process and the allowance in terms of the solid fuel used and its quality variations is superior to that of grate-fired boilers.

Improvements in grate-fired boilers coupled with upgrading of heat recovery and external flue gas cleaning can improve their economical and environmental performance, but not to the level of fluidised bed systems.

When major portion of the boiler fuel is sludge the net heat economy is low. In mills where also other solid fuels are used for steam or electricity production a better process efficiency is obtained by burning the sludge as minority fuel with them.

Main achieved environmental performance: Emissions from modern fluidised bed boilers burning pulping and reject sludge with support fuels can be efficiently controlled and optimised. The variety of fuels or their combinations used, the add-on control methods applied in the boilers and the varying ways of expression of the national regulatory limits, make that the case by case comparison of boiler performance is difficult.

Data on achievable emissions have not yet received.

Monitoring of emissions: Emission monitoring with online gaseous compound meters is increasing in popularity because of their improved reliability and lower cost as they become more common. Multi-point temperature and oxygen monitoring of the boiler is also beneficial.

Cross-media effects: Reduction of wastes may increase the emissions to the atmosphere.

Operational experiences: Fluidised bed boilers have been used with success for 10-15 years and with the current designs have proved to possess many benefits over the grate-fired boilers.

Economics: The modification of an existing bark boiler for sludge and reject incineration costs 0.5-0.7 MEuros at a 700 ADt/d integrated mill, provided that the boiler already has extra capacity to burn these wastes. The additional operating cost for the residue incineration is 250000- 350000 Euros/a.

A separate sludge and reject boiler for a mill of the same size costs 5-7 MEuros and its operating costs are 500000-600000 Euros/a.

Driving force for implementing this technique: The main driving force is the reduction of disposal of organic material to landfills.

Reference plants: Numerous mills in Northern and Western Europe.

Literature:

[J. Pöyry, 1997b], [Finnish BAT report, 1997], [Paper and Timber, 1993]

4.3.12 Use of sufficiently large buffer tanks for storage of concentrated or hot liquids from the process

Description of the technique: The use of large buffer tanks for hot liquids in groundwood (GW) or thermo-mechanical pulp (TMP) production is not relevant in most cases because these pulps are produced almost solely in integrated mills. Typically much of the process water used in these pulping processes is received as excess white water from a paper or board machine. GW and TMP water consumption is low in comparison to papermaking so there is commonly continuous bleedout of excess contaminated water to the sewer.

Chemi-thermo-mechanical pulp (CTMP) production has a slightly different situation, because most of the mills are non-integrated and produce market pulp. As with other mechanical pulping, different white water grades are produced and recycled inside the pulping process. In integrated mills the paper or board machine excess white water is fed as replenishment to the CTMP water system, in non-integrated mills fresh water is consumed. When bleaching is applied, water recycle by using bleaching filtrate for instance in chip impregnation improves water reuse. Excess contaminated water is sewerred for instance from chip wash and as excess white water or sometimes also from intermediate washing in pulp refining.

In CTMP pulping as opposed with chemical pulping there is less chances of finding points of cost-effective overflow or spill recovery of process waters or reasons for very large water storage tanks. By the implementation the typical counter current water flow principle to reach a low fresh water consumption, the balance still needs to sewerred. Nevertheless, the process tank capacities need to have sufficient volume to supply water during flow peaks, especially in pulp dilution and washing. These occur mainly when a pulping line is started up, during short-term fluctuations in the balance between pulp and paper production, or for instance when unbleached pulping is shut down but bleaching is still in operation.

The CTMP effluent is due to chemical chip treatment more contaminated than GW and TMP effluents, calling for more careful tank level management to minimise peak loads entering the external effluent treatment. The conversion of the electric energy in TMP and CTMP refining to energy in steam decreases the accumulation of heat to the water in the pulping system. In mills where steam is efficiently used for water heating or pulp or paper drying, the need for occasional steam blow-out could be decreased. In other mills decrease the need for cooling of steam with water and sewerred this hot fraction by maintaining a larger water volume in the production.

Applicability and characterisation of the measure: The evaluation and optimisation of necessary tank volumes can be carried out both in existing and new mills. For existing mills operating data from different production situations helps in determining proper tank management procedures and need for tank volume increase.

Main achieved environmental performance: The environmental impacts are typically low, but the runnability of the external treatment plant is improved with decreased frequency of spill discharges.

Monitoring of emissions: Level probes for key water chests are required especially for overflow control.

Cross-media effects: No major effects.

Operational experiences: By the improved mill closure the control of contaminated and warm or hot streams into the sewers has become more pronounced. However, in-mill optimisation to handle these streams often has been refinement or change in operating procedures and not so much improvements in liquid storage facilities

Economics: The investment costs are very case specific. When estimating a need of 2000 m³ of extra water or stock volume (0.5 -0.6 MEuros) and some additional tank, piping, electrification and instrumentation, the additional investment costs are 100000-250000 Euros. The operating costs are low, comprising mainly of maintenance.

Driving force for implementing this technique: These measures are promoted by their effect to their impact in controlling better the fluctuations in the pulping process and to some degree by their environmental impact.

Reference plants: Numerous modern mills around the world.

Literature

[CEPI, 1997b]

4.3.13 Secondary or Biological Treatment - Aerobic Methods

Description of the technique: The principles of wastewater treatment are the same as described in 2.3.13, 5.3.6 and 6.3.10. The dominating process for treatment of wastewater from mechanical pulp mills is the activated sludge process. Preferably two-stage processes is used. Some mills apply pure oxygen in a first stage, followed by a "normally" aerated second stage. Some mills use a high-loaded first stage followed by a lower-loaded second aeration tank. One mill has reported a biofiltration stage after two-stage activated sludge system. In principle, effluent from mechanical pulp mills can also be treated efficiently anaerobically because the concentrations in wastewater are often above 2000 mg COD/l. However, in most cases pulp and paper mill effluents are treated with aerobic methods, with the exception of CTMP or other concentrated effluent streams for which anaerobic treatment has sometimes been applied (see 4.3.7).

A large number of different process and plant designs exist for the activated sludge process. These alternatives may be different regarding design of the aeration basin, the clarifier, the aeration equipment, as well as the sludge recycling. One special process design is the pure oxygen activated sludge, where pure oxygen or oxygen-enriched air is used instead of regular air.

Applicability and characterisation of the measure: The process can be applied at both existing and new and new mechanical pulp (and paper) mills. In the existing mills some kind of water consumption reduction measures should preferably be carried out to reduce the investment costs.

The activated sludge process is often used, when high or very high treatment efficiencies are required. In the latter case, however, a two-stage biological process is an optional choice.

Activated sludge plants are used widely in the pulp and paper industry. As rough estimate the activated sludge process is used in 60-75% of all the biological effluent treatment plants in this industry. This is also the most common process used in recently built plants.

Advantages of the activated sludge process are the potential of high or very high treatment efficiencies, the possibilities to control the process (particularly the oxygen consumption), and the relatively low space demand.

Disadvantages are the high production of biological waste sludge and the high operating costs. An equalisation basin prior to the biological treatment can reduce disturbances and the risk of operational instability.

Main achieved environmental performance: Treatment efficiencies are variable, depending on effluent type, plant design and operating conditions. Typical values are within the ranges 90-98 % of BOD removal (normally 95+ %) and 75-90 % of COD removal.

The overall efficiency of TSS-removal of primary and secondary treatment is about 85-90 %.

Cross media effects: The effluent treatment plant produces sludge which after dewatering can be burned, providing in some cases net positive heat value. The treated wastewater is clean enough for reuse in some points of the production process. The problem is that usually the wastewater treatment plant is located so far from the mill that recycling is not economical.

Operational experiences: Activated sludge plants have been used for many years in all types of and new mechanical pulp (and paper) mills with good results.

Economics: The investment costs for a completely new activated sludge treatment plant are approximately 10-12 MEuros for a new 700 ADT/d integrated mechanical pulp mill. These costs include also the necessary primary treatment and sludge handling. The corresponding operating costs are 0.9-1.2 MEuros/a.

Driving force for implementing this technique: The activated sludge process is preferably used, when high or very high treatment efficiencies are required.

Reference plants: Numerous plants all over the world for all types of effluents.

Literature:

[CEPI, 1997b], [Finnish BAT report, 1997], [SEPA-report 4713-2, 1997]

4.3.14 Tertiary treatment of wastewater

Refer to Section 6.3.11.

4.4 Best Available Techniques

4.4.1 Introduction

In understanding this chapter and its contents, the attention of the reader is drawn back to the preface of this document and in particular the fifth section of the preface: “How to understand and use this document”. The techniques and associated emission and/or consumption levels, or ranges of levels, presented in this chapter have been assessed through an iterative process involving the following steps:

- identification of the key environmental issues for the sector; for mechanical and chemical-mechanical pulp and paper mills the major concerns are water use, wastewater discharge (COD, BOD, suspended solids, N, P), energy consumption (steam and electricity), solid waste such as rejects, sludge and ash, air emissions from energy generation (SO₂, NO_x, CO₂, dust), noise, waste heat to water and sometimes odour; the latter three stand for local impacts;
- examination of the techniques most relevant to address those key issues;
- identification of the best environmental performance levels, on the basis of the available data in the European Union and world-wide;
- examination of the conditions under which these performance levels were achieved; such as costs, cross-media effects, main driving forces involved in implementation of this techniques;
- selection of the best available techniques (BAT) and the associated emission and/or consumption levels for this sector in a general sense all according to Article 2(11) and Annex IV of the Directive.

Expert judgement by the European IPPC Bureau and the relevant Technical Working Group (TWG) has played a key role in each of these steps and in the way in which the information is presented here.

On the basis of this assessment, techniques, and as far as possible emission and consumption levels associated with the use of BAT, are presented in this chapter that are considered to be appropriate to the sector as a whole and in many cases reflect current performance of some installations within the sector. Where emission or consumption levels “associated with best available techniques” are presented, this is to be understood as meaning that those levels represent the environmental performance that could be anticipated as a result of the application, in this sector, of the techniques described, bearing in mind the balance of costs and advantages inherent within the definition of BAT. However, they are neither emission nor consumption limit values and should not be understood as such. In some cases it may be technically possible to achieve better emission or consumption levels but due to the costs involved or cross media considerations, they are not considered to be appropriate as BAT for the sector as a whole. However, such levels may be considered to be justified in more specific cases where there are special driving forces.

The emission and consumption levels associated with the use of BAT have to be seen together with any specified reference conditions (e.g. averaging periods).

The concept of “levels associated with BAT” described above is to be distinguished from the term “achievable level” used elsewhere in this document. Where a level is described as “achievable” using a particular technique or combination of techniques, this should be understood to mean that the level may be expected to be achieved over a substantial period of time in a well maintained and operated installation or process using those techniques.

Where available, data concerning costs have been given together with the description of the techniques presented in the previous chapter. These give a rough indication about the

magnitude of costs involved. However, the actual cost of applying a technique will depend strongly on the specific situation regarding, for example, taxes, fees, and the technical characteristics of the installation concerned. It is not possible to evaluate such site-specific factors fully in this document. In the absence of data concerning costs, conclusions on economic viability of techniques are drawn from observations on existing installations.

It is intended that the general BAT in this chapter are a reference point against which to judge the current performance of an existing installation or to judge a proposal for a new installation. In this way they will assist in the determination of appropriate "BAT-based" conditions for the installation or in the establishment of general binding rules under Article 9(8). It is foreseen that new installations can be designed to perform at or even better than the general BAT levels presented here. It is also considered that existing installations could move towards the general BAT levels or do better, subject to the technical and economic applicability of the techniques in each case.

While the BREFs do not set legally binding standards, they are meant to give information for the guidance of industry, Member States and the public on achievable emission and consumption levels when using specified techniques. The appropriate limit values for any specific case will need to be determined taking into account the objectives of the IPPC Directive and the local considerations.

Manufacture of wood-containing paper from mechanical pulp is not a single process but a series of unit processes, often linked and inter-dependent. Therefore, it is always a suitable combination of techniques that constitutes BAT for mechanical pulp and paper mill. The order of priority and the selection of the techniques or combinations of techniques depend on the local circumstances.

Best available techniques given below are, if not stated otherwise, applicable to new and existing plants. In paper mills, the applicability of a technique is less driven by the fact whether a mill is new or existing. Pulp and paper mills are characterised by the fact that machinery is rebuilt rather than replaced whole-scale. The modular rebuilding and development of plants means that each site is a unique product of its location and history. On the other hand, there is a series of unit processes, which are common in all countries.

Criteria to be considered in the determination of BAT in the specific cases are rather than specific costs for smaller mills are relatively higher (economies of scale). Other factors to consider are limitations of space, which some older mills might face, or unsuitable material or lay out of older equipment, which does not fit for a higher degree of water closure. More water system closure usually is combined with higher complexity of the system that needs to be monitored, controlled and understood. Smaller mills might sometimes not have the knowledge available which would be necessary to run and control more complex process solutions most efficiently.

4.4.2 BAT for mechanical and chemi-mechanical pulp and paper mills

For mechanical and chemi-mechanical pulp and paper mills the following techniques or combination of techniques are considered as BAT. The following list of BAT is not considered exhaustive and any other technique or combination of techniques achieving the same (or better) performance can also be considered; such techniques may be under development or an emerging technique or already available but not mentioned/described in this document. For integrated mechanical pulp and paper mills it is refer to Section 6.4 where further details on BAT for papermaking is given. If not stated otherwise, the data refer to yearly average values.

General measures

1. Training, education and motivation of staff and operators. Training of staff can be a very cost-effective way of reducing the environmental impact of mills.
2. Process control optimisation. To be able to reduce different pollutants simultaneously and to maintain low emissions, improved process control is required. The target of the controls is to keep the process at the desired operating point.
3. To maintain the efficiency of the technical units of pulp mills and the associated abatement techniques at a high level, sufficient maintenance has to be ensured.
4. Environmental management system which clearly defines the responsibilities for environmentally relevant aspects in a mill. It raises awareness and includes goals and measures, process and job instructions, check lists and other relevant documentation.

Measures for reducing emissions to water

1. Dry debarking of wood. Dry techniques use less water circulation through the drum stage. Water systems in debarking plants are kept very closed. Solid material is removed from the circulation water, which is only used for log washing, and separation of undesirable material. A part of the clarified water is separated to the wastewater treatment.
2. Water circulation system in mechanical pulping department. In order to keep the accumulation of dissolved and dispersed substances at an acceptable level the water circuits are opened to a certain extent
3. Effective separation of the water systems of the pulp and paper mill by use of thickeners. A dewatering lock after pulping leads to a significant decrease of contaminants in the paper machine water system. The filtrate of thickening is returned to the pulping process. This measure prevents that contaminants dissolved from the wood are travelling through the whole papermaking process. Isolation of process units makes it possible to remove contaminations inside the process unit in which they are generated.
4. Countercurrent white water system from paper mill to pulp mill depending on the degree of integration
The recirculation of process water from the paper machine to the pulp mill might not be possible when the mill has two or more paper machines making different types of paper, the white waters of which are incompatible, or when coloured paper is manufactured
5. Use of sufficiently large buffer tanks and storage for liquids from the process (mainly for CTMP)
6. Primary treatment, secondary biological, and/or in some cases, secondary chemical precipitation or flocculation of wastewater.
When only chemical treatment is applied the discharges of COD will be somewhat higher but mainly made up of easily degradable matter. Untreated mechanical pulping and bleaching waters are toxic to water organisms. Well-operated biological treatment can eliminate most of the toxicity of those effluents. Therefore, in addition to the process-integrated measures and primary and biological treatment is considered BAT for mechanical and chemo-mechanical pulp and paper mills. Activated sludge plants consisting of equalisation basin, aeration basin, secondary clarifier and sludge handling show excellent performance for the treatment those effluents. Low loaded activated sludge plants with a sludge load below 0.15 kg BOD/(kg MLSS*d) and typical retention times in the aeration basin of about one day are regarded as BAT. They can achieve high removal efficiencies (COD: 75-90%; BOD: 95+%) and a stable treatment system. A few mills achieved also good performances (>85% COD reduction) with high load biological treatment.

For CTMP mills three further measures are regarded as BAT

1. Efficient washing between pulping and paper mill. This measure reduces the carry-over of dissolved and dispersed substances from pulping and bleaching. If it doesn't harm the pulp and paper quality and other paper machines using the same pulp the circulation water of the paper mill can be used as wash water. The washing filtrate is returned to the pulp mill circulation water
2. Effluent treatment either by biological treatment systems in one or two stages with or without chemical treatment or internal chemical treatment of white water of the first washing stage plus activated sludge treatment of the rest. A combination of an anaerobic and aerobic treatment of the waste water is also regarded as an efficient treatment system. Finally, evaporation of the most contaminated waste water and burning of the concentrate plus biological treatment of the rest might be a solution for upgrading mills.
3. For new mills and those that significantly increase capacity the evaporation of the selected highly polluted partial wastewater streams to support the biological treatment or whole effluents and incineration of the concentrates is considered as BAT.

For integrated mechanical pulp and paper mills (which is the case for most mills), additionally to the measures related to mechanical pulping the measures described under the corresponding chapter on papermaking (chapter 6) have to be considered. However, the emissions levels associated with the use of BAT that are given further below include both the pulp and paper production.

The efficiency of each of these measures varies considerably with the design and operation practices at different mills. To be regarded as a BAT measure it must also be well designed and operated. A possible range of emissions of mechanical pulp and paper mills before biological treatment is shown in Table 4.15. The mills stand for some real world examples operating with different process conditions and water system configuration. The emission ranges might give an indication of releases to water when no biological treatment would be applied. In reality, all these mills have primary and secondary effluent treatment. The list of mills is a selection of mills where data were available or provided and is therefore not intended to be complete. It contains mills from different countries in Europe. The data are derived from information provided by TWG members, personal communication and [Zippel, 1999]. The method of analysing is the one used in the respective country. The efficiency of biological treatment of pulp mill effluents is discussed further below.

It has to be born in mind that some mills are using a mixture of fibres such as a certain percentage recovered fibre, different types of mechanical pulp, and also sometimes smaller amounts of purchased chemical pulp. This may lead to significant variations in the initial pollution loads.

Mills	COD [kg/ADt]	Tot N [kg/ADt]	Tot P [kg/ADt]	Flow [m ³ /ADt]	Production 97 [ADt/a]	Remarks
Steyrermühl, AT, Newsprint	18 ¹⁾ -35	n/a.	n/a.	17-20	450000	reductive bleached SGW, 1-or 2-staged bleached TMP + 50% DIP
Mill 2, DE	19	n/a.	n/a.	16	n/a	TMP, no further information available
Mill 3, DE, LWC	17	n/a.	n/a.	13	n/a	TMP, no further information available
Mill 4, DE, LWC	12	n/a.	n/a.	15	n/a	GW, no further information available
Mill 5, DE	18	n/a.	n/a.	14	n/a	GW, no further information available
Mill 6, DE	7	n/a.	n/a.	10	n/a	GW, no further information available
Mill 7, DE	9	n/a.	n/a.	16	n/a	GW, no further information available
Norske Skog Saugbrugs NO, SC paper ²⁾³⁾	63	n/a.	0.04	n/a.	530000	55% MP (peroxide bleached), 12 % CP, 33% filler
Norske Skog Follum, NO, Newsprint and MFC ²⁾³⁾	90	n/a.	0.04	n/a.	350000	> 95% MP (SGW and TMP whereof 70% peroxide bleached), < 5% CP
Explanatory Notes: n/a. = not available; MFC = Machine Finished Coated; CP = purchased chemical pulp, MP = Mechanical pulp produced on site, AS = activated sludge 1) The lower end of the range refer to dithionite bleaching, which is normally carried out in the pH range of 5-6. It does not notably increase the amount of dissolved organic material. The higher end of the range refer to bleaching with alkaline hydrogen peroxide 2) High alkalinity causes large dissolution of wood substances. Therefore, bleaching with alkaline hydrogen peroxide results in additional load of 5-15 kg BOD/t and 15-40 kg COD/t, which is of the same magnitude as in mechanical pulping itself. The discharge of phosphorus increases by 20-35 g/t and the discharge of nitrogen can increase to 400-500 g/t [Papermaking Science and Technology, 1999] 3) The figures given for the two Norwegian mills are discharge levels before any treatment (before primary treatment) and are therefore not comparable to the other figures.						

Table 4.15: Examples of yearly average emission levels to water after primary treatment of some mechanical pulp and paper mills in Europe (reference year: 1997)

The bulk of pollution is caused by mechanical pulping. Different pulping processes cause largely differing dissolution of wood substances into the process waters. Typical concentration from GW production wastewater is 2000 and 2500 mg/l. For TMP production higher concentration between 2000 and 3500 mg/l (or higher) can be expected. CTMP again gives significantly higher dissolution of wood material than TMP. Assuming a specific water consumption between 10 and 20 m³/ADt the COD concentration of the total wastewater from pulping and papermaking normally vary between 600 and 2000 mg/l before biological treatment.

In integrated mills the wastewater from the pulping department is mixed with water from other parts of the mill (e.g. coating wastewater, water from integrated DIP production) and treated in a common treatment plant. Typically, the COD load before biological treatment varies between below 10 kg COD/t and 35 kg COD/t (with a small share peroxide bleached TMP). For predominantly peroxide bleached TMP manufacturing also higher COD loads are reported (up to 90 kg/t before any (primary) treatment).

For mechanical pulp and paper mills it is difficult to present emission levels that are associated with the use of BAT before biological treatment because the pollution load depends significantly on the defiberizing conditions (e.g. temperature), bleaching sequences applied (pH levels) and the raw materials used (wood species, storage). The layout and degree of closure of the water loops (counter-current flows, use of thickeners, process water clarification) is another important influence. Consequently, data on the amount and composition of dissolved and dispersed substances in mill process waters before treatment vary and are mostly not sufficiently qualified to draw general conclusions. Another difficulty is that the water system of the mechanical pulping department is connected to the water system of papermaking which causes interference between the two systems.

Table 4.16 shows achieved emission levels of some mechanical pulp mills in Europe that have implemented a set of process-integrated BAT measures but not necessarily all and not necessarily to their full extent and biological waste water treatment as well. Within brackets emissions are given as concentrations.

Integrated mechanical pulp and paper mills	Reported achieved emission levels after biological treatment (annual averages)						raw materials and type of wastewater treatment
	COD [kg/Adt]	BOD _{5 or 7} [kg/Adt]	TSS [kg/Adt]	Total P [kg/Adt]	Total N [kg/Adt]	Flow ³⁾ [m ³ /Adt]	
Enso summa, FI, Newsprint	1.8 (75 mg/l)	0.21 (9 mg/l)	0.3 (13 mg/l)	0.007	0.07	24	no information
UPM Kaipola, FI, Newsprint/LWC	2.8 (150 mg/l)	0.1 (5 mg/l)	0.3 (16 mg/l)	0.005	0.07	19	no information
Steyrermühl, AT, Newsprint	2.5 (125 mg/l)	< 0.2 (10 mg/l)	< 0.2 (10 mg/l)	< 0.01	< 0.03	17-20	SGW, TMP + 50% DIP, low load AS
Braviken, SE, Newsprint	2.0 (135 mg/l)	n./a.	0.39 (26 mg/l)	0.004	0.1	15	TMP + RCFP; biol. treatm. + chem. precip.
Kvarnsveden, SE, Newsprint, SC	2.0 (135 mg/l)	n./a.	0.22 (15 mg/l)	0.002	0.054	15	TMP + GWP; biol. treatm. + chem. precip.
Mill 2, DE, coated (e.g LWC)	0.85 (65 mg/l)	< 0.1 (8 mg/l)	0.15 (12 mg/l)	0.006	0.04 (inorg. N)	13	30% purchased CP, 30% MP, 30% fillers, DIP, 2-stage biofilter
Mill 3, DE, LWC	0.8 (95 mg/l)	0.1 (12 mg/l)	0.07 (8 mg/l)	0.01	0.04 (inorg. N)	8.5	30% purchased CP, 30% MP, 10% DIP, 30% fillers, AS
M-S Kirkniemi, FI, LWC	2.0 (180 mg/l)	0.15 (14 mg/l)	0.5 (45 mg/l)	0.003	0.04	11	AS + chemic. precipitation
Ortviken, SE, Newsprint, LWC	2.0 (105 mg/l)	n./a.	0.29 (15 mg/l)	0.004	0.10	19	TMP; biol. treatm. + chem. precip.
Myllykoski, FI, LWC/SC	3.4 (180 mg/l)	0.3 (16 mg/l)	0.5 (25 mg/l)	0.011	0.06	19	Activated sludge + chem. precip.
UPM Jämsänkoski, FI, SC	2.4 (160 mg/l)	0.06 (4 mg/l)	0.4 (25 mg/l)	0.006	0.09	15	Activated sludge + chem. precip.
M-S Lielähti, FI, non-integrated CTMP	15 (650 mg/l)	1.1 (48 mg/l)	1.6 (70 mg/l)	0.025	0.31	23	Activated sludge
Rockhammar, SE, non-int. CTMP	12	n./a.	0.8	0.007	0.2	20	Biol. treatm. + chem. precip.
Waggeryd, SE, non-integ. CTMP	22	n./a.	2	0.03	0.9	19	Biological treatment
Fors, SE, integrated CTMP	20	n./a.	1.5	0.003	0.2	16	Biol. treatm. + chem. precip.

Explanatory notes:
 CP = purchased chemical pulp, MP = Mechanical pulp produced on site, AS = activated sludge, n./a. = no data available
 The list of mills is a selection of mills where data were available or provided and is therefore not intended to be complete. The data are derived from available environmental reports, statistics from Finnish Environment Institute, SEPA report 4987 (data for 1998) and from personal communication. The method of analysis is the one used in the respective country. In Sweden and Finland the values for BOD are given as BOD₇

Table 4.16: Examples of achieved emission levels to water after biological treatment of integrated pulp and paper mills in Europe manufacturing wood-containing paper (reference year: 1997)

Assuming adequate design and capacity of the waste water treatment plant and appropriate operation and control by skilled operators the following discharge **after** biological treatment are associated with the use of BAT:

Parameter	Units	Integrated mechanical pulp and paper mills such as newsprint ¹ , LWC paper ² , SC paper ³ mills
BOD	kg/t of paper	0.2 - 0.5
COD	kg/t of paper	2.0 – 5.0
TSS	kg/t of paper	0.2 – 0.5
AOX	kg/t of paper	< 0.01
Total P	kg/t of paper	0.004 - 0.01
Total N	kg/t of paper	0.04 - 0.1
Wastewater amount	m ³ /t of paper	12 - 20
Explanatory notes:		
1) It is assumed that > 50% of the fibres consists of mechanical pulp manufactured at the mill. Different mixtures of fibre furnish can be found in European newsprint mills . Fibre furnish might be e.g. 50-60% bleached TMP, 40-50% DIP.		
2) It is assumed that > 50% of the fibres consists of mechanical pulp manufactured at the mill. Different mixtures of furnish can be found in European LWC paper mills . Fibre furnish might be e.g. 30-40% purchased bleached kraft pulp, 50-60% PGW or TMP		
3) It is assumed that > 50% of the fibres consists of mechanical pulp manufactured at the mill. Different mixtures of furnish can be found in European SC paper mills. Fibre furnish might be e.g. 10-20% purchased bleached kraft pulp, 80-90% PGW or TMP. 20-45% of the raw material might consists of fillers and sizes		

Table 4.17: BAT associated emission levels as yearly average for manufacturing of wood-containing paper (> 50% mechanical pulp)

Values refer to integrated mills after biological treatment. Emissions from the paper machine are included. BAT for papermaking is described in Section 6.4

For mills bleaching with alkaline hydrogen peroxide BAT associated emission levels are rather the upper end of the range and in a few specific cases even higher (e.g. if the fibre furnish consists predominantly of peroxide bleached TMP pulp). On the other hand, integrated mechanical pulp and paper mills that use a significant amount of purchased chemical pulp as fibre furnish can achieve lower values down to 1 kg COD per tonne of paper produced.

Other grades of mechanical pulp and paper mills

In mechanical pulp mills that are integrated with a paper mill the effluent loads for the end product include both the contribution of the pulp plant and the paper mill. In most paper mills producing wood containing grades the required chemical pulp (if needed) is supposed to be purchased from off-site mills. The contribution of re-pulping of this chemical pulp to the total effluent load is negligible compared to the contribution of the mechanical pulp mill. However, some paper and board mills producing LWC paper or cartonboard (e.g. liquid container board or folding box board) are integrated with bleached chemical pulp mills. In those cases, the emissions from kraft pulping have to be added according to fibre furnish. It is referred to BAT reference levels for kraft pulping as presented in Section 2.4.

BAT emission levels for integrated **cartonboard** mills (> 50% mechanical pulp) will be quite similar to those from LWC paper mills. The fibre furnish for a multi-layer board might be e.g. 25-30 % bleached kraft pulp, 70-75 % TMP; Fillers and coating colour may amount to 10-25 %. However, a lot of other mixtures of furnish exists in European cartonboard mills.

BAT emission levels for integrated wood containing **tissue** mills (> 50% mechanical pulp) should be in the same range as for integrated SC or newsprint paper mills. There are only very few of wood containing tissue mills in Europe. The fibre furnish for wood containing tissue might consist of e.g. 50-60 % bleached mechanical pulp and 40-50 % purchased chemical pulp. No specific BAT emission levels are presented for this paper grade.

In contrast, the emission levels associated with the use of BAT for the manufacturing of **CTMP** are significantly different because CTMP gives significantly higher dissolution of wood material than TMP. BAT emission levels after treatment are shown in Table 4.18.

Parameter	Units	CTMP ¹
BOD	kg/ADt	0.5-1.0
COD	kg/ADt	10.0-20.0
TSS	kg/ADt	0.5-1.0
AOX	kg/ADt	-
Total P	kg/ADt	0.005-0.01
Total N	kg/ADt	0.1-0.2
Wastewater amount	m ³ /ADt	15-20

Explanatory notes:
 1) Emissions are related to non-integrated CTMP production. Alkaline or neutral Na-sulphite pretreatment, Refining yield 94-95% [data from J.Pöyry, 1998 and mill data]

Table 4.18: BAT associated emission levels as yearly average for manufacturing of CTMP
Values refer to non-integrated mills after biological treatment. Emissions from the paper machine are not included. Integrated mills have to add emissions from papermaking as described in Section 6.4 according to the share of production

Table 4.17 and Table 4.18 should be read together with the following additional explanations:

Chemical oxygen demand (COD): The reduction rate for COD is related to the types and amounts of effluents treated (e.g. peroxide bleached TMP, reductive bleached SGW, DIP production, effluents from coating), the construction and hydraulics of the treatment plant and appropriate adjustment of the operating parameters. The wastewater from mechanical pulping is easier degradable than those from chemical pulping. COD removal rates of 75 - 90 % are achieved by well designed and controlled low loaded plants. Consequently, emission levels of 2 - 5 kg COD/ADt can generally be achieved by mills manufacturing wood-containing paper. The concentration measured in effluents of this mills are in the range of 125 - 200 mg COD/l. CTMP mills discharge higher concentrated wastewater. Because of the chemical pretreatment of the woodchips CTMP mills discharge higher emissions to water.

Biological oxygen demand (BOD₅ or τ): In well designed treatment plants BOD is removed almost completely (95% + removal) from mechanical pulp mills waste water when the carbon-phosphorus-nitrogen ratio and oxygen supply is maintained sufficient and well controlled. The BOD concentration in treated effluents below 25 mg/l (often close to the detection limit) are associated with BAT. Depending on the water flow this corresponds to 0.2 kg BOD₅/Adt and 0.7 kg BOD₅/Adt.

Total suspended solids (TSS): Under normal operation conditions, the water from the secondary clarifier is fairly clear and its suspended solids content in the range of 20 to 30 mg/l. This corresponds to discharges of 0.2 – 0.5 kg TSS/Adt. The values depend on the surface load of the secondary clarifier and the characteristics of the biomass.

Phosphorus and nitrogen (Tot-P and Tot-N): Mineral nutrients are usually added to the biological treatment plant to keep the balance C : P : N which is of crucial importance for the growth of active biomass. It is necessary to find and keep a balance between incoming N- and P-compounds that are available for biomass and the amount of nutrients, if any, added which requires a certain fine-tuning of the nutrient feed. When the system is well optimised the phosphorus discharge of below 0.5 mg tot-P/l and 1 - 5 mg tot-N/l are achieved. The corresponding loads are 0.005 - 0.01 kg P/Adt and 0.05 - 0.2 kg N/Adt respectively.

Measures for reducing emissions to air

Auxiliary boilers

Depending on the actual energy balance of the mill, the type of external fuels used and the fate of possible biofuels as bark and wood-waste additionally there are atmospheric emissions from auxiliary boilers to consider. Emission levels associated with BAT from auxiliary boilers incinerating own biofuels and different fossil fuels are given in Table 4.19. The total releases to air are very site specific (e.g. type of fuel, energy demand, production of electricity). It has to be noted that auxiliary boilers within the pulp and paper industry are of a very variable size (from 10 to above 200 MW). For the smaller only the use of low-S fuel and combustion techniques can be applied at reasonable costs while for the larger also control measures. This difference is reflected in the following table. The higher range is considered BAT for smaller installations and is achieved when only quality of fuel and internal measures are applied; the lower levels (in brackets) are associated with additional control measures like SNCR and scrubbers and are regarded as BAT for larger installations.

Released substances	Coal	Heavy fuel oil	Gas oil	Gas	Biofuel (e.g. bark)
mg S/MJ fuel input	100 - 200 ¹ (50 - 100) ⁵	100 - 200 ¹ (50-100) ⁵	25-50	<5	< 15
mg NO _x /MJ fuel input	80 - 110 ² (50-80 SNCR) ³	80 - 110 ² (50-80 SNCR) ³	45-60 ²	30 -60 ²	60 -100 ² (40-70 SNCR) ³
mg dust/Nm ³	10 - 30 ⁴ at 6% O ₂	10 - 40 ⁴ at 3 % O ₂	10-30 3% O ₂	< 5 3% O ₂	10 - 30 ⁴ at 6% O ₂
Notes:					
1) Sulphur emissions of oil or coal fired boilers depend on the availability of low-S oil and coal. Certain reduction of sulphur could be achieved with injection of calcium carbonate.					
2) Only combustion technology is applied					
3) Secondary measures as SNCR are also applied; only larger installations					
4) Achieved values when electrostatic precipitators are used					
5) When a scrubber is used; only applied to larger installations					

Table 4.19: Emission levels associated with the use of BAT for different fuels

VOC emissions

Due to high temperature of defiberizing, a part of the volatile wood compounds are evaporated during processes. The amount and composition of volatile organic compounds (VOCs) are greatly dependent on the resin content of the wood. In cases where wood species with high extractive content are used and generated VOC emissions are not sufficiently recovered in the heat recovery units and the start-up scrubber for TMP steam, collection and further treatment of volatile compounds is regarded as BAT. VOC containing exhaust air can be incinerated in existing boilers.

Emissions from incineration of waste residues

BAT is the use of fluidised bed technology at solid waste boiler. Flue gases are cleaned according to the requirements set for incineration of the given composition of the fuel input.

Measures for reducing solid waste

Most of the solid material that forms waste flows is created during debarking (bark, debarking loss of wood, sawdust, and chipping dust). Other solid waste consist of fibre losses during pulping, and sludge from primary and secondary wastewater treatment. In many mills all these residues with high organic content are recovered and burned in auxiliary boilers. Generally, the following measures are considered as BAT:

1. Minimisation the generation of solid waste and recover, re-cycle and re-use these materials as far as possible.
2. Separate collection of waste fractions at source and, if necessary, intermediate storage of residuals/waste to make possible an appropriate handling of remaining waste products
3. Incinerating all non-hazardous organic material (bark, wood waste, effluent sludge, etc.) in emission optimised auxiliary boilers, specially designed for burning of moist, low calorific value fuels (as e.g. fluidised bed boilers).
4. External utilisation of residuals/waste as substitutes in forestry, agriculture or other industries, if possible
5. Minimisation of disposal of rejects to landfills

It should be noted that there is little detailed and reliable information available on achievable amounts of solid wastes. There is a lack of statistical data and various terms for different waste fractions are used in Europe. Some countries report only those solid waste - primarily inorganic solid wastes - which no longer can be recycled or reused, but have to be disposed off to landfill. This implies that all the organic wastes which have a reasonable heating value and/or which can be incinerated without the risk of hazardous emissions in the auxiliary boiler of a mill are already excluded from the given solid waste amounts (bark and wood waste, primary and biosludge from waste water treatment). Hence, the solid waste disposed of at landfill comprises mainly boiler ashes, some wood and bark waste rejects and miscellaneous cleaning and mixed household-type wastes.

For the reasons mentioned above, no achievable values on the amount of non-hazardous solid waste are presented.

A small amount of hazardous waste is generated in all mills. Such waste include oil and grease residues, used hydraulic and transformer oils, waste batteries and other scrap electrical equipment, solvents, paints, biocide and chemical residues, etc. Normally they amount to about 0.05-0.1 kg/t of product.

Energy saving measures

In general in this sector BAT is considered to be the use of energy efficient technologies. A lot of options for energy saving in many stages within the manufacturing process are available. Usually these measures are linked with investments to replace, rebuild or upgrade process equipment. It should be noticed that energy saving measures are mostly not applied only for energy saving. Production efficiency, improvement of product quality and reduction of overall costs is the most important basis for investments.

To decrease energy consumption the following measures are available:

1. Implementation of a system for monitoring energy usage and performance. Based on reliable energy performance information appropriate action can be taken. Energy management includes setting, controlling, reviewing and revising energy performance targets.
2. Upgrading of equipment. When replacing equipment less energy consuming equipment with possibilities for automated process control instead of conventional manual systems. Automated controlled systems are more efficient to control and can result in more accurate processing and energy savings (see also Section 6.3)
3. Minimisation of reject losses by using efficient reject handling stages and reject refining. If fiber bundles (shives) and undeveloped coarse fibres are removed from the main process line, the energy, which was already spent for first grinding/refining would be lost. The reduction of reject losses after grinding and mainline refining and the further refining of shives and coarse fibres to develop the properties to the quality level needed thus decreases specific energy consumption.

4. Use of effective heat recovery systems (applies only for TMP and CTMP). Large volumes of steam are generated in TMP refining because around two-thirds of the refining electrical energy is transformed in thermal energy in the form of hot saturated steam. The impurities present in the TMP steam make the heat recovery unit necessary because the direct use of TMP steam is not possible. The TMP steam is separated from the fibres in cyclones and then condensed in the reboiler against vaporising clean steam. The clean steam is normally used in the paper machine department
5. Application of co-generation of heat and power where the power/steam-ratio allows it

For further measures to reduce energy consumption that are generally applicable to paper mills it is referred to Section 6.3. Major possibilities for improvement discussed in this section, are e.g. optimization of the de-watering at the wire section by installation of a wide nip press. and use of energy efficient technologies. Also the reduction of direct use of steam by careful process integration by using pinch analysis is mentioned there.

In many European countries, information on energy balances of paper mills is poorly available in public. Different reporting schemes, if any, for energy consumption are used. Energy demand also depends on the product quality (e.g. degree of refining) and partly on local conditions. Therefore, it is difficult to present energy consumption values associated with the use of BAT. The ranges of energy consumption shown in Table 4.20 should only be taken as an indication about the approximate need of process heat and power at energy efficient mechanical pulp and paper mills. Further examples of energy efficient mills including the specific conditions might be possible to add in a reviewed version of the BREF.

Type of mill	Process heat consumption (net) in GJ/Adt ¹⁾	Power consumption (net) in MWh/Adt
Integr. machine finished newsprint (100% TMP)	- 1.3 ²⁾	2.2
Integrated SC magazine paper (100 % TMP)	- 0.3 ²⁾	2.1
Integrated newsprint (>50% mechanical pulp)	0-3.0	2.0-3.0
Integrated LWC mill (>50% mechanical pulp)	3.0-12.0	1.7-2.6
Integrated SC mill (>50% mechanical pulp)	1.0-6.0	1.9-2.6
Integrated Cartonboard (>50% mechanical pulp)	3.5-13.0	2.3-2.8
Non-integrated CTMP	0	2.0-3.0
Explanatory notes: (-) indicates a surplus The units can be converted from MWh to GJ according to 1 MWh = 3.6 GJ and 1 GJ = 0.277 MWh Data from [J.Pöyry, 1998], [SEPA Report 4712-4, 1997], [Finnish BAT Report, 1997] 1) The net process heat consumption depends mainly on the type of refining and the degree of heat recovery 2) The values can only be reached if heat recovery, paper machine press section and the use of electricity are all implemented and operated in an ideal way. In existing processes this is rarely the case		

Table 4.20: Indication for energy consumption associated with the use of BAT for different types of production of wood-containing papers per tonne of product

Noise attenuation

BAT is the reduction of noise levels audible in the vicinity of paper mills. The measures applied will depend to a large extent to the specific noise problem of a mill and the targets set. Usually they will be much stricter when the mill is located adjacent to a residential area.

Chemical usage

It is referred to Section 6.4

4.5 Emerging Techniques

4.5.1 Use of new evaporation techniques as “kidney” for internal cleaning of process water

Description: In mechanical pulping most of the organic material released during production comes from a few sources (e.g. filtrate water of bark compression, separated flow from debarking circulation water, dissolved organic material during grinding/refining, bleaching filtrates). Currently, in most mills wastewater treatment is done together for all mill effluents, which is a purposeful way to achieve a stable operation in the biological treatment. Recently, a few mills introduced new concepts, which focus on internal treatment of most concentrated or problematic partial wastewater streams by other techniques. Thus, it is tried to separate contaminants closer to their place of origin to decrease the size of the water treatment equipment needed. In principal, to reduce the amount of contaminants, micro-flotation, membrane filtration, chemical oxidation, evaporation and combinations of these techniques could be used. Energy consumption and investment and operating costs in the given application will have a crucial influence on the choice of treatment system.

For mechanical pulp and paper mills multi-effect vacuum evaporation seems to be especially promising because sufficient amounts of waste heat is available to operate the treatment system.

Status of development: Two mechanical pulp mills in Sweden and Finland have recently built an evaporation plant to treat a large portion of the TMP (StoraEnso Kotka, FI) and CTMP effluent (Stora Fors, SE). Both mills are using a new kind of co-current type Multi Effect Evaporator called ZEDIVAP™ to produce pure water for reuse. Free flow falling-film lamellas are used as heat transfer surfaces. Optimisation work is still carried out in both mills.

Environmental implications: This new application of advanced wastewater techniques opens the door to significant reductions in effluent volumes and loads to recipient. The process utilises waste heat streams available in the mill and the effluent’s own latent heat. In this case, the electricity consumption of the evaporation plant is approximately in the same range than in conventional biological systems. The total energy demand depends on the number of effects. For instance, a plant with 10 effects needs only 10% of the energy of a single effect. However, the handling and treatment of the concentrates are still waiting for a satisfactory solution. In the present, there are very site-specific solutions (burning of concentrates in adjacent kraft pulp mills recovery boiler). A prerequisite for the application of those systems is that strict water management is followed in all departments of a mill.

Economic considerations: Modern techniques for internal cleaning and reuse of process waters can be as cost effective as traditional wastewater purification (biological treatment). [Edelmann, 1999] has compiled figures on energy consumption, and investment and operating costs for the major treatment options as shown in the following table. However, whether this technique can be economically justified depends on the specific conditions of the given mill.

Water treatment methods	Electricity consumption kWh/m ³ water	Typical capacity (m ³ /d)	Investment costs Euro/(m ³ /d)	Operational costs Euro/(1000 m ³)
Chemical treatment of raw water	0.30	30000	170	73
Biological effluent treatment	1.20	30000	620	136
Microflotation	0.23	10400	20	104
Ultrafiltration	2.60	5000	470	153
Multiple effect evaporation	1.34	3600	840	35
Mechanical vapour compression	13	3600	1360	328
Cooling tower	0.12	39000	130	3

Note: Figures are based on equipment deliveries only and total project costs/local application costs are not included

References: [Edelmann, 1999], [Gartz, 1996], [Gartz, 1998], [Wigsten, 1995], [Legnerfält, 1997]

4.5.2 New energy efficient TMP processes

Description: The TMP process consumes large amounts of electrical energy in the range of 1600-3200 kWh/ADt. The process shows a great flexibility in many respects and it is not likely that the industry would switch the existing TMP processes to PGW (apart from some cases), which consumes less power (about 600-1200 kWh/ADt less) than TMP production for the same grades.

Therefore, a lot of development work has been focusing on reduction of the power consumption in the TMP process. There have been promising pilot trials such as the KCL multistage process, which indicate that significant power reductions of about 10-15% (200-450 kWh/t) are possible by changing the refining strategy. This claim cannot be fully verified at present stage. However, since the mid-1990s there are also a few mill-scale applications of new energy efficient TMP processes (RTS, Thermopulp®).

Status of development: There are two new TMP systems on the market, the RTS process and the Thermopulp® process, that consume substantially less energy than “normal” TMP processes. In the mid-1990s, several lines of the Thermopulp® process went into operation both in Europe and North America. The first RTS installation was at Perlen Papier AG, Switzerland, in 1996. Both system can be considered as available techniques but would normally only be installed at new mills or when existing equipment is replaced.

Environmental implications: The so-called “RTS” process reduces the energy consumption in chip refining by increasing the disc speed. The high speed operation is restricted to the first refining stage. At the same time the temperature is raised during this stage. “R” stands for retention time, the “T” for temperature, and the “S” for speed. The first full-scale experience suggests that an energy reduction in the order of 15% compared to conventional TMP is possible using this system. Specific energy consumption of the first commercial RTS operation is 1.85 MWh/ at a Freeness level of 94.

In the Thermopulp® process, the first refining stage is performed at a relatively low temperature. The pressure and temperature are raised before the second stage refining, which is performed at very high pressure and temperature (up to 700 kPa and 170°C). Energy savings of 10-20% have been reported. Specific energy consumption in mill scale at a North American mill is 1.75 MWh/t at a Freeness of 160.

Economic considerations: No data available. Energy savings must be balanced with investment costs. It can be expected that the new technology will only be implemented gradually due to remaining life-time of present equipment and plants.

References: [SEPA-Report 4712-4, 1997], [Paper Science and Technology, 1999]

5 RECOVERED PAPER PROCESSING

Recovered fibre has become an indispensable raw material for the paper manufacturing industry, accounting about one-third of the total raw materials because of the favourable price of recovered fibres in comparison with the corresponding grades of market pulp and because of the promotion of wastepaper recycling by many European countries. In Europe there is an average utilisation rate of recovered paper of 43 %. But it has to be taken into account that the maintenance of the fibre cycle relies on the feed of a certain amount of primary fibres to ensure the strength and other properties of the paper to be produced.

For effective use of recovered paper it is necessary to collect, sort and classify the materials into suitable quality grades.⁴ Therefore, after collection recovered paper is brought to the collection yards where it is sorted. Detrimental substances as e.g. plastics, laminated papers etc. are removed before balling as well as possible. The sorted recovered paper is usually compacted by baling machines. Industrial recovered paper from large generators is usually delivered to and processed in recovered paper yards integrated in the paper mill.

5.1 Applied Processes and Techniques

The recovered paper processing system varies according to the paper grade to be produced e.g. packaging paper, newsprint or tissue paper and the type of furnish used. Generally, recycled fibre (RCF) processes can be divided in two main categories:

- Processes with exclusively mechanical cleaning i.e. *without deinking* comprising products like testliner, corrugating medium, uncoated board and cartonboard
- Processes with mechanical cleaning and *de-inking* comprising products like newsprint, tissue, printing and copy paper, magazine papers (SC/LWC), coated board and cartonboard or market DIP

Many different recovered paper processing systems are applied in European paper mills. However, they are all based on similar process steps that may be combined differently to fulfil their specific task. All process systems are aiming at defibration, deflaking and removal of impurities i.e. efficient separation of fibrous material and impurities and contaminants. Recycled fibre plants consist of similar "building blocks" designed for the specific task. These typical stages of recycled fibre processing are as follows:

Recovered paper storage

Recovered paper is normally delivered to the paper mill in the form of bales kept together by metal wires or straps. The bales are opened by cutting the wires or straps that are collected and sold as metal waste. To some mills recovered paper is also delivered as loose material in big containers or by bulk dumping. The recovered paper is stored on recovered paper yards integrated in the paper mill.

Repulping of the dry recovered paper

The recovered paper is put into a pulper together with hot water or white water, and pulped with mechanical and hydraulic agitation resulting in their disintegration into fibres. After repulping the recovered paper has a pulping consistency for subsequent treatment. Some chemicals such as deinking agents and NaOH are often added as pulping additives. Usually the detachment of inks already begins in the repulping stage. Different technical solutions are available for various types of raw materials and products. There are three types of pulper: low consistency (LC: 4-6% DS), high consistency (HC: ca. 15 -20%) and drum pulpers. There are batch and continuous

⁴ CEPI has published in February 1999 the European List of Standard Grades of Recovered Paper and Board⁴. This list gives a general description of the standard grades by defining what they do and do not contain.

types. Contaminants and clusters are removed continuously during operation by a dirt trap (e.g. screen plate) and are sent to a reject conveyor, in order to avoid the contaminants breaking into small pieces or accumulating in the pulper. There is an increasing use of secondary pulpers for further defibration, deflaking and cleaning from heavy-weight (HW) and lightweight (LW) dirt. The installations trade under different names but are based on similar functioning. Also screening drums are used.

Normally, the water for disintegration is totally re-circulated process water that come as white water from the paper machine.

Mechanical removal of impurities

The removal of mechanical impurities is based on the differences in physical properties between fibres and contaminants, such as size, specific gravity compared to fibres and water. Basically there is screen-type equipment with different dimensions of screen opening (holes and slots) and various types of hydrocyclones (high consistency cleaners, centrifugal cleaners etc.).

The partially cleaned pulp slurry is pumped from the pulper to hydrocyclones (high density cleaners) in which centrifugal forces remove smaller heavy weight particles. The rejects of these cleaners as well as of the pulper disposal system usually have to be disposed of by landfilling (high content of inorganic material).

The next process stage is screening to separate contraries, which are larger than the openings of the perforated baskets of the pressurised screens. The selection of screen type depends on end product and the quality of the fibre furnish used. Coarse screening (3-4% consistency) for the removal of coarse contaminants during stock preparation can be distinguished from fine screening in the approach flow (1% consistency) of the paper machine. The applied devices are similar in functioning but have different fineness of the separating optimum. Generally, screening at a lower consistency is more efficient, but it requires extended machinery installations and consumes more energy. The reject has to be deposited or further treated.

Depending on the furnish quality to be achieved the stock preparation plant for recovered paper processing has to be equipped with additional machines such as fractionators, dispergers or refiners. A fractionator separates the pulp in two fractions rendering it possible to treat short and long fibres of the pulp slurry in different manners. The energy demanding process of disperging can be performed in order to achieve improved fibre-to-fibre bonding (better strength characteristics) in the paper produced and to reduce visible dirty specks in size. A stock preparation plant for the processing of recovered paper can be optionally equipped with refiners to improve optical and strength characteristics of the paper. Refining is associated with a substantial energy demand.

A possible arrangement of RCF process with mechanical cleaning for the production of case making materials (here: testliner) is shown in figure below. It has to be pointed out that in practice each plant is individually equipped with machines of one or several suppliers, depending on the recovered paper grades used, the demands of the final product quality, the runnability of the paper machine and on local conditions regarding environmental issues.

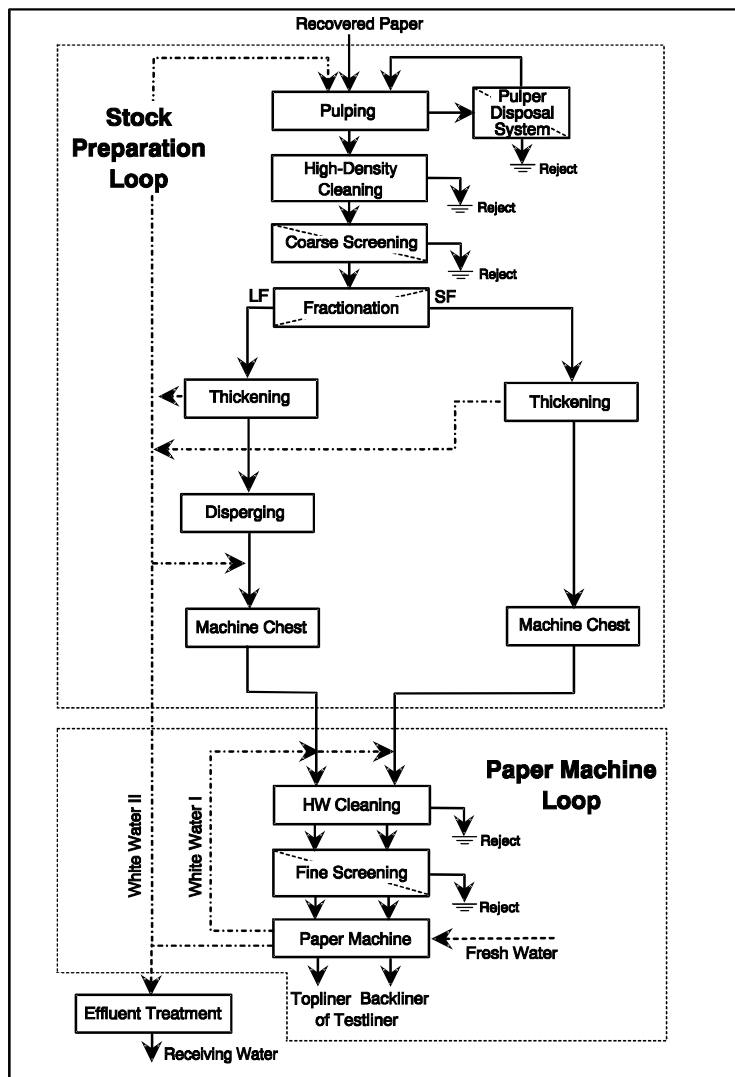


Figure 5.1: Flowsheet of an example for a stock preparation plant concept for processing recovered paper for case making material (2-ply testliner) [IFP, 1998]; HW = heavy-weight impurities; LF = Long fibre fraction; SF = Short fibre fraction

The preparation of recovered paper for the manufacturing of testliner and corrugated medium is applied by about 150 mills in Europe. It is the first market in tonnage for paper-board in Europe (case materials⁵ account for 26% percent of the total paper and board production using a share of 86% of recycled pulp as an European average).

Processes with flotation deinking (optional)

Ink removal is necessary in plants manufacturing paper grades where brightness is important e.g. for newsprint, printing and writing paper, tissue or light topline of recovered paper based cartonboards. The main objectives of deinking are increasing of brightness and cleanliness and reduction of stickies. It should be noted that the difference between de-inked and non de-inked grades is in the process and not in the product itself. Depending on the quality of the recovered paper used, market requirements or production needs, also packaging papers and boards could be de-inked.

⁵ Case materials: Papers and boards mainly used in the manufacture of corrugated board. They are made from any combination of virgin and recovered fibres but the raw material used by this industry is mostly based on waste paper-board. Included are kraftliner, testliner, semi-chemical fluting, and waste paper based fluting (wellenstoff).

A complete deinking plant includes also the above mentioned basic unit operations repulping, screening and cleaning for removal of coarse contaminants (non-paper items as stones, sand, metal, string, glass, textiles, wood, plastic foils, paper clips etc.). Additionally to mechanical cleaning of the furnish a chemical pretreatment of the pulp and a removal of printing inks in flotation cells is carried out. A prerequisite for successful deinking is that the ink particles are released from the fibres and kept in dispersion. For this purpose deinking chemicals as NaOH, sodium silicate, hydrogen peroxide, soaps or fatty acids and chelating agents are added mostly already in the pulping sequence (usually there is no need for the use of chelating agents in recovered paper bleaching). The dispersed ink particles are then separated from the fibre slurry by means of (multi-stage) flotation techniques. The operation principles of flotation deinking are the following: Air is introduced to incoming pulp in fine bubbles; ink particles are collected by surface chemical characteristics to air bubbles; ink laden froth is skimmed out from the surface. Depending on the cell size and construction there may be several cells in series to achieve a proper dwell time for ink removal. In order to reduce fibre loss with deinking sludge the foam from primary cells is often treated with secondary cells in cascade mode. Ink froth and rejects are dewatered separately in a centrifuge or wire press type equipment up to 50% DS. Deinking sludge is incinerated or deposited.

After deinking the pulp is thickened and sometimes washed using sieve belt presses, (disc) thickeners, screw presses, and washers. After these cleaning steps, the pulp may still contain small residual impurities, such as remains of printing ink particles, wax or stickies, which originate e.g. from hot-melt glues etc. These impurities can be dispersed so finely with a disperser that the particles are invisible to the naked eye. Before dispersion the dry solids content of the pulp has to be increased from around 5 - 12% % to 25-30% because dispersion requires strong friction forces and high temperatures around 95 °C or more. The dispersers itself are a similar device as refiners as described in Section 4.1.2. After dispersion the stock is diluted again.

The order of the operation may vary from mill to mill and some of the steps may be repeatedly performed.

A deinking plant concept with flotation deinking for the preparation of RCF for newsprint is shown in Figure 5.3.

Processes with wash deinking and ash removal (optional)

Flotation deinking is efficient for particle sizes from 5-100 µm. Ink particles, which are smaller than the optimum range for flotation deinking can be removed by washing deinking which is basically a multistage dewatering. Besides inks, fillers and fines are removed by washing. Washing is often carried out in several stages with counter-current water flow i.e. the filtrate of the secondary stage is used for dilution of the stock in the preliminary stage. Coated papers are especially sensitive to impurities in the uncoated base paper and require very clean RCF pulps. Therefore, a modern deinking plant for preparation of recovered paper to LWC paper includes often both flotation and washing deinking as they complement each other.

If ash removal is required as for tissue paper or for market DIP the system must always include a washing stage as shown in Figure 5.4.

Bleaching (optional)

Before entering a storage tower the pulp is often bleached by use of bleaching chemicals. Generally hydrogen peroxide (P), hydrosulphite (Y) or formamidine sulfinic acid (FAS) are used. Bleaching chemicals are added directly in the disperser to maintain or increase the brightness. The reaction itself takes place in a bleaching tower ensuring a sufficient dwell time. Any possible increase in brightness depends on the raw material and on the pre-treatment of the stock. Hydrogen peroxide bleaching is carried out in the presence of NaOH, sodium silicate and sometimes chelating agents. For almost wood-free secondary fibre stock so-called unconventional bleaching chemicals oxygen and ozone can be used.

Finally the pulp is pumped to the storage chests or mixing chests. These chests serve as a buffer between the stock preparation and the actual paper machine, to promote process continuity. In the mixing chests the required additives are added and the correct fibre consistency is adjusted for proper sheet-forming in the paper machine.

Process water purification

Water from the dewatering stages may be clarified in a micro-flotation unit. The process water is then reused in the process. The micro-flotation unit gives a sludge that is thickened and deposited or incinerated. In case of washing deinking the total water usage is reduced by recycling the wash water as well. Solids have to be removed from the filtrate by a separate flotation unit.

Final cleaning and dewatering

Different types of fine screens and cleaners remove residual contaminants before the highly diluted pulp slurry is fed to the paper machine.

Dewatering/thickening may be done by disc filters and screw presses to achieve the pulp consistency needed as well as to keep the white water loops separated.

Reject and Sludge Handling

In the processing of recovered paper various types of rejects and sludge in varying quantities are collected and have to be handled. These are treated in the sludge and reject system. A reduction in the quantity of residues to be disposed of can be achieved if similar types of rejects from various process steps in the stock preparation and the approach flow system are collected and treated together. Fibre recovery also contributes to minimising the quantity of residues.

5.1.1 Examples of Recovered Paper Processing Systems

Various product characteristics require different cleanliness and brightness properties from the RCF pulps and the process concepts vary accordingly. For example, de-inking is not required in many board grades. On the contrary, a very efficient multistage process is required for high speed paper machines, thin paper or for grades where brightness is important. The degree of sophistication of the whole process depends on the furnish used and the paper grade to be manufactured. Therefore it is not reasonable to describe "one typical" recovered paper processing system.

In the following the main recovered paper processing systems that can be distinguished are discussed more in detail by way of example:

- RCF stock preparation for packaging paper and paperboards (testliner and corrugated medium)
- RCF stock preparation for newsprint and simple printing and writing papers
- RCF stock preparation for LWC/SC papers and high-grade printing and writing paper
- RCF stock preparation for tissue and market deinked pulp (DIP).

The recovered paper processing systems may differ from each other by using different types of furnish and they have different impacts on the environment with respect to energy and fresh water demand, effluents and residues.

5.1.1.1 Packaging Paper and Boards

For the production of packaging papers or board from recovered paper i.e. testliner and corrugated medium only mechanical cleaning is applied i.e. no deinking process is needed. For these paper grades supermarket and mixed recovered paper grades are commonly used. The

following diagram shows a system for the preparation of secondary fibre testliner. For the preparation of testliner stock there are more complex two loop systems (Figure 5.2) and lower cost single loop systems in operation. The two loop system allows easier control of the process resulting in improved paper machine efficiency and operates with a screening stage at the approach flow purely as a safeguard measure (police function). During pulping coarse rejects are separated and the flake (flock) size is pre-calibrated. The following multi-stage cleaning and screening system removes heavy particles (e.g. sand), flat disturbing components, stickies, fine sand and leads to deflaking of the stock with good optical homogeneity. For testliner and fluting systems some mills are operating with totally closed water loops. Closed water loops operate satisfactorily from the point of view of manageable plant conditions and good product quality if around 3 to 4 m³ of process water per tonne finished stock are treated in an integrated biological clarification plant (see Section 5.3.4).

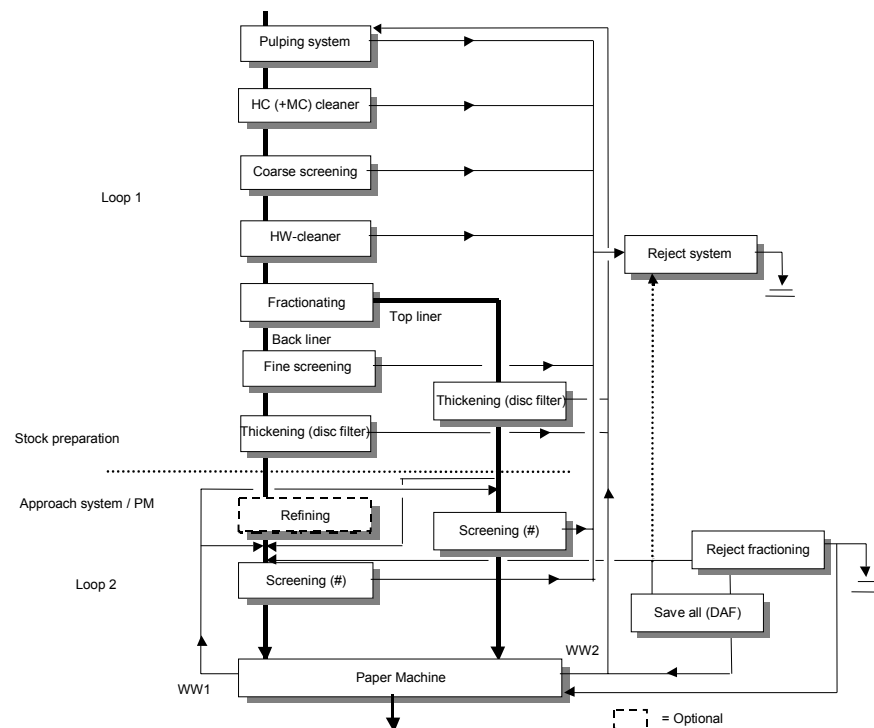


Figure 5.2: Example of an overall plant concept for testliner (2-loop system)

HC + LC = high & low consistency cleaners; HW = Heavy-Weight; DAF = Dissolved Air Flotation; # = Slot screens.

The processing of recovered paper tends to be similar for the different grades of packaging paper. High-grade folding box board tends to require a greater deal in terms of process equipment than testliner, testliner manufacturing usually requires a greater deal than fluting

5.1.1.2 Newsprint and Simple Writing and Printing Paper

The system shown in Figure 5.3 represents an example of a possible lay out for the production of stock for newsprint. The raw material used is a typical deinked pulp consisting of a 50:50 mixture of newspapers and magazines. The system is characterised by a two-stage flotation and bleaching combined with an intermediate dispersion. For upgraded newsprint qualities with higher demands on brightness, a reductive stage with hydrosulphite may follow thickening. For the production of graphic papers from recovered paper, water loop design and water clarification is especially important.

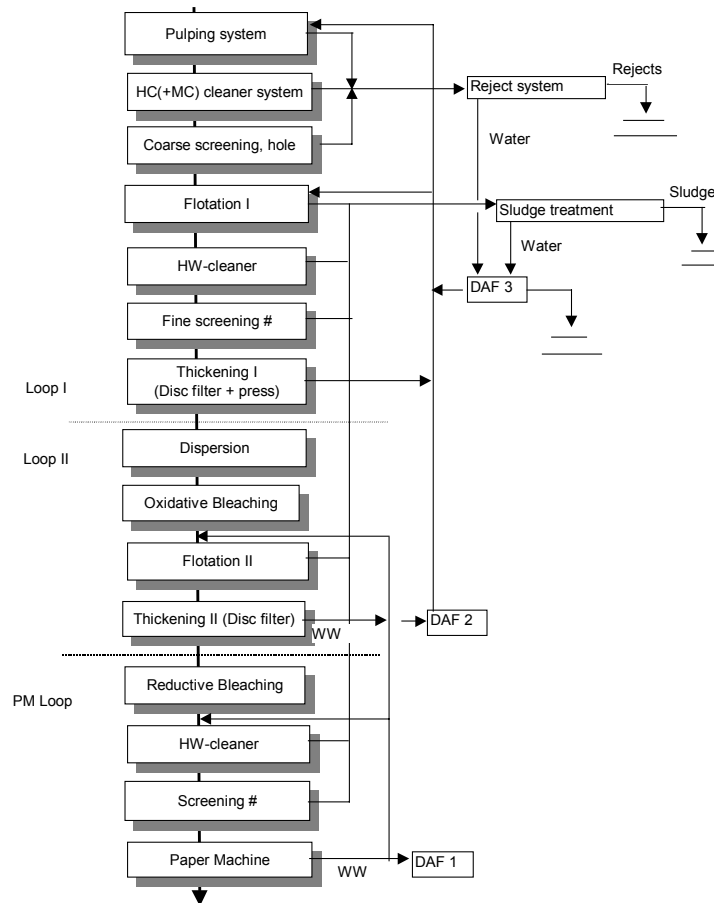


Figure 5.3: Example for an overall plant concept for (improved) newsprint

There are also other approaches to newsprint line process configurations

LC = Low Consistency; MC = Middle Consistency; HC = High Consistency; HW = Heavy-Weight; DAF = Dissolved Air Flotation; Oxidative bleaching (peroxide): for brightening the fibre stock and reduction of fibre mottling effect; Reductive bleaching (Hydrosulfite, FAS): for colour stripping

A systematic separation of the individual water loops based on the counter current principle is essential. Deinking lines can consist of various configurations and there can be two, three or in some cases four loops. Above, a two-loop system in the stock preparation system with a separate paper machine loop is shown. Internal clarification of the water circuits which are separated by thickening stages is carried out by dissolved air flotation (DAF) in order to control the loads of colloidal and anionic substances in process water and to maintain the fines and ashes at a controllable level in the process water loops. Sludge from the production line and from the flotation units is fed to sludge treatment. The coarse rejects separated in the production line are thickened in the reject system. Upgraded newsprint is usually manufactured in two-loop systems achieving about 63% ISO brightness (since reductive bleaching), low dirt counts (since flotation II), ash contents in the range of 10 - 12% (since flotation II) and a low amount of stickies (since additional slot screening). Compared to it, standard newsprint can be produced in one-loop systems i.e. without a secondary flotation stage. As a consequence, the brightness is lower (ca. 59 % ISO since no reductive bleaching), the amount of specks higher (since no sec. flotation) and the ash content is higher as well (in the range of 14 - 15% since no sec. flotation).

Recovered fibres are also used for lower grades of printing and writing paper manufacturing. These recycled grades are normally wood-containing and intended for office use as copy paper or stationary products. As a process system a similar flotation-based system as for upgraded newsprint as shown in Figure 5.3 can be utilised. As raw material a fairly constant proportion (50:50) of newsprint and magazines is used.

5.1.1.3 LWC/SC-Paper

When processing household recovered paper into DIP stock for higher grade wood-containing graphic papers such as SC and LWC grades exact requirements have to be achieved. This includes the need of a low level of disturbing components, high surface quality (i.e. free of shives and fibre bundles to ensure a smooth surface) and demanding optical requirements (e.g. brightness, cleanliness) of the finished product.

The furnish normally consists of recovered newsprint and magazines. SC papers are bulk printing papers produced on high speed machines. One of the main criteria for processing household recovered paper (deinking furnish) into bulk printing papers is constant quality. Therefore, the screening, cleaning and dispersing stages are very important. Because of the high optical requirements concerning brightness and cleanliness a two-stage flotation and bleaching is necessary.

An overall plant concept could look similar to the one presented for improved newsprint as shown in Figure 5.3. In this stock preparation concept the problem of disturbing components (colloidal contaminants, anionic trash) which may disturb the sensitive retention mechanism on the paper machine is solved by an appropriate water circuit/water clarification design in stock preparation. The system has clearly distinctive water loops, the first of which is normally alkaline and extends from the pulper to the thickening stage prior to dispersing. The second loop ends at the thickening stage prior to secondary bleaching. Thickening stages with strict water loop separation ensures the reduction of contaminants in process water. The separated loop concept is based on the principle that disturbing contaminants can not travel throughout the whole process water system. The anionic trash and colloidal contaminants containing filtrates from thickening are clarified by micro-flotation based on the flocculation and precipitation principle.

The necessary surface characteristics can be achieved by an additional refining stage for reduction of the large, long TMP fibres occurring in household recovered paper. Refining improves smoothness and printability of the paper. The refiner can be placed after the reductive bleaching stage in a similar concept as shown in Figure 5.3.

If the ash content of the finished stock is permitted to exceed 8 - 10 % there is no need for a washer. The use of a washer leads to relatively high losses. Therefore, for economical reasons it is favourable if a washer could be avoided.

5.1.1.4 Tissue Paper and Market Pulp

When using recovered paper for the production of high quality tissue or market DIP, it must be processed in such a way that not only coarse contaminants, but also printing inks, stickies, fines and fillers have to be removed. This considerable reduction in ash and fines means about 30% - 100% more recovered paper is needed compared with the finished stock which means a relatively high amount of waste has to be handled and treated. There are examples (e.g. Niederbipp mill, Switzerland) where all rejects, including sludge, are incinerated on site, generating steam for mill consumer points, resulting in a reduction of residues to ash which is used as an aggregate in the building industry (cement). The major difference of these grades compared to newsprint mentioned above (5.1.1.2) is the requirement of deashing (removal of the fines and fillers) due to the requirements on PM runnability and softness and absorbency of the end product. As an example, depending on the grades of recovered paper used as raw material the ash content may vary between 15% and 38% (in case of coated woodfree papers). The direct impact of the ash content on the amount of solid waste generated during recovered paper processing should be considered when comparing figures on the amount of solid waste.

For most products as e.g. kitchen rolls or toilet paper the same raw material as for newsprint could be used i.e. a mixture of newsprint and magazines or in more general terms medium and high qualities of recovered paper. But if available for a reasonable price, predominantly wood-free furnish (office recovered paper) may be used.

Figure 5.4 shows a simplified diagram of the recovered paper preparation plant. Main features of the system are the following: a high consistency pulper with dumping system where coarse contaminants are held back by a perforated screen plate and immediately removed. The rejects are then post-treated in a perforated drum screen and finally thickened in a reject screw press. Accepts are treated in high consistency cleaners followed by low consistency cleaner as a second stage removing mainly metallic trash such as paper clips, staples, etc. The stock is further processed in multistage screening and cleaning system. As in all stock preparation plants for processing recovered paper the basic principle in pulping, cleaning and screening is to ensure early discharge of rejects and contaminants.

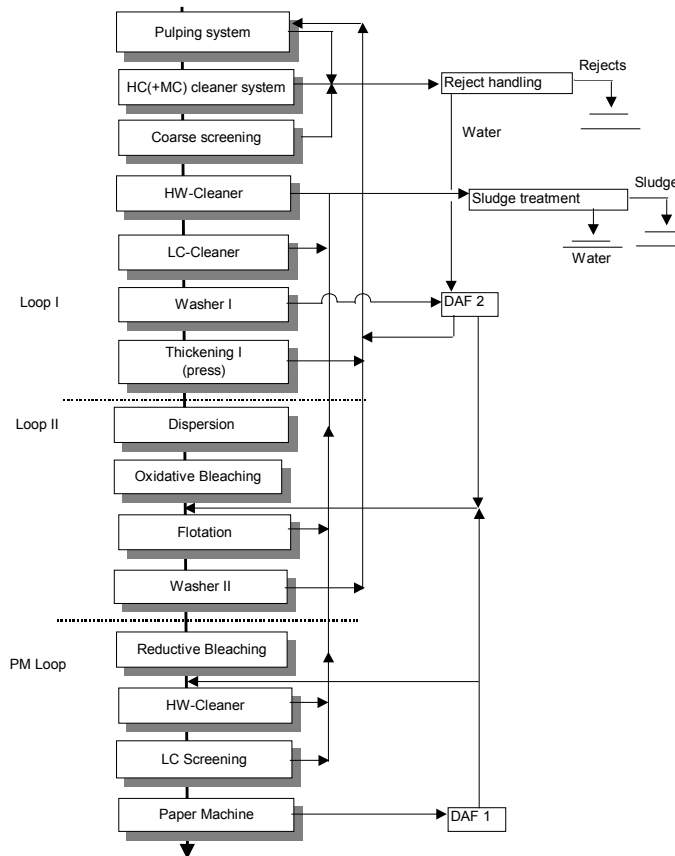


Figure 5.4: Example for an overall plant concept for a recovered paper preparation plant for tissue paper

HC = High Consistency; MC = Middle Consistency; LC = Low Consistency; HW = Heavy-Weight; DAF 1 + 2 = Dissolved Air Flotation 1 + 2

Washing is carried out in low pulp consistency and it involves efficient use and recirculation of washing water. The circulating water has to be cleaned and the washing water ink and other solids have to be removed by dissolved air flotation or other efficient water cleaning technology. Washing 1 serves for removal of ash, fines and fine ink particles and is followed by a wire press for thickening the stock to about 30 %. The washing filtrate is cleaned in flotation unit with the addition of cationic flocculants. Ash and fines are removed and the water is returned to the system. The stock is heated by means of a heating screw and treated in a disperger that separates any ink still adhering to the fibres and simultaneously mixes in the bleaching additives. The flotation stage removes the ink particles separated by dispersing as well as dirt specks and stickies. Secondary bleaching may follow washing 2 and the stock is then sent either to the storage tower or a final screening and cleaning in the approach flow of the paper machine. The handling of rejects and sludge is a crucial point for RCF tissue mills

because of the relatively high amount of sludge from different sources (recovered paper preparation, DAF, tissue machine, biological wastewater treatment plant) with an organic carbon content of around 50.

Additional information on tissue manufactured from virgin fibres can be found in Chapter 6.

5.2 Present Consumption/Emission Levels of RCF Based Paper Mills

5.2.1 Overview of input/output

An overview of raw material and energy input and the output of products, residues for further utilisation and major releases (emissions, waste etc.) of RCF based paper mills is presented in Figure 5.5.

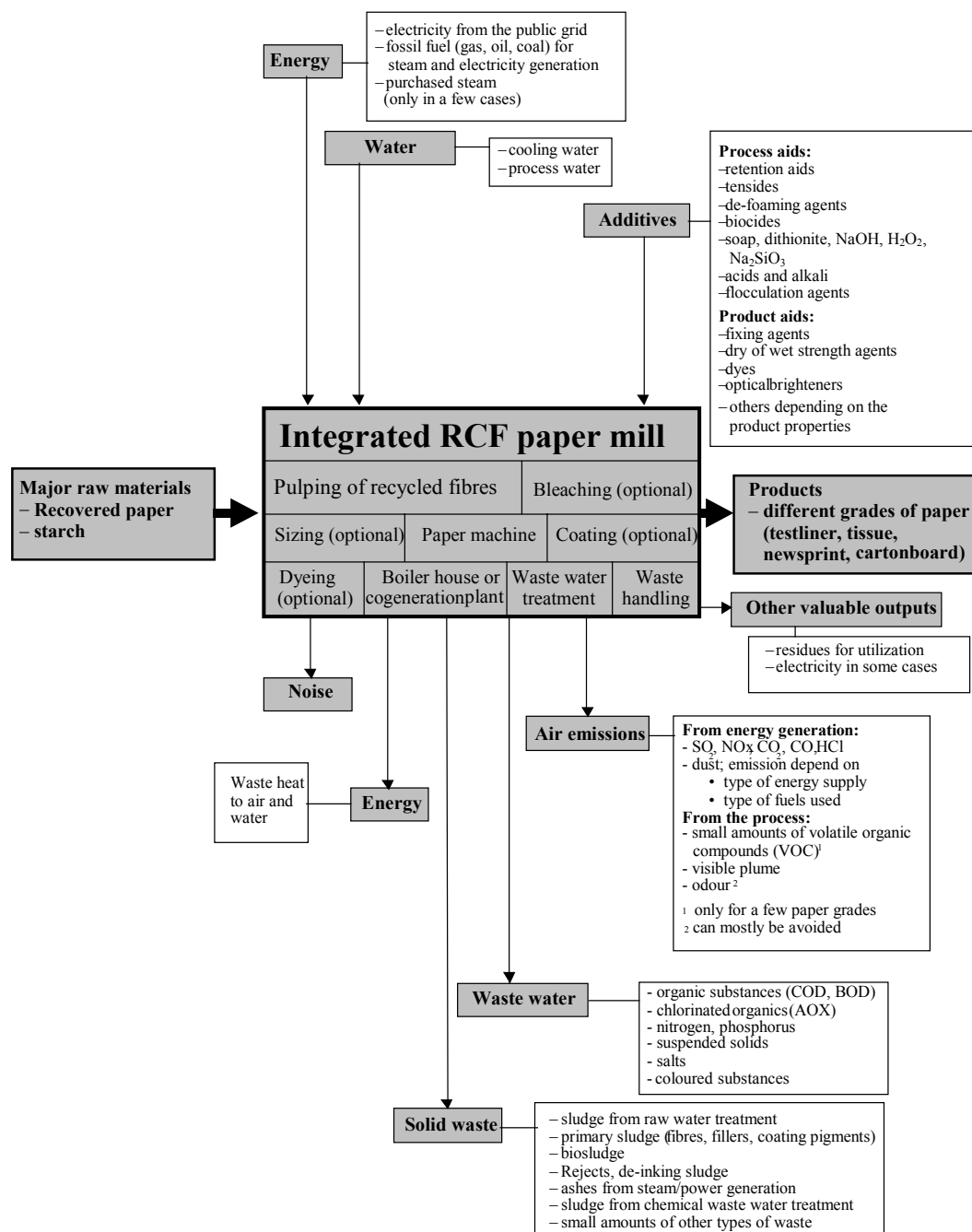


Figure 5.5: Mass stream overview of an integrated recovered paper processing mill

The presence of some of the substances depend mainly on the paper grade and paper properties to be achieved and the type of energy supply

As shown in figure the raw materials for RCF based paper production consists mainly of recovered paper, water as well as some chemical additives. Large quantities of water are used as process water and cooling water. As processing aids and to improve the product properties (paper auxiliaries) various additives are applied during paper manufacturing. The environmental impact of recovered paper processing comprises basically emissions to water, solid waste generation and atmospheric emissions mainly related to energy generation by combustion of fossil fuels in power plants. When abatement techniques are applied to reduce emissions, cross-media effects can occur. In this chapter the quantitative consumption and emission levels for the different main types of RCF processing mills are given. First of all, figures for overall input-/output levels for stock preparation and whole paper mills (considered as a black box) are presented followed by consumption and emission data for the main processes with environmental concern (Section 5.2.2).

Paper manufacturing in RCF based paper mills can be subdivided into three parts: stock preparation - approach flow/paper machine - and upgrading of manufactured paper. Stock preparation and paper machine are connected closely with each other over the process water system (see 5.2.2.2). Table 5.1 gives an overview on the major raw materials used and emissions during stock preparation of recovered papers for main paper grades being produced in Europe. The figures compiled in the table comprise exclusively the stock preparation i.e. the subsequent paper machine is not included. An exception had to be made for the water flows because water flows between stock preparation and paper machine are normally linked.

Consumption of raw material and emissions to water, waste	Packaging Paper	Newsprint	LWC/SC Paper	Tissue Paper and Market Pulp
Recovered paper quality (depends on availability and price of recovered paper and quality of the end product)	Sorted mixed paper and boards, recovered paper from stores	Deinkable recovered paper (50:50 newsprint and magazines)	Deinkable recovered paper (50:50 newsprint and magazines);	Deinkable recovered paper (50:50 newsprint and magazines); wood-free office recovered paper
Energy consumption ¹⁾ - Electricity - Thermal energy (e.g. steam)	150-250 kWh/t 0 MJ/t	300-420 kWh/t 450-900 MJ/t (=0.2-0.4 t _{steam} /t)	400-500 kWh/t 650-1100 MJ/t (=0.3-0.5 t _{steam} /t)	400-500 kWh/t 650-1100 MJ/t (=0.3-0.5 t _{steam} /t)
Chemicals ²⁾ - Repulping - Flotation I - Flotation II - Bleaching - Flocculants used for internal clarification of process water and sludge treatment ⁴⁾	Biocide ----- ----- ----- 0 kg/t (internal clarification in the paper machine loop (WW II))	0.5-1.0% H ₂ O ₂ 0.5-1.0% NaOH 1-2% Na ₂ SiO ₃ 0.3-0.6% soap 0.2-0.4% soap (NaOH+fatty acids) 1-2% H ₂ O ₂ 0.5-1.2% NaOH 1 - 1.8% Na ₂ SiO ₃ 0.4 - 1% Dithionit up to 0.2% NaOH Flocculation auxiliary agents: 0.5-1 kg/t	0.5-1.0% H ₂ O ₂ 0.5-1.2% NaOH 1-2% Na ₂ SiO ₃ 0.3-0.6% soap 0.2-0.4% soap (NaOH+fatty acids) 1-2.5 % H ₂ O ₂ 0.5-1.5 % NaOH 1-2 % Na ₂ SiO ₃ 0.4 - 1% Dithionit up to 0.2 % NaOH Flocc. auxil. agents: 1.6-2.6 kg/t Flocculants.: 1.5 - 2.5kg/t	0.0-1.0% H ₂ O ₂ 0.3-0.6% soap ----- 1-2 % H ₂ O ₂ 0.5-1.2 % NaOH 1-1.8 % Na ₂ SiO ₃ 0.4 - 1% Dithionit up to 0.2 % NaOH Flocc. auxil. Agents: 1.8-2.8 kg/t
Water - Water flow ⁵⁾ - Emissions before biological wwtp	0 - 4 m ³ /t paper TSS ³⁾ : usually below 200 mg/l COD: 27-36 kg/t (6750-9000 mg/l) AOX: < 4 g/t (= 1 mg/l)	8 - 16 m ³ /t paper TSS ³⁾ : usually below 200 mg/l COD: 17-27 kg/t (1700-2700 mg/l) AOX: < 10 g/t (= 1 mg/l)	8 - 16 m ³ /t paper TSS ³⁾ : usually below 200 mg/l COD: 17-27 kg/t (1700-2700 mg/l) AOX: < 10 g/t (= 1 mg/l)	8 - 16 m ³ /t paper TSS ³⁾ : usually below 200 mg/l COD: 26-35 kg/t (2600-3500 mg/l) AOX: < 10 g/t (= 1 mg/l)
Waste - solid wastes (dry basis) ⁶⁾ - organic content	50-100 kg/t paper 70-80%	20% losses 170-190 kg/t paper 35-45%	35% losses 450-550 kg/t paper 45-55%	500-600 kg/t paper 40-50%
Explanatory notes: ¹⁾ An essential factor for variations in energy consumption is the use of an disperger which consumes 60 - 100 kWh/t. Furthermore, the losses have to be considered: Processes with higher losses require machines with higher capacities and higher specific energy. The number of process stages in stock preparation/machines has also an influence. ²⁾ All chemicals consumption is expressed as 100% effective chemicals and not as commercial solutions containing various amounts of water except for Na ₂ SiO ₃ which is expressed as commercial solution. The ranges can be explained by differences in the quality of used recovered paper, inks to be removed and product quality to be achieved. ³⁾ Usually there is a micro-flotation unit installed before discharging the effluents to the wastewater treatment. This results in a relief of the primary treatment or makes it possible to do without primary treatment. Without micro-flotation unit the TSS content depends on the facilities for de-watering of sludge and rejects. ⁴⁾ The use of flocculants depends mainly on the number of micro-flotation units for process water clarification and on the amount of sludge to be de-watered. Water flows from washers are high and needs a relatively high amount of flocculants if to be treated ⁵⁾ The data for water flow refer to the water used in the whole mill i.e. stock preparation + paper machine. The water flow means outgoing water from biological treatment and exclude sealing water ⁶⁾ Including sludge from process water treatment (micro-flotation units)				

Table 5.1: Consumption and emission levels for stock preparation of different paper grades produced

The data refer only to the stock preparation itself i.e. the subsequent paper machine is not covered by the data [data from operational experiences provided by a supplier]. An exception is made for water flow because concerning water consumption it is hard to separate stock preparation from the paper machine For further data that represent current practice of whole plants it is referred to Table 5.2 – 5.4

The overall consumption and emission levels of whole paper mills for the main paper types produced from recovered fibres are shown in Table 5.2 (testliner and wellenstoff), Table 5.3 (newsprint) and Table 5.4 (tissue) below.

One has to bear in mind that the actual values computed as an average value of measurements over a yearly period are different from the one that may be found in permits. Depending on the countries permitting systems, the latter refers usually to shorter periods of 2 hours, one day or one month to ensure practicable monitoring of compliance. This specific time period during which the monitoring values have to be met is set in the permit and varies within European countries (see ANNEX II, on existing national and international regulations). But, the actual measured data given in the Table 5.2 to Table 5.4 can give a good first guidance what environmental impact is related to a given installation.

In Table 5.2 weighted average data for testliner and wellenstoff are presented. The data are derived from the European Database for corrugated board which were compiled for life cycle studies (issue 1997), issued by FEFCO, Groupement Ondulé and Kraft Institute. The ranges of the parameters represented are based on corresponding paper mills in Denmark, France, Germany, Italy, the Netherlands, Spain and the UK. The data for the production of Testliner and Wellenstoff was collected from mills, which produce 52 % (5.2 M tonnes) of the total annual production of corrugated base papers from recovered paper in Europe. The data is given per tonne net saleable paper (nsp). It has to be emphasised that the weighted average figures documented do not represent figures of a specific mill with a given technology.

Weighted average in the framework of the FEFCO-study represents a so-called “Best Average Environmental Practice (BAEP)”. That means, when a certain technology is used by the majority of the participating mills, and this technology is expected to be used in more mills within the near future, the weighted average of the data of the mills using this technology has been calculated instead of the weighted average of all the mills. The environmental performance of these mills is then called BAEP.

Input			Output		
Raw materials	Value	Unit	Product	Value	Unit
Recovered paper (delivered weight, including moisture)	1100	kg/t	Wellenstoff testliner	+ 1000	kg
Biocides, dry weight	0 - 0.12	kg/t	Emissions		
Colorants, dry weight	0.2 - 1.0 *	kg/t	CO _{2, fossil}	320** - 600	kg/t
Defoamers, dry weight	0.10 - 0.40	kg/t	CO _{2, regenerative}	0 - 15	kg/t
Retention agents, dry weight	0.3 - 2.4	kg/t	CO	n.a.	kg/t
Sizing agents, dry weight	0.1 - 3.0*	kg/t	NO _x	0.4 - 1.1	kg/t
Starch, dry weight	20.0 - 50.0	kg/t	SO ₂	n.a.	kg/t
Energy			Dust	n.a.	kg/t
Total fossil fuel	5700** - 9600	MJ/t			
Purchased electricity	2.8 ¹⁾ - 403	kWh/t	COD	0 - 2.2	kg/t
Primary energy, total ****	2140 - 3220	kWh/t	BOD ₅	0 - 0.2	kg/t
			Suspended solids	0 - 0.5	kg/t
			AOX	n.a.	kg/t
			N _{total}	n.a.	kg/t
			P _{total}	n.a.	kg/t
			Evaporated water	1 - 2****	m ³ /t
			Wastewater flow	0 - 11	m ³ /t
Water demand			Residues		
Raw-/fresh water	1 - 13	m ³ /t	Waste to landfill	30 - 70 (at 100% DS)	kg/t

Explanatory notes: n.a. = not available; b.d. = bone dry
¹⁾ The low value for purchased electricity refers to paper mills with large CHP plants.
* Given range only valid for testliner production
** Figures are only valid in the case of steam generation (which means no cogeneration)
*** Arithmetic difference between input and output of water
**** The contribution of purchased electricity to the specific primary energy consumption is calculated assuming an energy yield of the electricity generating companies of 36.75%, i.e. purchased electricity of 0.47 MWh/t corresponds to 1.28 MWh/t primary energy (1 kWh = 3.6 MJ). The lower end of the range for purchased electricity does not seem realistic. Therefore it an average electricity consumption of 200 kWh/t is assumed (or 555 kWh/t primary energy)

Table 5.2: Environmental data as yearly average values for testliner and wellenstoff
Figures refer to the situation in 1996 [FEFCO, 1997]. All data are given per tonne of net saleable product (nsp). The figures represent weighted average data (“best average environmental practice”, see p. 232). Air emissions are referring to the generation of steam only

The recovered paper grades used for the production of Testliner and Wellenstoff comprise 93 % and 94 % respectively of grades according to category A of the European list of recovered paper grades, including mixed recovered paper grades, supermarket waste as well as new and used corrugated case material.

In total about 50 kg residues are generated by the papermaking process per tonne nsp. Related to the recovered paper input of 1.1 tonne/tonne net saleable paper, 45 kg residues per tonne of processed recovered paper (= 4.5 %) are treated by the mills. In the figures for the residues are included the ashes, the organic and inorganic sludges and all the rejects going to landfills as well as the incinerated organic sludges and residues. On average between 91 % (Testliner) and 95 % (Wellenstoff) of the residues are dumped on landfills. The weighted average amount of

incinerated residues seems to be small (3 % in Wellenstoff and 7 % in Testliner production). Mills equipped with boilers for the incineration of residue burn almost all their rejects with exception of pulper and high-density cleaner rejects. Between 0.9 and 3.6 kg of organic sludges/tonne net seable product (nsp) are reused in the production process of Testliner and Wellenstoff.

The fossil fuel used is to 87 % natural gas in the production of Wellenstoff and 94 % for Testliner production. All mills produce steam for the drying of the paper in the paper machine, but not all mills produce electricity by themselves. In some cases electricity is purchased as grid power. The air-borne emissions mainly depend on the type of fuel used. In combination with a well adapted flue gas purification the most significant ecological impact results from the fossil CO₂ emissions (for further information refers to 5.2.2.7).

Water consumption for the production of Wellenstoff and Testliner ranges between 2 and 13 m³/tonne nsp. When papers are produced with a closed water system, the lowest water consumption corresponds to the amount of water evaporated during paper drying. The weighted average figures of the water consumption are almost identical for both paper grades at about 6.5 m³/tonne nsp. The average specific effluent ranges between 4.9 and 5.7 m³/tonne nsp. Some mills also operate with a totally closed water system and zero effluent.

The water-borne emissions are reported as the substances leaving the mills with the effluent after a final wastewater treatment. The levels of suspended solids, COD and BOD are low for the weighted average and approach zero for mills with a closed water system. The nitrogen and phosphorus content of the wastewater of RCF paper mills is very low. A controlled addition of nutrients to the biological wastewater treatment is necessary to provide nutrients for maintenance and growth of the micro-organisms. Assuming a controlled dosage to ensure optimal performance of the wastewater treatment system N_{tot} concentrations below 10 mg/l and P_{tot} concentrations below 2 mg/l are achievable (as daily average).

The values for RCF based newsprint and tissue mills presented in Table 5.3 and Table 5.4 may not reflect the whole range of variations in the use of raw materials and emissions that can be observed in paper mills in Europe. On the contrary, because of a scarcity of available data groups of mills standing for a typical (but not representative) situation have been compiled. Table 5.3 shows weighted average data for RCF based newsprint. The data are derived from 4 German paper mills manufacturing mainly newsprint from recovered papers (standard and high-grade newsprint, reference year: 1996). The four mills stand for 72% of the total production of newsprint in Germany i.e. 1.24 Mt/a newsprint and 73000 t/a DIP. A small amount of GWP, TMP and chemical pulp is included in these figures. 2 mills of the four uses only recovered paper as fibrous raw material. The values presented are considered typical for RCF based newsprint mills. The data is given per tonne of paper produced. The water-borne emissions are reported as the substances leaving the mills with the effluent after biological wastewater treatment.

Input			Output		
Raw materials	Value(min-max)	Unit	Product	Value	Unit
Recovered paper (9% moisture)	1120 (990-1270)	kg/t	Newsprint	1000	kg/t
Wood chips (55% moisture)	130 (0-330)	kg/t	market DIP (small amount)	5.9	kg/t
Roundwood	50 (0-230)	kg/t	Emissions (min-max)		
Kraft pulp	10 (0-30)	kg/t	CO ₂		kg/t
Pigments	30 (0-100)	kg/t	CO _{2, regenerative}		kg/t
Additives ¹⁾	53.17 (40.61-60.99)	kg/t	NOx	0.72 (0.56 - 1.06)	kg/t
			CO	0.14 (0.02 - 0.56)	kg/t
Energy (min-max)			SO ₂	0.54 (0.01-2.68) ⁵⁾	kg/t
Natural gas	1720 (0 - 3490 ²⁾)	kWh/t	Dust	0.010 (0.003-0.05)	kg/t
Fuel oil, light	40 (0 - 180)	kWh/t	COD	3.31 (2.47 - 4.45)	kg/t
Fuel oil, heavy	300 (0 - 1510)	kWh/t	BOD ₅	0.12 (0.03 - 0.28)	kg/t
Regenerative fuels	510 (0 - 970)	kWh/t	Suspended solids	no data	kg/t
Hydro power	50 (0 - 110)	kWh/t	AOX	2 (1 - 3)	g/t
Purchased electricity	470 (-10 ²⁾ - 710)	kWh/t	NH ₄ -N	20 (10 - 50)	g/t
Primary energy, total ³⁾	3880 (3630 - 3990)	kWh/t	Phosphate	5 (2 - 10)	g/t
			Wastewater flow	10.56 (7.7 - 14.97)	m ³ /t
Water demand (min-max)			Residues (min-max)		
Surface water	19.34 ⁴⁾	m ³ /t	Bark	5.6 (0 - 28.6)	kg/t
Ground water	0.61	m ³ /t	Rejects, paper residues	100.2 (0 ⁶⁾ -381.4)	kg/t
			Ash, from waste incineration ⁶⁾	90.8 (0 - 173.2)	kg/t
			Waste, total ⁶⁾	196.7 (91.8-410.7)	kg/t

1) Additives are process & product aids expressed as commercial solutions containing various amount of water
2) The maximum value of natural gas consumption refers to a mill with gas-turbine. A surplus of electricity is produced so that a small amount of power is delivered to the public grid (10 kWh/t).
3) The contribution of purchased electricity to the specific primary energy consumption is calculated assuming an energy yield of the electricity generating companies of 36.75%, i.e. purchased electricity of 0.47 MWh/t corresponds to 1.28 MWh/t primary energy (1 kWh = 3.6 MJ).
4) The water demand includes process and cooling water. Cooling water is partly used as process water
5) The maximum value is measured when fossil oil is used as main source of energy, the lower value when natural gas is used. All air emission data are derived from continuous monitoring data, yearly average
6) Minimum value (no rejects) are found when rejects and sludge is burned on-site. The amount of ash generated as a product of incineration is zero when no incinerator is operating and high when higher amounts of additional fuels are burned. If on-site incineration is applied the remaining waste is mainly ash (min.). Otherwise the untreated waste stands for the maximum value.

Table 5.3: Yearly average consumption and emission levels from RCF based paper mills manufacturing mainly newsprint (standard and high-grade newsprint)

Tissue mills are characterised by manufacturing a big variety of products. Many tissue machines make frequent grade changes for different products reducing somewhat efficiency of water, energy and raw material use. Converting into finished product is often integrated with tissue production. Tissue mills need relatively high fresh water use on showers because the cleanliness of wires and felts is critical to the very light-weight sheet formation (down to 12 g/m²). Concerning fibrous raw material used there are both tissue mills based on 100 % virgin fibres and those using 100 % recovered fibres (for information on tissue mills made from virgin fibres it is referred to Chapter 6 of this document). In between there are all types of mixtures of fibres using 10 %, 20 % and so on up to 90 % recovered fibres. The influence of raw materials on the whole environmental performance of a mill significant mainly related to the high sludge volumes generated during wash de-inking (removal of all fillers from recovered paper). The

differences in emissions to water are not significant assuming proper effluent biological wastewater treatment. The environmental performance of the whole mill is influenced by other factors as chemicals used, type of fuel used and energy generation and process lay out.

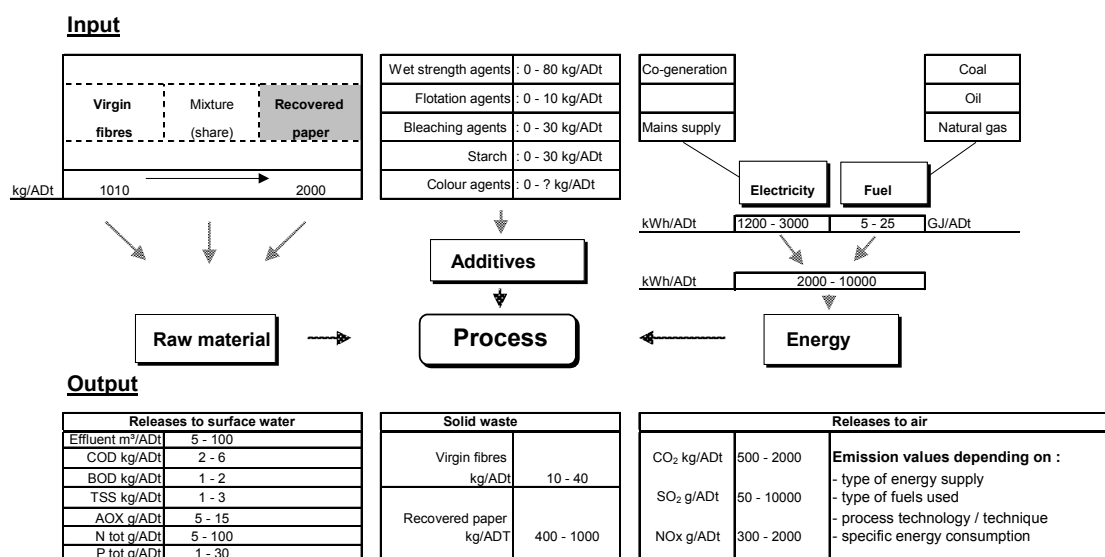


Table 5.4: Typical yearly average consumption and emission levels for the manufacturing of tissue [Data from ETS, 1998, because of a lack of data, releases to water could not be distinguished to wastewater from RCF based tissue mills and those using virgin fibres]

Although in Europe nearly all RCF based mills are integrated - except two mills producing deinked market pulp - it has to be noticed that integrated RCF based mills are often only partly integrated i.e. part of the fibrous materials may be purchased pulp. Often paper mills manufacture paper products consisting of a mixture of different fibre types.

The raw material consumption and releases to environment of recovered paper processing are discussed one by one in the next paragraph.

5.2.2 Consumption and emission levels arising from process units

The following aspects associated with paper manufacturing based on recovered fibre processing are of concern:

- Recovered paper consumption
- Water use
- Use of additives
- Energy demand
- Wastewater emissions
- Solid waste generation from stock preparation, process water clarification and wastewater treatment
- Air emission from energy generation
- Air emissions from sludge and residue incineration (optional)
- Noise from paper machines (local)
- Odour from vapours and from wastewater treatment plant (local)

As for the reported emission and consumption figures, it should be borne in mind that, due to the use of some different measurement methods in the various Member States, data are not

always strictly comparable from country to country. (See Annex III for more information on this issue but the different methods used do not alter the conclusions drawn in this document).

5.2.2.1 Recovered paper consumption

For the manufacturing of different types of papers as "brown" packaging papers" or "white" graphic papers different amounts and qualities of secondary fibres are used. For the production of one tonne of paper between 1100 kg (for corrugated medium) and 2000 kg (for tissue and market DIP) recovered paper is used. Lower types of recovered paper are commonly used as raw materials for products with lower requirements, while better grades are used for products with higher requirements.

There are many different types of recovered paper traded in the European market which are generally classified according to origin, quality and usage. The classification varies from country to country. According to the list of European standard qualities of recovered paper recovered paper is roughly classified into four groups, corresponding to ordinary, medium, high and kraft qualities [EN 643, 1994] which are further sub-classified. Lower grade recovered paper contains more impurities and must be cleaned more intensively to fulfil the product requirements compared to higher grade recovered paper. Higher grades are mainly used for processing of graphic papers and tissue and there are two disadvantages in it: Higher grades are usually more expensive and they may not continuously be available in sufficient quantities. Since uniformity is important for pulp furnishes, the quantitative and qualitative variations of impurities and contaminants should be as small as possible. Thus, the collection methods and the segregation of the recovered paper at an early stage may be more important than the technical efforts to develop new processes for secondary fibre production. Besides the collection method the origin of the secondary fibres has an important influence on the quality of the furnish. Different types of recovered paper may be distinguished: "collected wastepaper" from houses and markets such as corrugated containers, newspapers and magazines, "industrial recovered paper" as cuttings, brokes and over-issued papers generated in printing, paper-container manufacture and book binding mills and "semi-industrial recovered paper" occurring in supermarkets, department stores and large offices.

It is expected that the percentage of impurities in recovered paper will increase because of the continuous increase of recycling of waste paper. This effect will be enhanced by intensified use of fillers in the paper production. Overall it is expected that the amount of impurities in recovered paper will increase, which in turn will lead to increasing cleaning and bleaching steps. It will also lead to increasing solid wastes at RCF paper mills.

5.2.2.2 Water use

Paper and board mills commonly use large quantities of water. On the other hand, in most paper mills a large amount of water is recycled and thus the specific water volume used for manufacturing of RCF paper has decreased during the last twenty years. In Europe, both groundwater and surface water is used. Depending on the paper grade the water must be pre-treated in order to fulfil the requirements set for process water. If necessary, iron, manganese and sometimes algae and turbidity has to be removed by means of flocculation, complexation and/or sand filtration. Water has various basic applications in the paper industry as process water, cooling water and boiler feed water (for further details see Section 6.1.3, water circuits and fibre recovery). As shown in Figure 5.6 process water is extensively recycled in the production process.

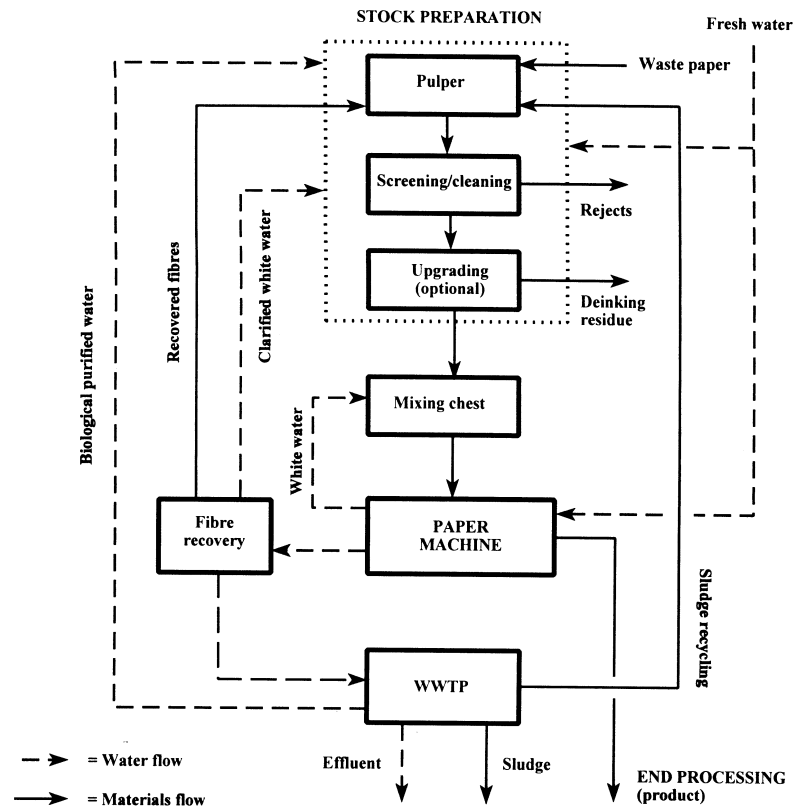


Figure 5.6: Basic flow chart of the recovered paper processing paper and board production [Dutch Note on BAT, 1996]; WWTP = Wastewater Treatment Plant

All paper and board mills recycle drainage water of the wire section (white water). White water is recycled untreated as diluent to the mixing chest (short circuit) or it is reused after clarification in the fibre recovery unit at specific locations in the process where higher water quality requirements are to be met. Excess flow from the fibre recovery unit the stock preparation is discharged to keep the water balance and to purge unwanted substances that should not enter the approach flow of the paper machine. The possible rate of recycling depends on the quality requirements of production and on the quality of the treated process/wastewater. Besides, the quality of process design of the water circuits strongly influences the limit of reuse without disadvantages for production and product quality. In Figure 5.7 and Figure 6.10 examples of possible stock-water systems for integrated RCF based mills for brown and white paper grades are given.

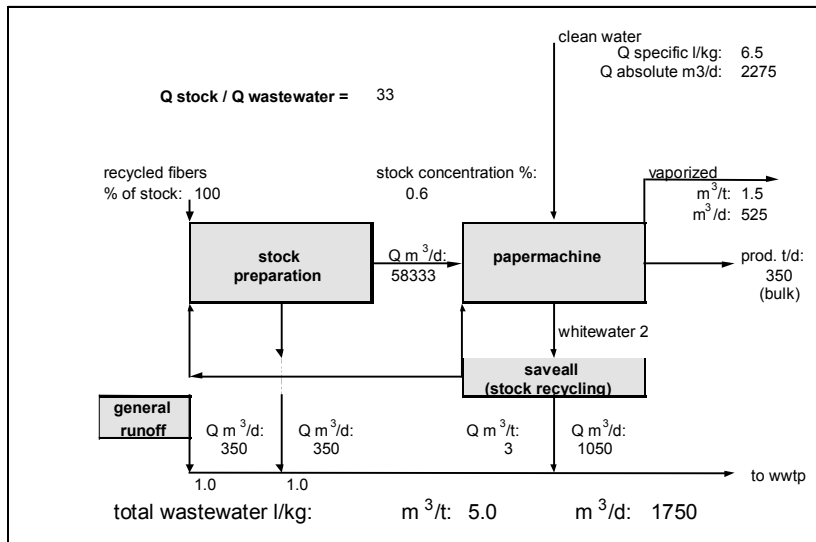


Figure 5.7: Example of water circuits for an integrated RCF mill for corrugated medium without de-inking (100% recovered paper)
 [Provided by Möbius]

The example for a rather closed circuit in the production of non-deinked paper from recovered fibres shows that fresh water is only used at the paper machine side (and for the preparation of additives). The white water is recycled back to the stock preparation and used for slushing of the recovered paper and different steps of mechanical cleaning of the pulp. A partial stream is discharged to the wastewater treatment plant (wwtp). About 1.5 m³/t of paper is vaporised in the dryer section of the paper machine. Statistically in the example of Figure 5.7 the water is used 33 times in the process.

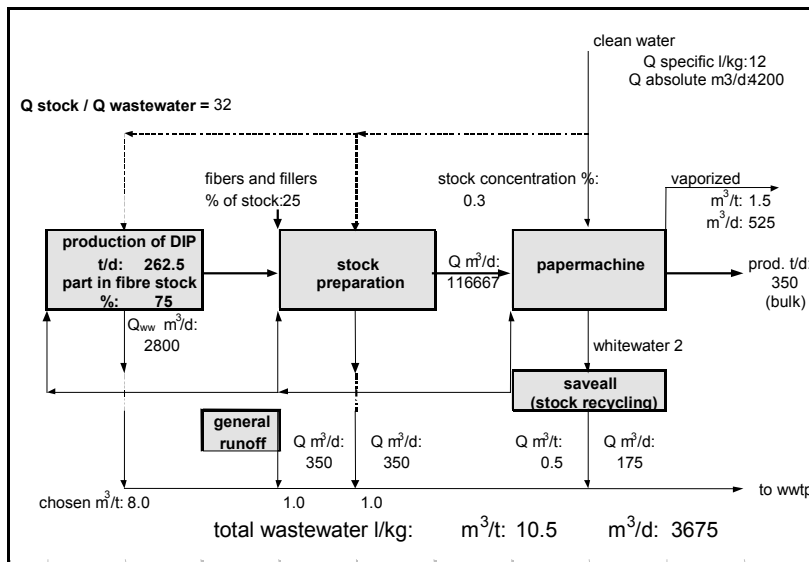


Figure 5.8: Example of an optimised stock-water-system for an integrated production of de-inked pulp
 [Moebius, 1994; original version corrected by the author]

In Figure 5.8 an example of a rather closed water circuit in integrated production of paper with a high content of de-inked pulp (DIP) is shown. Process water flows counter current to the materials flow i.e. white water is recycled to the de-inking plant and the stock preparation.

Excess flows from different part of the mill are discharged in order to protect the approach flow of the paper machine - where higher water quality is required - from disturbing substances and to balance the amount of water used in the system. At the paper machine clean water is used to ensure the high water quality requirements at this part of the paper manufacturing process. The ratio between the fibre suspension fed to the paper machine and the discharged wastewater is 32 : 1, i.e. water is used 32 times within the circuit. To avoid drawbacks of the water re-use the whole fibre-water-additive-system of the mill has to be analysed and optimised. In some mills (partial) removal of impurities inside the process to a desired level is applied in order to fulfil the process water quality requirements set for a specific paper grade or process unit. The partial removal of impurities is often referred to as a “kidney” treatment.

Table 5.5 summarises the specific water consumption of different recovered paper processing mills.

Process	Specific Water Consumption [m ³ /t]*
Uncoated folding boxboard	2 - 10
Coated folding boxboard	7 - 15
Corrugated medium & Packaging paper	1.5 - 10
Newsprint	10 - 20
Tissue	5 - 100
Writing and printing paper	7 -20
Notes: * It has to be noted that about 1.5 m ³ water per tonne of paper is vaporised in the dryer section of the paper machine i.e. do not appear as wastewater	

Table 5.5: Typical water consumption in RCF based paper and board production

5.2.2.3 Use of additives

To improve the product properties various additives are applied in the paper and board industry. The amount and types of additives vary with the paper grade and the installed equipment. The additives applied by the paper industry can be classified into product aids which are applied to optimise the specific properties of the paper according to the customers requirements and process aids. The latter facilitate the operation of paper processing in order to enhance the runnability of the process. Examples of the main additives and their application are given in Table 5.6. If the additives are used as directed they should not cause significant negative impacts on the efficiency of the wastewater treatment plant. Sudden changes in loads because of system cleaning or batch-wise additive adjustments to fulfill product requirements, might have a negative impact on the performance of the waste water treatment plant. Then, the biomass may need a certain period for adapting to the additives appearing in the effluents. During this limited time period the efficiency of the treatment plant may be reduced and the settling of the sludge may be possibly deteriorated (increase of the sludge volume index). Therefore, additives should be handled carefully, cautiously and as directed. This is how the remarks in the right column of Table 5.6 should be interpreted.

Product aids	Purpose	Examples	Remarks
Fillers	- Improve printability properties, opacity and brightness and smoothness and gloss - Replace (saving) fibres	Kaolin or clay, talc, lime, gypsum, titanium dioxide	
Sizing agents	- Improve surface quality - Make paper hydrophobic	Modified starch, modified natural resins, wax emulsions, synthetic products like alkyl ketene dimers and maleic acid anhydride copolymers	Some may be toxic to bacteria when they are cationic
Fixing agents	- Improve adsorption of additives to fibres	Alum [Al ₂ (SO ₄) ₃]	Mostly cationic products which may be toxic to bacteria
Dry strength agents	- Improve strength properties in dry conditions	Modified starch	Some may be toxic to bacteria when they are cationic
Wet strength agents	- Improve strength properties in wet conditions	Urea formaldehyde polymer, melamine-formaldehyde polymer, epichlorohydrincondensates	Usually toxic to bacteria, some increase the AOX
Dyes	- Give paper a certain colour and/or brightness	Azo compounds, quarternary ammonium compounds	Difficult to eliminate; some are toxic; may contain heavy metals
Optical brighteners	- Give paper a white impression	Chemicals based on 4,4-diamino stilbene-2,2-disulfonic acid	Some cationic substances may be toxic
Coating chemicals	- Give paper certain surface properties	Pigments, binders, wet strength agents, dispersion and lubrication agents, Defoaming agents, Slimicides	Binders must be destabilised before mixing with other ww, otherwise they may disturb the clarification
Process aids	Purpose	Examples	Remarks
Retention aids	- Retention of fibres, fines and fillers - Increase production by improving dewatering - Decrease emission of pollutants	Alum, sodium aluminate, polyaluminiumchloride, starch products, gums, anionic polyacrylamides, nonionic polyacrylamides, cationic polymers	Mostly cationic products
Deinking and bleaching chemicals	- Release ink from fibres - Bleaching - Keep ink particles in dispersion	NaOH, Fatty acids, H ₂ O ₂ , hydrosulphite, FAS, complexing agents, sodium silicate, tensides	Sludge settling in final clarifiers may be hindered
Complexing agents	- Removing metal ions by forming metallic complexes to prevent decomposition of bleaching chemicals	DTPA or EDTA	Hardly or not biologically degradable
Tensides	- Cleaning of felts, wires and machinery - Cleaning of water circuit system - Dispersions of substances	Acidic and alkalic surfactants	May cause floating sludge
Defoaming agents	- Prevention and destroying of foam	Fatty acids ethoxylates, poly-oxi-ethylene, fatty acid derivates, higher alcohols, phosphoric acid esters, vegetable oil products	May lower the oxygen input in wwtp
Biocides (Slimicides)	- Prevention growth of micro-organisms	Organic bromine, sulphur or nitrogen compounds, quarternary ammonium compounds	Some contain AOX, they are toxic when reaching the wwtp in higher concentrations

Table 5.6: Main process and product aids and their application in the paper industry

Basic chemicals for the papermaking industry as e.g. acids and bases are not covered. The remarks relate to the substance as such neglecting that they are usually highly diluted and to a certain extent retained in the paper (further details are compiled in ANNEX I)

[Dutch notes on BAT, 1996; modified by EIPPCB]

Substances used for de-inking are shown in Table 5.7. De-inking chemicals have little retention to cellulose and can be expected to be present in the de-inking sludge that is landfilled or incinerated.

Chemical	Use [kg/t of de-inked stock]
Sodium hydroxide	10 - 20
Sodium silicate	20 - 30
Soap	5 - 8
Talc	10 - 15
Hydrogen peroxide	5 - 25
Chelating agent (DTPA) ¹⁾	2 - 3
Sodium dithionite	6 - 10
Sulphuric acid	8 - 10

Table 5.7: Typical chemical doses in the de-inking process including bleaching [Finnish BAT Report, 1997]. ¹⁾ Usually there is no need for the use of chelating agents in recovered paper processing/bleaching unless there are excessive concentrations of Fe and Mn-ions⁶

Additives are often not completely used up during the process or not completely retained on the paper sheets especially as far as process aids are concerned. A certain amount is discharged via wastewater. Excess additives are also leaving the system via rejects and sludge (refer to 6.2.1.3). Some of these additives can have a negative influence on the practical functioning of the wastewater treatment plant and/or the quality of the receiving water in case that they are not degraded or eliminated in the wastewater treatment plant. In some Member States Water Quality Authorities require insight in the quantities and nature of the applied additives. In the Netherlands, for example, companies have to submit relevant information on the nature and composition of the additive. This information is then used in an assessment methodology [RIZA, 1998] which determines the impact of additives to the aquatic environment. Additives may only be applied if they have passed the assessment methodology with a positive score or are retained by a suitable technique..

5.2.2.4 Energy demand

Paper and board mills require substantial amounts of steam for heating of water, pulp, air and chemicals to the demanded process temperature and above all for drying the paper. Besides, large quantities of electricity are required for driving the machinery, pumping, vacuum, ventilation and wastewater treatment. In paper mills energy is usually the main factor in operating costs. Because the secondary fibres have already passed through stock-preparation equipment when the original paper was made, RCF pulping require comparatively less total energy for processing than is needed for chemical and especially for mechanical pulping. For example, in the Netherlands for recovered paper processing an average specific electricity consumption of 322 kWh/t (neglecting the difference in specific electricity consumption between RCF processing with and without deinking) have been reported. The total specific energy consumption⁷ amounts to 10.9 GJ/t for non-deinking mills and 12.1 GJ/t for paper mills with deinking [Dutch note on BAT, 1996].

⁶ C. Pauli, R.Patt, V.Gehr, O.Kordsachia, On the effects of additives in a peroxide supported alkali/oxygen bleaching stage of waste paper and mechanical pulp (in German), WfP, No. 20, 1993, p. 852-857.

⁷ For calculation of the total specific energy consumption it has to be considered 1 kWh=3.6 MJ. Purchased energy is generated by electricity companies with an energy yield of about 38.1%. Therefore, the contribution of purchased electricity to the specific energy consumption have to be calculated as follows: 1 kWh = 3.6/0.381 = 9.45 MJ.

In RCF mills steam is normally produced internally by each company. Electricity can, if necessary, be purchased from the public grid. Paper mills commonly have a balanced need for steam and electricity that makes it obvious to apply co-generated heat and power installations (CHP). CHP supplies these energy needs by simultaneous generation of power and useful heat (steam) and has a considerably higher total yield (80-95%) compared with "separate generation" i.e. generating heat and purchasing electricity (the latter with a yield of about 40%). The CHP of paper mills sometimes produce more electricity than actually needed on the basis of the heat demand. This excess electricity may be supplied to the public grid.

In Table 5.8 below some detailed figures on energy consumption required for the stock preparation of recovered paper used for tissue and newsprint are compiled. All data are related to modern equipment and stock preparation concepts designed for high quality systems. The values stand for real examples of recently build stock preparation concepts. Normally, the process concepts chosen vary from mill to mill to a certain extent. However, the major building blocks of the systems are required by each RCF processing mill. In so far they can give an indication on the range of energy demand that can be expected for these types of RCF paper mills.

When figures on energy consumption are compared the following aspects should be kept in mind:

- The yield of the process varies mainly according to the raw material
- The country and the area where waste is collected affects significantly the raw material quality
- Because of bad recovered paper quality some mills may have to take additional efforts in the stock preparation
- Usually, when energy consumption is discussed, only main equipments are included i.e. pumps and agitators are not part of the system considered. These „passive“ process components do not improve pulp quality but are nevertheless relevant in terms of electricity demand.
- The contribution of pumps and agitators to the total installed power may vary from 20 up to 30%. From the energy point of view process concepts that decrease the amount of pumps are therefore important. In the example for RCF newsprint in Table 5.8 the share of pumps to the total energy demand is 30 %.
- Peripheral sub-systems for water, sludge and rejects such as DAF, reject screw presses, or sludge presses are also not included because they are not considered as main equipment. Their energy demand has to be added to the figures.
- There is a difference between *installed* power (main equipment) and average power demand that is actually *used*. As a rule of thumb, the true consumed power is 70 - 75 % of the installed power. This ratio varies according to the process stage and equipment supplier.

	Tissue DIP-line (200 t/d)	Newsprint DIP-line (1000/d)
Raw material	Old magazines,/mixed office waste	Old newsprint/old magazines
Yield	55 - 60%	80%
Total specific power (estimated)	230 kWh/t of DIP pulp ¹⁾	300 kWh/t of DIP pulp ²⁾
Total specific low pressure steam	0.3 t steam/t of DIP pulp	0.3 t steam/t of DIP pulp
Specific energy demand for major unit processes		
Feed conveyor	1 kWh/t of DIP pulp	0.4 kWh/t
High Consistency Pulping ¹⁾	39 kWh/t of DIP pulp (CHD pulping incl coarse screening)	16 kWh/t (drum pulper)
Coarse Screening	Not required	18.5 kWh/t
MC-Cleaner	Pumping energy	Pumping energy
Sand removal (cleaner)	Pumping energy	Pumping energy
Fine screening	17 kWh/t of DIP pulp	22 kWh/t
Flotation I	18 kWh/t of DIP pulp	33 kWh/t
Washing I	8 kWh/t of DIP pulp	No washing
Disc filter (thickening)	not required	1 kWh/t
Dispersion (incl. Thickener)	55 kWh/t of DIP pulp ²⁾	67 kWh/t ²⁾
Dissolved Air Flotation	no data (difficult to calculate in kWh/t DIP pulp)	no data (difficult to calculate in kWh/t DIP pulp)
Flotation II	5 kWh/t of DIP pulp	19 kWh/t
Washing II	10 kWh/t of DIP pulp	No washing
Sludge Press	no data (not main equipment)	no data (not main equipment)
All pumps	not included ³⁾	91 kWh/t ⁴⁾
Explanatory notes: Normally the values are presented as installed KW. When specific energy consumption is derived from these figures an approximation to the real situation has to be made. 1) CHD pulping = Continuous High Density pulping. In many mills standard batch HD is applied (higher energy demand) 2) These values are representing rather figures below average. For the best qualities a consumption of up to 70 – 80 kWh/t is not uncommon in some mills. Normally for thickening and dispersion an electricity demand between 85 – 90 kWh/t is reported (see figures further below). 3) For the tissue stock preparation equipment no pumps and agitators are included 4) Apart from the pumps for the flotation system all pumps and agitators are included		

Table 5.8: Real world examples for the energy consumption in the production of tissue and newsprint from recovered paper [data from Valmet]

Modern equipment is applied. Note that the energy consumption depends on the raw materials used, the stock preparation layout, the installed equipment, and the product properties to be achieved (for other, more typical examples it is referred to Table 5.1 and this section further below). The figures include the stock preparation only and not the paper machine. For the latter refer to Section 6.2.2.4

For further detailed figures on the specific energy demand of unit processes in the stock preparation plant for the processing of recovered paper without de-inking (2-ply testliner) it is referred to Section 5.3.7.

In Table 5.9 and Table 5.10 for a newsprint mill based on 100 % recycled fibres figures are given for the energy consumption and energy balance. The energy consumption is divided into heat and electric power. The example refers to a Swedish mill with a production capacity of 500000 t/a newsprint.

Department	Process heat [MJ/Adt]	Electric power [kWh/Adt]
Pulp mill		
Deinking	200	175
Washing and screening	0	50
Bleaching	0	75
Total pulp mill	200	300
Stock preparation	0	235
Paper machine	5300	350
Total paper mill	5300	585
Effluent treatment	0	32
Specific energy consumption per t/paper	5500	917

Table 5.9: Energy consumption in an integrated Swedish mill with a production capacity of 500000 t/a of newsprint from deinked pulp
Base year: 1995 [SEPA Report 4712-4, 1997]

In Table 5.10 for the same mill figures for the energy balances are presented.

Department	Heat [MJ/Adt]	Electric power [kWh/Adt]
Pulp mill		
Turbine generator	0	0
External supply	+ 200	+ 332
Consumption	- 200	- 300
Effluent treatment	0	- 32
Excess energy from pulp mill	0	0
Paper mill		
Consumption	- 5300	- 585
External supply	+ 5300	+ 585
Total external supply	5500	917

Table 5.10: Energy balances of two integrated RCF newsprint mills with a production capacity of 500000 t/a and 250000 t/a respectively
Base year: 1995 [SEPA Report 4712-4, 1997]

In principle, energy consumption in recovered fibre processing depends on the design, type and amount of the process steps involved to achieve a certain product quality. Especially the increase of brightness and decrease of specks is linked to increasing energy input. For example, a German newsprint mill with a capacity for processing of 1900 tonnes recovered paper per day reported a significant increasing energy demand by putting into operation a peroxide bleaching step with disperger and an additional secondary flotation for the manufacturing of upgraded newsprint instead of standard grades. Whereas standard de-inked stock consumes about 350 kWh/t and 250 t steam per day bleached high-grade de-inked pulp requires 420 kWh/t. It have to be taken into account that purchased electricity is often generated by electricity companies

with an energy yield of about 38 %. Therefore, to generate the required purchased electricity for recovered paper processing (i.e. 0.35 - 0.45 kWh/kg DIP) a primary energy consumption between 1 and 1.3 kWh/kg DIP is required.

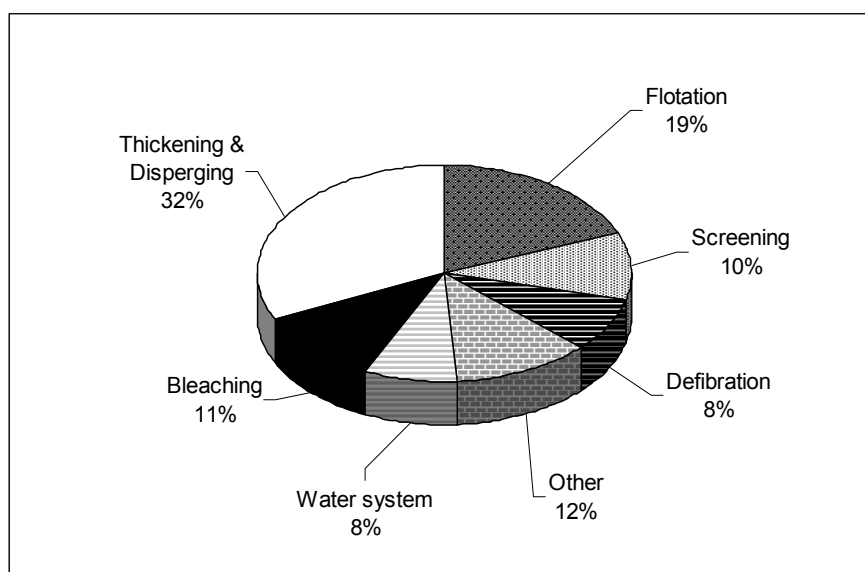


Figure 5.9: Specific energy consumption for recovered paper processing of a newsprint mill [Merkel, 1997]. Flotation includes two stages; screening includes pre- and secondary screening; "others" includes ventilation, the dryer for a part of the DIP-stock, water clarification systems etc.; water system does not include water clarification; bleaching is conducted in a disperger

The figure on energy consumption of the single process stages shows that about one third is consumed by thickening and disperging. For repulping installations the following ranges have been reported: conventional pulper 25 - 80 kWh/t, drum pulper 15 - 20 kWh/t, secondary pulper 15 -40 kWh/t [all figures: UBA, 19/1994]. Thickening before disperging consumes about 30 kWh/t. Heating the furnish up to 90°C and operating the disperger require about 60-100 kWh/t. Flotation needs about 27-33 kWh/t. The energy consumption for flotation depends on the amount of flotation cells, the design of the pipings in the mill and the types of air injectors applied. Wire presses and screw presses for de-watering require about 10 kWh/t.

5.2.2.5 Wastewater emissions

Emissions from paper industry to wastewater in particular - but also energy demand and waste generation - are closely related to the requirements set for the paper grades, the quality of the raw materials (recovered paper) and applied abatement techniques. Additives used, internal process management, housekeeping and the technical status of the installation have also an effect on the emissions levels achieved.

Wastewater from a RCF paper mill is mainly generated during cleaning steps. It is common practice to withdraw wastewater at locations where the process water is mostly polluted. However, the location of wastewater generation varies from mill to mill. The process water is mainly contaminated during cleaning, deinking and fibre recovery. Therefore, wastewater from RCF based paper mills consists of

- Water from reject separation by screens and centrifugal cleaners
- Filtrates from washers, thickeners and sludge handling
- Excess white water depending on the rate of recycling

Wastewater of the European paper and board industry is to a great extent discharged directly to the surface water after primary and biological treatment at the site or is discharged to a municipal sewage treatment plant after primary clarification for suspended solids removal. In Table 5.11 and Table 5.12 average water emission data after exclusively primary treatment from RCF based paper mills discharging to municipal wastewater treatment plant and those with on-site biological treatment are compiled.

Parameter	Without deinking		Deinking mills	
	mg/l (min-max)	kg/t (min-max)	mg/l (min-max)	kg/t (min-max)
BOD₅ ¹⁾	1900	4.7	550	10
COD	3800 (570 - 9000)	9.4 (1.2-24)	1100 (440 - 1900)	20 (7 - 40)
Kj-N ²⁾	16 (10 - 40)	0.05 (0.02 - 0.1)	20 (13 - 25)	0.35 (0.19-0.62)
Discharge volume		5.5 (0.4-15.5) m ³ /t		15 (9 - 39) m ³ /t

Notes:
 1) The BOD₅ value is estimated assuming that COD = 2* BOD₅ [Dutch note on BAT, 1996].
 2) Kjeldahl Nitrogen is the sum of organic and ammoniac nitrogen. Part of the organic N may be hydrolysed during effluent treatment, ammonium-N is a potential nutrient for the biomass of the treatment plant.

Table 5.11: Average water emission for RCF mills after primary treatment and before discharge to a sewage treatment plant

The data have been measured by competent water authorities and self-control measurements of the companies in 1994/95. [Dutch notes on BAT, 1996]

Parameter	Without deinking		Deinking mills	
	mg/l (min-max)	kg/t (min-max)	mg/l (min-max)	kg/t (min-max)
BOD₅ before treatment *	1800	12.3	770	8.3
BOD₅ after treatment	10 (3 - 28)	0.06 (0.01 - 0.13)	9	0.09
COD before treatment *	3200	22	1900	21
COD after treatment	150 (60 - 270)	0.77 (0.29 - 1.12)	290	3.1
Kj-N ¹⁾	5.6 (3 - 13)	0.03 (0.01 - 0.04)	7.8	0.08
P_{tot}	1.5 (0.5 - 1.8)	0.01	n.a.	n.a.
TSS	25 (17 - 40)	0.13 (0.06 - 0.21)	n.a.	n.a.
Discharge volume		5.7 (3.1-11) m ³ /t		11 m ³ /t

Notes:
 * Influent data on BOD₅ were not available. Therefore, the influent data are calculated based on wastewater loading data of one mill without deinking and one mill with deinking. [Dutch note on BAT, 1996].
 1) Kjeldahl-N after effluent treatment gives only an indication of the amount of organic N in the effluent and does not cover the total N-load that includes the oxidised N-compounds nitrates and nitrites.

Table 5.12: Average water emission for RCF mills discharging to water bodies after primary and biological treatment at the site.

The data has been measured by competent water authorities and self-control measurements of the companies in 1994/95. [Dutch notes on BAT, 1996]

Chemical Oxygen Demand

COD emissions originate from both raw materials and additives. Deinking and bleaching processes releases a substantial part of the COD from the recovered paper. COD emissions data

of paper mills with sewer discharge show large variations depending on the stage of processing during measurement. The removal and equalisation of COD is carried out at the municipal sewerage treatment plant. COD emission data of paper and board mills equipped with a biological wastewater treatment at the site show little variation. The variations shown in Table 5.12 are caused by mills whose wastewater treatment plant (WWTP) is not operating well. These mills are considering an upgrading of their WWTP. Deinking processing results in higher COD emissions than emissions caused by processing without deinking. In the latter case, much of the COD is retained in the product.

BOD₅

BOD₅ emissions data after biological treatment show no significant difference between recovered paper processing with and without deinking. In properly working treatment plants the concentration of BOD₅ after treatment is below 20 mg/l independent of the concentration of the inflow. After biological treatment BOD₅ emissions of 0.01 - 0.13 kg/t paper and board have been reported [Dutch note on BAT, 1996]. The differences in the specific BOD-load is mainly caused by differences in the water flow. The ratio BOD₅ : COD of paper mill effluents after primary treatment of about 0.5 indicates that paper mill effluent is easily biodegradable.

Nutrients

Wastewater treatment plant effluents mostly contain low concentrations of nutrients in the form of nitrogen and phosphate. The presence of these compounds is mainly caused by the necessary addition of these nutrients for effective operation of the biological treatment plant that needs a nutrient supply in the range of BOD₅ : N : P = 100 : 5 : 1. Organic bounded Nitrogen compounds may also originate from some additives. During biological treatment part of it may be hydrolysed to ammonium - others not - and transformed to nitrate compounds.

Total Suspended Solids

TSS data after treatment show only little variation. The upper level of the TSS ranges is caused by paper mill wastewater treatment plants that are not well operating. Because of the type of organics in paper mill wastewater there is a relative tendency to build up bulking sludge in activated sludge treatment systems. Control measures to avoid and control this undesirable phenomenon are available.

Heavy metals

Heavy metals concentrations in paper mill effluents are generally negligible low. There is no significant increase in concentrations if secondary fibres are used. Nevertheless, occasional measurements of Dutch deinking processing mills have shown that some deinking process mill effluents may contain elevated concentrations of copper and zinc. In that case, printing ink in recovered paper is considered to be the main source of heavy metals. The heavy metals observed occasionally in the effluents are mainly in the form of stable organic complexes [Luttmer, 1996, quoted in Dutch notes on BAT].

AOX and other organic micro-pollutants

Sources of absorbable organic halogen compounds are some additives (especially wet strength-agents), recovered paper based on chlorine bleached pulp and to some extent printing inks. As chlorine bleaching is practically abandoned today AOX containing compounds derived from recovered paper based on chlorine bleached pulp have considerably decreased over the last years. AOX reduced neutral wet strength agents are also available on the market and are an option for further reduction of AOX emissions. Therefore, the AOX concentration is expected to have a downward trend over the years. Occasional measurement in Dutch RCF paper mills (with and without deinking) has shown that average AOX concentrations are in the range of 200 µg/l.

Organic micro-pollutants as chlorophenols or polychlorinated biphenyls may be detectable in some RCF paper mill effluents in very low concentrations depending on the raw materials used

(recovered paper, printing inks, and additives). In occasional measurements in Dutch RCF mills chlorophenols up to 1 µg/l (0.1 - 0.7 µg/l) and polychlorinated biphenyls only in traces (values below the detection limit to 0.11 µg/l [max. value]) have been observed [Dutch note on BAT, 1996].

Salts

Salts, mainly sulphate and chloride, are introduced mainly through recovered paper and some additives as alum. In certain areas, for instance if surface water is a main resource for the production of drinking water or for water quality reasons, attention is given to the discharge of salts. Depending on the types of recovered paper used as raw material and the degree of closure of the water circuits sulphate concentrations up to 1000 mg/l have been observed even if during processing no aluminium sulphate has been used.

5.2.2.6 Solid waste generation

Most of the impurities from the processed recovered paper end up as waste. The major waste materials are rejects, different types of sludge and - in case of on-site incineration of residues - ashes. The major sources of solid waste in RCF based paper mills are stock preparation, process water clarification and wastewater treatment. Depending on used raw materials, process design and type of process and wastewater treatment respectively different amounts and qualities of residues (rejects, sludge) are generated. The residues have to be handled and treated (thickened and de-watered) to generate a residue with a high dry solids content. Achievable dry contents for rejects and sludge are compiled in Table 5.13 and Table 5.14.

Applied reject handling machines	Hydraulic reject press	Pneumatic reject press
Achievable dry contents at < 70% fibre content	up to 65 %	55 - 58 %
< 30% fibres content	ca. 70 %	60 63 %
Energy consumption [kWh/t]	15 - 20	8 - 12

Table 5.13: Achievable dry contents for rejects and corresponding energy consumption for different fibre contents, [Data from a machinery supplier]

Applied sludge handling machines	Wire press incl. pre-thickening	Screw press incl. pre-thickening
Achievable dry contents at < 50% ash content	up to 55 %	up to 65 %
> 50% ash content	up to 60 %	up to 70 %
Energy consumption [kWh/t] (incl. pre-thickening)	10 - 15	18 - 20

Table 5.14: Achievable dry contents for sludge and corresponding energy consumption for different ash contents, [Data from a machinery supplier]

The residues can be sub-divided roughly in heavy and coarse rejects, light and fine rejects and sludge. Depending on origin and nature, the sludge again may be sub-divided into de-inking sludge, sludge from micro flotation units from process water clarification and sludge from wastewater treatment (primary sludge, excess sludge from biological treatment). The achievable dry solid contents after de-watering and thickening are 60-80% for coarse rejects, 50-65% for fine rejects and about 60% for sludge.

The amount of residues in RCF based paper mills result from the quality of recovered paper used as raw material and the effort and expense made in preparation of secondary fibres for certain product and process requirements. For the main paper grades and recovered paper qualities the average amounts of residues related to the input of raw material are given in Table 5.15.

Product	Recovered paper quality	Total losses	Rejects		Sludge		
			Coarse/ Heavy	Fine/ Light	Deinking	Process Water Clarification	Waste water
Graphic papers	Newspaper, magazines Higher qualities	15-20 10-25	1-2 < 1	3-5 < 3	8-13 7-16	2-5 1-5	≈ 1
Tissue	Office recovered paper, files, ordinary and medium qualities	28-40	1-2	3-5	8-13	15-25	≈ 1
Market DIP	Office recovered paper	32-40	< 1	4-5	12-15	15-25	≈ 1
Testliner /Fluting	Shopping centre waste, recovered paper from households Kraft qualities	4-9	1-2	3-6	----	0-(1)	≈ 1
		3-6	< 1	2-4	----	0-(1)	
Paper board	Shopping centre waste, recovered paper from households	4-9	1-2	3-6	----	0-(1)	≈ 1

Table 5.15: Amount of residues related to the input of raw material [%] depending on qualities of recovered paper used and paper grade produced

According to [Borschke, 1997]. The amount of wastewater treatment sludge is assessed assuming an amount of excess sludge of 0.6 kg/kg BOD₅ eliminated (as dry solids) generated during treatment, which is a common figure for activated sludge plants. Thus, depending on the quality of recovered paper and on the process design about 10 kg excess sludge from biological treatment per tonne of paper (on a dry basis) may be expected.

Rejects

Rejects are impurities in recovered paper and consist mainly of lumps of fibres (shives), staples, and metals from ring binders, sand, glass and plastics. Rejects are removed in the largest possible form and in the earliest possible stage in the stock preparation. Rejects constitute approximately 6.5% of the purchased recovered paper and have no recycling potential and so they are dumped or incinerated. If the thickened residues are incinerated in an environmentally compatible incineration plant e.g. fluidised bed generating steam for mill consumer points the residue is reduced to ash which may be used in the building industry or disposed of. However, whether reuse of ashes produced by incineration is feasible, depends on the market demand for this material. On-site incineration of rejects is only applicable to large mills, which generate higher amounts of solid waste. A typical composition of rejects from recovered paper processing (differences in raw materials and products) are given in Table 5.16.

Parameter	Share of single fractions [%] ¹⁾	Average values from a single mill
Water content	45 %	33.3 %
Plastics	25.9 %	
Fibre	27 %	
Glass and stones	0.11 %	
Metals	0.88 %	
Organic substances	1.05 %	
Cl - content of the plastics	5.45 %	
Cl - content related to fuel	1.43 %	1.21
Calorific value H _U (100 % DS)	23800 kJ/kg	25335
Calorific value H _U (55 % DS)	11991 kJ/kg	12828 kJ/kg
Notes:		
1) Average from 18 single samplings in German RCF paper mills		

Table 5.16: Composition of rejects from the recovered paper processing for corrugated medium (4-6% reject)

Qualities of processed recovered papers: mainly "collected recovered paper" from households and markets and corrugated board residues

Sludge from process water clarification (paper residue)

These types of sludge are mainly generated at the fibre recovery in the white water circuits and the mechanical treatment unit of the wastewater treatment plant. The paper residue consists of mostly short fibres and fillers (both around 50%) depending on the recovered paper being processed. In the board industry and for production of corrugated medium it is often recycled to the process. For higher-grade products, paper residue does not meet the quality requirements for recycling and is incinerated or dumped. Depending if there is a previous deinking process the sludge may contain to a certain extent inks and pigments particles. Fibre recovery contributes to minimising the quantity of residues. The typical composition of paper residue from fibre recovery and mechanical treatment of wastewater are given in Table 5.17.

Parameter	Unit	Range of values
Dry solid content	%	29.4 - 52.7
Volatile solids	% DS	25.5 - 76.1
Lead	mg/kg DS	10 - 210
Cadmium	mg/kg DS	0.01 - 0.98
Chromium _{total}	mg/kg DS	8.8 - 903
Copper	mg/kg DS	19.9 - 195
Nickel	mg/kg DS	< 10 - 31.3
Mercury	mg/kg DS	0.1 - 0.89
Zinc	mg/kg DS	34.2 - 1320

Table 5.17: Composition of sludge from fibre recovery and chemical-mechanical treatment of wastewater

Synopsis of the complete results of chemical analysis of solid wastes from paper manufacturing conducted at German PTS, published in [Solid waste handbook, 1996]

Deinking sludge

This residue contains mainly short fibres, coatings, fillers, ink particles, extractive substances and deinking additives. Ink particles are a potential source of heavy metals but as shown in Table 5.18 the typical pollutant contents of deinking residue have comparable pollutant loads as sludge from biological wastewater treatment plants with slightly higher values for some

substances as copper and zinc. There are relatively significant variations in the pollutant content of the recovered paper and consequently in the de-inking sludge.

Component	Unit	Contents per kg dry solids			
		De-inking sludge [1]	De-inking sludge [2]	De-inking sludge [3]	Wastewater treatment sludge [1]
Cadmium (Cd)	mg	< 0.1	< 0.67	0.02 - 1.54	< 0.1
Mercury (Hg)	mg	< 0.1	0.08	0.1 - 0.89	< 0.1
Copper (Cu)	mg	350	238	64.2 - 345	40
Zinc (Zn)	mg	350	141	34.2 - 1320	250
Lead (Pb)	mg	35	41	9.5 - 79.4	30
Nickel (Ni)	mg	5	5.7	< 10 - 31.3	10
Chromium (Cr)	mg	20	24(Cr _{total})	4.8 - 96.6	10
PCB's	µg	95	n.d.	< 300	5
Chlorophenols	µg	75	n.d.	n.d.	120
Volatile solids	%DS	n.d.	33.2	32.7 - 63.6	48
Notes:					
[1] = Dutch note on BAT, 1996; [2] = Representative sampling from a German paper mill, [3] = Synopsis of the complete results of chemical analysis of solid wastes from paper manufacturing conducted at German PTS, published in Solid waste handbook, 1996]; n.d. = not determined					

Table 5.18: Typical pollutant contents of de-inking sludge from RCF paper mills compared to sludge from municipal WWTP

Deinking sludge is normally dumped or incinerated. The ash can serve as a resource for building materials.

Wastewater treatment sludge

These sludge is generated at the biological units of the biological wastewater treatment plant and is either recycled to the product (corrugated medium and board) or thickened, dewatered and then incinerated (on- or off-site) or dumped. In many Member States the dumping of waste with high organic content is discouraged by the governments and will be prohibited in the near future. The EU Directive on the landfill of waste will support this tendency in setting targets to cut the amount of biodegradable (municipal) waste sent to landfills. The typical composition and pollution potential of sludge from biological wastewater treatment are given in the right column of Table 5.18 and in Table 4.8.

5.2.2.7 Emissions to the atmosphere

Air emission from energy generation

Emissions to air from paper and board mills originate mainly from energy generation (steam and electricity) and not from the manufacturing process itself. Major pollutants in case of gas firing are CO₂ and NO_x, in case of oil or coal firing CO₂, NO_x, SO₂, dust and low concentrations of heavy metals. These emissions occur at the site of generation. Steam is normally generated at the paper mill in dedicated boilers, so the emissions occur at the site. In many cases, electricity is purchased from the grid, so the emissions occur at the power plant. The electricity/steam consumption ratio at paper mills enables the co-generation of heat and power (CHP). Many paper mills apply CHP and then all emissions to air associated with the energy consumption occur at the site. The typical emissions from on-site installations for co-generated heat and power generation are presented in Section 5.3.9 and for steam generation by combustion of different types of fuels (gas, coal, oil) in Section 6.3.15.

Only in some special cases emissions (measured as organic carbon) from the dryer section of the paper machine may occur. If so, they are caused by the use of additives (coating chemicals) or by not well-designed water circuits and wastewater treatment plants respectively but in most cases they are of negligible concern. Therefore, atmospheric emissions from paper mills are mainly related to energy generation.

Air emissions from on-site incineration of sludge or rejects (optional)

The recovered paper processing and papermaking generates a number of wastes with a high organic content (e.g. paper, rejects, de-inking sludge, and biosludge). This waste was formerly landfilled, but an increasing number of companies incinerates its rejects and sludge in on-site incineration plants generating steam used in production processes. The incineration is associated with emissions to air. Examples of measured emissions from incineration of different types of RCF paper mill residues are compiled in Table 5.19. These values include the most relevant pollutants to be expected.

Parameter	Unit	Measured Values ⁸ (average figures for 1997) Rejects from a RCF packaging paper mill (without de-inking) *	Measured Values ⁹ (daily average figures for 01-09/ 1997) Rejects from a RCF newsprint mill with de- inking **	Limit values according to German regulations (daily mean values) ***
Dust	mg/Nm ³	3.2	6.6	10.0
SO ₂	mg/Nm ³	26.0	1.2	50.0
NO _x	mg/Nm ³	195	'95: 271; '96: 227; '97: 176	200
CO	mg/Nm ³	14.1	14	50.0
HCl	mg/Nm ³	1.7	2.6	10.0
HF	mg/Nm ³	0.06	no data (n.d.)	1.0
Total-C	mg/Nm ³	1.4	1.1	10.0
Cd, TI	µg/Nm ³	< 17.0	(n.d.)	50.0
Hg	µg/Nm ³	5	(n.d.)	50.0
Sb, As, Cr, Co, Cu, Mn, Ni, V, Sn	µg/Nm ³	71.0	(n.d.)	500
Dioxins/Furans	ng I-TE/Nm ³	0.097	(n.d.)	0.1
Explanatory notes: All values refer to standard conditions and oxygen content of 11 % per volume. * Emission data of reject incineration in a multiple hearth combustion plant; the flue gas purification is equipped with a two-stage wet scrubber for removal of acid pollutants (mainly SO ₂ and HCl). For minimising dioxin emissions, a mixture of activated carbon and zeolithe is injected into the recycled flue gas stream. Reduction of NO _x emissions is achieved by SNCR using ammonia, which is injected into the combustion chamber. Dust emission is reduced by an electrostatic precipitator ** The reduction of NO _x has been achieved by use of SNCR i.e. injection of ammonia; dust emission is reduced by use of bag filters *** According to the Seventeenth Ordinance on the Implementation of the Federal Immission Control Act (Ordinance on Incinerators for Waste and similar Combustible Material), of 23 November 1990				

Table 5.19: Measured emission data from incineration of rejects and sludge from two German RCF mills

The left column refers to measured average values of a RCF packaging paper mill (without de-inking). The right column shows measured values from incineration of different types of sludge from a deinking plant (sludge from raw and wastewater treatment, sludge from process water clarification and de-inking sludge) before and after measures for NO_x reduction. The values are compared with German legal standards

⁸ See Section 5.3.11, example 1.

⁹ Environmental Declaration 1997 Sachsen Papier Eilenburg GmbH.

Odour from vapours and from wastewater treatment plant (local)

Local air problems might occur due to odour and coarse dust. No BAT measures will be identified for these because they are local matters.

Especially in case of closing up the water circuits below a water consumption of around 4 m³/t odours caused by lower organic acids and H₂S may be perceived in the neighbourhood of paper mills. But, also in paper mills with less water circuit closure annoying odours may be found. They may be caused by too long retention times of process water in the water system (pipes, chests, etc.) or deposits of sludge causing the built up of hydrogen sulphide. If so, they can be avoided by suitable process engineering measures. The wastewater treatment plant of RCF paper mills may also emit significant quantities of odour. If the wastewater treatment is well designed and controlled annoying odours can be avoided.

Coarse dust from raw material handling (local)

The recovered paper is stored on recovered paper yards that are integrated in the paper mill. During the transport of the recycled paper to the pulper dust might be generated especially when recovered paper is delivered as loose material in big containers or by bulk dumping. The control of this dust is rather a matter of industrial safety than of environmental protection. It is not further described here.

5.2.2.8 Noise from paper machines (local)

In the neighbourhood paper machines may give rise to nuisance as a result of noise. Many mills have taken measures to reduce noise generation. For more details on noise levels from paper machines please refer to 6.2.1.8.

Besides noise, sometimes (low-frequency) vibrations may give rise to nuisance on local level.

5.3 Techniques to consider in the determination of BAT

In this paragraph all **relevant** techniques currently commercially available for prevention or reduction of emissions/waste and reducing consumption of energy and raw materials, both for new and existing recovered paper processing mills are given. " Techniques to consider in the determination of BAT " means technical alternatives with the best environmental and economical performance or possibilities for improvement to achieve integrated prevention and control of pollution.

These techniques cover in-process measures and end-of-pipe technology as well. However, there is a certain overlapping between the further down described process-internal solutions and external control measures. This list of techniques is not exhaustive and may be continued when reviewing this document.

In the description of the techniques the advantages and drawbacks of the implementation are outlined. The descriptions are all structured in the same manner i.e. for each technique a description, main achieved emission levels, applicability, cross-media effects, economics, operational data, reference plants and literature are presented.

Some measures described in this paragraph are only valid for specific paper grades based on recovered fibres e.g. recovered paper without de-inking whereas others are applicable independently from the paper grade produced. The former will be noted otherwise the measures are considered to refer to the recovered paper processing in general.

Recovered paper plants are, with very few exceptions, integrated with a paper mill. Therefore, there is a certain overlapping between recovered paper pulping and stock preparation on the one hand and papermaking and associated processes on the other. In that cases cross references to the respective chapters will be given.

Finally, a lot of measures and principles for improvement can be applied to both recovered paper mills and paper mills from virgin fibres. These points will be noted with cross-references as well to avoid unnecessary repetition and to show similarities and differences between the production of different paper grades.

In Table 5.20 an overview of techniques for reduction of emissions from recovered paper processing is given. It was tried to give possible cross-media effects of every technique in the same table. It can be concluded that it is not an easy task to describe cross-media effects in a way that would not cause any dispute. There are a lot of "grey-zones" in the assessment of cross-media effects. Furthermore, they may depend on other techniques, which may be linked to a given measure, the reference to which a technique is compared with and the system boundary taken into account as well. Therefore, the qualitative assessment of cross-media effects should only be taken as help for operators or inspectors which side effects a measure may possibly occur and a starting-point when considering possible shifts of pollution. The results of the assessment should not be considered as imperative. Furthermore, some of them can be avoided by prevention and control measures. The corresponding paragraphs under the detailed discussion of every technique give further explanations. The table may also indicate at which environmental media (water, air, waste, and energy) a measure is aiming at.

In the rows of Table 5.20 the single available techniques are compiled. In the columns the tendency of effects caused by different techniques raw material consumption and emissions are indicated qualitatively by using arrows up "↑" and down "↓". The arrows down "↓" indicate savings of raw materials or energy and a reduction of emissions into the different media water, air and soil. Arrows up "↑" indicate an increase of emissions, consumption and impacts on the production process. Some of the measures for pollution prevention and control presented in this section concern more than one environmental medium (as water, air or soil) at a time. Some

techniques may have a positive and/or negative impact on other environmental media or on raw material and energy consumption (cross-media-effects). The given effects will be noted by using the arrows. An arrow in brackets "(↑)" means only a slight - often negligible - increase of energy consumption, raw material use or emission to environment when implementing a certain measure. The economic aspects (investments, operational costs) are not included in the table but are explained in the text. In principal, data on economics can only give a rough picture and indicate the levels of costs. They will vary with the design of the whole plant and depend among others on the size of the mill and how a measure fits together with other mill equipment.

Each technique is provided with a reference mark, which helps to identify the according section in the text where each single technique is discussed in detail.

Techniques to consider in the determination of BAT	Effects on the consumption and emission levels (cross-media effects)					
	Chemical consumption	Energy (E) & water (W) consumption	Emission to water	Emission to air	Solid waste	Applicability
5.3.1 Separation of less contaminated water from contaminated one and recycling	(↓)	↓	(↓)	0	0	All grades
5.3.2 Optimal water management (water loop arrangement) and water clarification	(↓)	↓	↓	0	(↓)	All grades
5.3.3 Reduction of fresh water consumption by strict separation of water loops	0	↓	(↓)	0	0	All grades
5.3.4 Closed water loop with in-line biological process water treatment	0	(↓)	↓	0	(↓)	"brown grades"
5.3.5 Anaerobic techniques as first stage of biological wastewater treatment	0	↓ E	↓	(↓)	↓	"brown grades"
5.3.6 Aerobic biological wastewater treatment	(↑)	↑ E	↓	0	↑	All grades
5.3.7 Upgrading of stock preparation plants with decreased energy consumption and emissions .)	0	(↓↑) depending on the concept chosen	0	0	(↓↑)	"brown grades"
5.3.8 Generation of clarified water for de-inking plants	(↑)	(↑)	(↓)	0	(↑)	de-inked grades
5.3.9 Co-generation of heat and power	0	↓	0	0	0	All grades
5.3.10 Reject and sludge handling and processing on-site (de-watering)	↑	(↑)	0	0	0	All grades
5.3.11 Environmentally sound residue utilisation and disposal	0	↓	(↓)	(↑)	↓	All grades
Example 1 Energetic utilisation of rejects from RCF mills without de-inking in in reject incineration plants	↑	(↓)	0	(↑)	↓	mainly "brown grades"
Example 2 Co-incineration of rejects from RCF mills without de-inking in coal-fired power plants	0	↓	0	(↑)	↓	mainly "brown grades"
Example 3: Incineration of residues (rejects and sludge) from DIP-plants combined with power and steam generation						mainly "white grades"
Notes: ↑ = increase; ↓ = decrease; 0 = no (or negligible) effect; (↑) or (↓) = low influence depending on the conditions						

Table 5.20: Overview of techniques to consider in the determination of BAT for recovered paper processing mills; cross-media implications and a note on the applicability is also indicated

5.3.1 Separation of less contaminated water from contaminated one and recycling of this process waters

Description of the technique: This measure is part of optimal water management in paper mills. Water management in paper mills is a complex task that has many aspects. To give an overview the main principles for internal measures to reduce fresh water consumption and

discharges from recovered paper mills (system closure) are briefly summarised below. In each case it is referred to the sections of the document where more detailed information can be found.

- Use of suitable techniques to separate less contaminated water from contaminated process water. Measures to be considered are the separation and reuse of cooling water and the reuse of less contaminated sealing and process waters used in vacuum systems. This measure is discussed hereafter.
- Reduction of fresh water consumption by recycling of white water in different positions depending on the water qualities required. Positions in the process of special interest when reducing fresh water consumption are dilution of fibre raw materials and fillers, dilution of process and product aids, the shower water system, the vacuum system and sealing water for pumps and agitators (see Section 5.3.2 and Section 6.3.1)
- Reduction of fresh water consumption by strict separation of water loops together with counter-current flows (see Section 5.3.3).
- Generation of clarified water from white water as a substitute for fresh water, usually made in the fibre recovery unit by use of bow-screens, polydisc filters (see Section 6.1.3) or dissolved air flotation (see Section 5.3.8).
- Measures to handle the possible negative effects of the increased recycling of process water (see Section 6.3.2)
- In some cases the further purification of clarified white water is applied (see Section 6.3.3). This purified water meet relatively high quality requirements

Separation of clean cooling waters from process effluents and their reuse for other purposes are ways of reducing fresh water consumption. For protection a micro-screen or other strainer is recommended to remove solids. Where cooling water fractions are sewerred it should be avoided to mix them to contaminated process water sewers to ensure wastewater treatment efficiency and reduce treatment costs.

The most common equipment for vacuum generation, the liquid ring pump, consumes sealing and process water at a rate of about 1 l/min per installed kW [tm 007, JP 1994]. The installed power for a vacuum system in a big newsprint machine may be as high as 3000 kW. This would result in a sealing and process water consumption of some 7 m³/t for the newsprint machine. The sealing water will be contaminated with fibres and the temperature will rise when it passes the liquid ring pump. The need for fresh water as sealing and process water of the liquid ring pumps can be reduced very much by recycling the water from the pumps through heat exchanger or cooling tower or. This is common in many European paper mills. Sometimes the process water for the ring pump must be clarified by use of e.g. a bow-screen before it enters the heat exchanger. It can also be necessary to control the pH value in recirculation loop.

Increase of the capacity of the process water storage may be needed in order to avoid unnecessary overflows of recycled water when there is a break or other imbalance situation in the processing of pulp. The increase of capacity implies usually installation of additional tanks, pipes and pumps.

Applicability and characterisation of the measure: Process-integrated measure. The separation and reuse of clean cooling waters and water from vacuum systems and sealing waters can be realised in existing and new mills. Separation and reuse of clean cooling waters from process effluents is relatively easy to carry out at new installations but more complicated to implement at existing plants. However, cooling water separation and recycle after cooling are common. The same is valid for the recirculation of sealing waters.

Main achieved environmental performance: The measure has a significant effect on reduction of fresh water requirement and wastewater discharge. In existing mills fresh water use reduction of 10-15 m³/ADt of cooling waters can be achieved. Separation of used cooling water from contaminated paper machine effluents can reduce the hydraulic loading to the external effluent treatment.

By appropriate sealing water recirculation it is possible to reduce the fresh water consumption for liquid ring pumps to $< 1 \text{ m}^3/\text{t}$. At the same time it is possible to recover part of the energy if heat exchangers are used.

Cross-media effect: No important effects to environment. Some energy savings are possible.

Operational experiences: Separation and recycling of less contaminated water from contaminated is common practice in many European mills but the degree of water recirculation varies.

Economics: Recycling of cooling and sealing waters requires typically additional investments in piping, pumping and filtration of the water. The increase of the water storage capacity implies usually installation of additional tanks. Data on specific costs are not available.

Besides the costs for implementing the described measures cost savings can be expected as e.g. lower costs for raw water (treatment) and energy consumption.

Driving force for implementing the technique: Fresh water reduction by recirculation of less contaminated water is a reasonable measure from an economic point of view. Discharge of less contaminated cooling and sealing water fractions together with contaminated process water are discouraged in many countries.

Example plants: Numerous plants in Europe

Literature:

[CEPI, 1997], [J. Pöyry, 1994b]

5.3.2 Optimal Water Management (water loop arrangement) and water clarification

Description of the Technique: The water loops in the production of paper are generally laid out for a minimised fresh water consumption. In today's water loop systems process water is re-used several times, as it is shown in Figure 5.10.

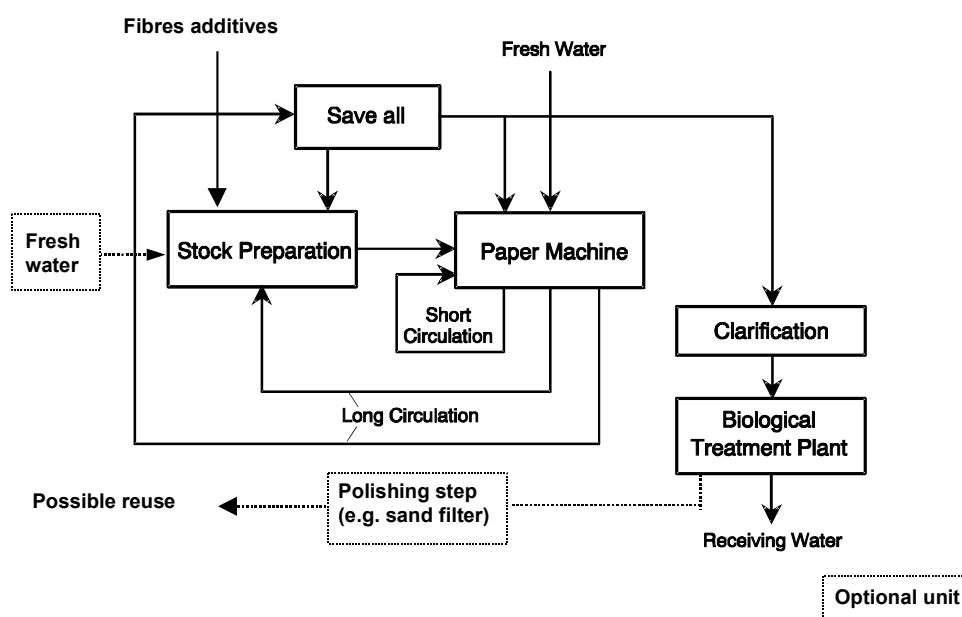


Figure 5.10: Scheme of water loops in paper mills
[ISP, 1998; modified by EIPPCB]

The main principle of the re-use of process water is the backward process water flow in the systems, counter current to the fibre flow. All paper mills use untreated, fibre enriched white water from the paper machine for stock dilution in the mixing chest ahead of the paper machine (short circulation or primary circuit) or in the stock preparation (long circulation or secondary circuit).

Part of the white water is clarified in save alls (see Section 6.1.3) applying filtration (polydisk filters, drum filters), flotation (dissolved air flotation, DAF) or sedimentation (sedimentation funnels, laminated separators). The clarified water is then re-used for the replacement of fresh water, for example, at the showers used for cleaning machine clothing (wires, felts). Excess clarified process water is discharged to the wastewater treatment plant. In some cases purified wastewater is partly re-used as process water as e.g. for RCF based wellenstoff and testliner and to less extent in RCF based newsprint.

A minimised fresh water consumption in the production of wellenstoff and testliner in the range of 4 to 7 m³ fresh water /tonne of paper produced is achievable. A few European mills are even operating with a totally closed water system. The fresh water consumption in these mills ranges from 1.0 to 1.5 m³/tonne paper produced. This corresponds to the volume of the water, which is evaporated in the dryer section of the paper machine.

In many paper mills fresh water is only used for the dilution of chemical additives and at locations of the paper machine where a highly, solid-free water quality is necessary, e.g. spray pipes and edge sprays.

However, closing up the process water system offers both advantages and disadvantages. Enhanced water system closure lead to a considerable loading of the process water with colloidal and dissolved organic and inorganic compounds which may cause serious problems in the production process if no control measures to avoid possible drawbacks are undertaken (see 6.3.2). Some of the advantages and disadvantages of water system closure are summarised in Table 5.21.

Advantages	Disadvantages
<ul style="list-style-type: none"> - less water consumption - less ground water withdrawal - less fresh water pre-treatment - less wastewater discharge - production increase not hindered by end-of-pipe treatment - decrease fibre en filler losses - elevated process temperature --> improved dewatering of the paper web on the wire - reduced energy demand 	<ul style="list-style-type: none"> - build-up of (suspended) solids - build-up of organic and inorganic substances - more complicated processes - corrosion problems - increasing use of additives - clogging of equipment - product quality related problems - scaling and slime forming - rise of temperature of the process water (can also be an advantage, see left column)

Table 5.21: Some advantages and disadvantages of water system closure in paper mills [Dutch notes on BAT, 1996]

In totally closed water systems (only applicable for testliner and wellenstoff production) additional serious problems may occur which needs to be controlled:

- significant decrease of the oxygen content of the process water approaching anaerobic conditions associated with a microbiological induced reduction of sulphate to hydrogen sulphide and the formation of odorous low-molecular fatty acids
- intensified growth of microorganisms
- aggressive corrosion caused by high temperature and high contents of chlorides, sulphates and organic acids

- significant emission of odorous organic compounds from the dryer section of the paper machine to the surrounding of the paper mill
- impaired quality of the paper produced, affected by odorous compounds
- higher demand of slimeicides.

Most of these problems occur at fresh water consumption levels below 4 - 7 m³/t of paper. In order to control these serious problems, some mills manufacturing "brown papers" re-opened their already closed water circuit and are now producing with a small volume of wastewater in the range of 2.5 to 5.0 m³/tonne paper produced.

Because of local environmental requirements, a few European paper mills applied new methods in the middle of the 90s in order to control the demanding conditions of their closed process water loops (see Section 5.3.4). They installed in-line treatment plants to reduce the organic load of the process water.

In order to control all problems described when closing up water systems and to fulfil paper quality requirements, a fresh water consumption of 4 to 7 m³/tonne paper produced is often regarded as necessary. This corresponds to a specific wastewater volume of 2.5 to 5.5 m³/tonne paper produced. Due to its suitable BOD₅/COD-ratio the wastewater can be treated very efficiently in combined anaerobic/aerobic or aerobic treatment plants (refer to 5.3.5).

In RCF based newsprint (deinked grade) the lowest wastewater volumes reported are down to about 7 m³/t and are normally in the range of 10 - 15 m³/t.

Applicability and characterisation: Process integrated technique. For "brown" packaging paper fresh water reduction to a level of 4 to 7 m³/tonne paper produced can be realised both in existing and new mills. However, it seems that this level can be reached at low expense only in rather new or recently upgraded mills. In older mills still having a higher fresh water consumption, the reduction may cause corrosion problems, depending on the quality of materials used for machines and pipes. Additionally, existing wastewater treatment plants have to be optimised.

Main achieved environmental performance: Water systems closure generates less wastewater but with an increased level of organic contamination in the water circuits. As a result, the treatability of the wastewater can be improved. For testliner and wellenstoff reducing fresh water consumption to a level of 4 to 7 m³/tonne paper produced increases the COD of the process water on a concentration range which is suitable for an anaerobic wastewater treatment associated with the benefit of biogas generation. In deinking plants the degree of water system closure is limited due to the paper properties to be achieved (brightness, cleanliness). Wastewater flow down to about 10 m³/t is achievable. The wastewater is usually treated by aerobic systems (trickling filter or/and activated sludge systems).

Monitoring of emissions: Monitoring devices are flow meters for fresh water feed on the paper machine and turbidity measurements for clear white water.

Cross media effects: Intensified process water re-use increases the temperature of the process water. Therefore, steam consumption for heating up the process water can be reduced. A fresh water consumption of 4 to 7 m³/tonne paper produced minimises the risk of odorous emissions via the exhaust air of the paper machine. The applicability of anaerobic wastewater treatment methods results in a reduction of fossil fuel demand for papermaking (see Section 5.3.5).

Operational data: The production of wellenstoff and testliner with a specific fresh water consumption of 4 to 7 m³/tonne paper produced is common. Experiences show that this range of fresh water consumption does not result in negative effects on the runnability of paper machines and on paper quality. The experiences are good even in existing mills and current paper machine design supports well their application. A number of full-scale plants manufacturing corrugating medium with good product qualities are operating in Europe.

Economics: Minimising fresh water consumption decreases the costs of fresh water purification and wastewater treatment. The measures applied depend on the specific conditions in paper mills. Therefore, it is not possible to indicate specific costs. Sufficient storage capacity for storage of white water is necessary.

Driving forces for implementing the technique: Closing up the water system is a prerequisite for efficient wastewater treatment (a lower investment and operating costs and higher removal efficiencies). Driving forces for implementing measures to reduce fresh water consumption are as follows:

- Saving fresh water costs (in some countries)
- Saving costs of wastewater purification
- Saving costs for wastewater duties
- Local environmental conditions.

Example plants: Numerous mills in Europe are operated with fresh water consumption minimised to the described level.

Literature:

[IFP, 1998], [Dutch notes on BAT, 1996], [Mönnigmann, 1996]

5.3.3 Reduction of fresh water consumption by strict separation of water loops together with counter-current flows (water loop closure)

Description of the technique: In the recycling of process water in integrated pulp and paper mills i.e. nearly all RCF based paper mills the main principle is that the white water flow from paper mill to pulp mill should be taken counter-current to the product flow. In an integrated pulp and paper mill, the pulp department, the bleaching department (if existing) and the paper mill have each its own white water circulation, from which the excess water goes backwards to the previous department where water quality is less demanding. The excess white water from the paper machine is used instead of fresh water in the bleaching department, and the excess water from the bleaching department is used instead of fresh water in the pulp mill.

Considerable amounts of fresh water can be saved with this arrangement. Fresh water is primarily only needed as makeup into the paper machine system.

However, in a tissue mill sometimes a lot of fresh water is required for efficient washing of machine felts.

It is of great importance to minimise the white water from going in the same direction as the product flow, *i.e.* from bleaching plant to the paper machine. This is accomplished by subtracting as much water as possible from the fibre flow before it enters the bleaching system and again before it enters the paper machine system. In this way, the carry-over of process disturbing compounds to relatively clean process water systems is minimised.

The separation of the water loops is carried out with thickeners like de-watering screws and wire presses or a washing stage *i.e.* a thickening step. Figure 5.11 shows the proposed lay out for a Dutch paper mill that has recently investigated the potential for water loop closure. The extra thickener leads to an improved separation of the "dirty" stock preparation and the "clean" paper machine and thus to significant reduction of organic substances that enters the paper machine loop.¹⁰

¹⁰ The factor by which this load is decreased is in good approximation given by the ratio of the flow volume from stock preparation into the paper machine loop and the total flow volume entering the paper machine loop. This ratio gives the degree by which the "dirty" flow is diluted in the clean, fresh water flow.

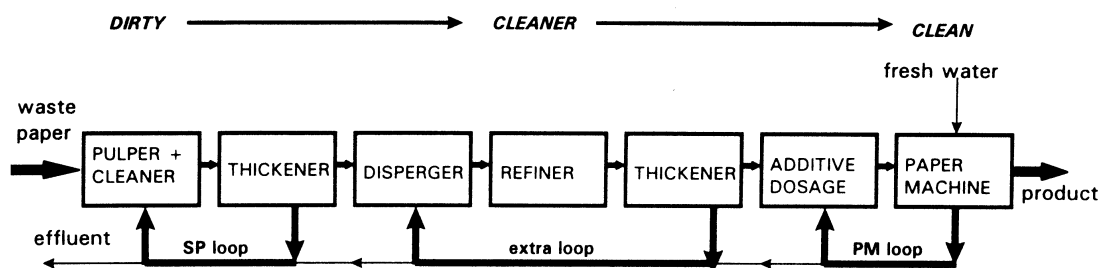


Figure 5.11: Lay out of water loops in a paper mill with separation of water loops and counter-current flows

SP = stock preparation; PM = paper machine [RIZA, 1997a]; In this example it has been calculated that the amount of COD generated in the stock preparation that enters the PM loop can be reduced by a factor of about 2 to 4

Applicability and characterisation of the measure: This process-integrated measure can be applied to both new and existing plants.

Main achieved environmental performance: Reduction of fresh water consumption, possible reduction in the discharge load of COD and no increase in concentration in the paper machine water loop thus enhancing the runnability of the process. The reduction rate depends mainly on the situation before the improvements and the wastewater system applied afterwards. The achieved environmental improvements should be considered as entity with the external effluent treatment applied. Strict separation of water loops generates good opportunities for in-line treatment, in order to remove disturbing substances (so-called kidney treatment). For further information on kidney treatment refer to 5.3.4, 5.5.4, 6.3.3 and 6.5.1.

Measures for reduction of emissions to surface water are often closely related to reduction of fresh water. Water system closure does not reduce the pollution load but generates less wastewater with increased contamination levels. As a result the efficiency of the wastewater treatment can be improved. Less wastewater has to be purified and in general concentrated wastewater flows can be treated more effectively.

By recirculating of process waters and increasing of storage capacity the waster water amounts can be reduced but not in the same extent as by collecting and separating of clean, warm cooling waters.

Advantages of lower fresh water consumption and water loop closure respectively are:

- Lower volumes to external effluent treatment i.e. the treatment plant can be built with smaller hydraulic capacities and lower investment costs. Contaminants are more concentrated in the effluent which contributes often to higher removal effectiveness
- Lower costs of raw water
- Lower losses of fibres and fillers
- Lower energy consumption
- Higher temperatures in the process water systems result in faster de-watering on the paper machine wire

The need for fresh water in a modern recovered paper preparation plant can be reduced to approximately 1 m³/tonne. Consequently only about 10 % of the total fresh water demand in a modern integrated newsprint mill based on recycled fibres (≈ 10 m³/tonne) is consumed in the recovered paper preparation plant.

However, in a tissue mill sometimes a lot of fresh water is required for efficient paper machine felt washing. In RCF based mills without de-inking no fresh water is needed in the stock preparation.

Cross-media effects: The separation of water loops by insertion of thickeners leads to considerable change in the composition of the paper machine water loop with respect to the levels of organic and inorganic substances (e.g. anionic trash). This will lead to a changed additive regime in the wet-end that, in turn will have its effect on the COD levels. In certain applications the insertion of an extra water loop may drop the temperature in the paper machine loop e.g. when the paper machine loop is separated from the disperger and refiner that act as a heating device for process water (see Figure 5.11).

Operational experience: The main principle, white water flowing backwards in the system, counter current to the product can be applied only in integrated pulp and paper/board mills. Recovered paper plants are, with very few exceptions, integrated with a paper mill. In stock preparation the cleanness of the process water is less critical than in the white water of the paper machine. Therefore, the stock preparation utilises to a very large extent excess clarified white water from the paper mill and internally clarified white water. But potential drawbacks of water system closure need to be controlled (see 6.3.2). Otherwise the build-up of suspended solids as well as dissolved organic and inorganic substances in the white water system may cause negative effects (see 5.3.3)

Economics: The costs of this measure depend on the number and nature of water circuit rearrangements necessary and the type of additional installation needed.

Driving force for implementing the technique: The driving force for recycling process water is to decrease the wastewater load from integrated RCF mills. A local driving force could be the reduction of ground water abstraction.

Example plants: Numerous plants in Europe

Literature:

[CEPI, 1997b], [J. Pöyry, 1994b], [RIZA, 1997a]

5.3.4 Closed Water Loops with In-line Biological Process Water Treatment

This technique is currently only to consider in the determination of BAT for "brown papers" manufactured from recovered papers. However, the basic principle, treatment of a part-stream of the total process by use of a combined physical and biological system are of interest for many other paper mills. The process water treatment plants can be regarded as 'kidneys' in the totally closed water circuits.

Description of the technique: A few paper mills producing wellenstoff and testliner in Europe and North America had been successful in bringing their wastewater discharges to zero and operate a so-called closed water system. However, the inevitable accumulation of dissolved and colloidal organic matter in closed water circuits creates severe problems as corrosion, unpleasant odour in the paper produced and also in the vapour exhaust of the paper machines. In order to reduce organic pollution of the process water, treatment techniques ordinarily used for end-of-pipe wastewater treatment were adapted to in-mill treatment. A part stream of the process water is treated in biological treatment plants and the purified water is reused for paper production. The main advantage of in-line treatment is that only a part of the COD load from a purge of white water needs to be eliminated to keep a given level of contaminants in the circuits. This makes the in-line wastewater treatment plant economically attractive. Currently, there are different technical options in operation. Two of them are briefly described below:

Option 1: Anaerobic treatment followed by a re-aeration step and a decarbonization plant. After removal of recoverable fibres by physical treatment a part of the total process water stream is purified in a treatment plant and reused as process water. The deconcentration loop is composed of an anaerobic treatment in a fluidised bed reactor completed with a re-aeration stage for conversion of sulfides into sulphates, and a decarbonation plant to avoid scaling of calcium carbonate in the anaerobic reactor and other parts of the water system.

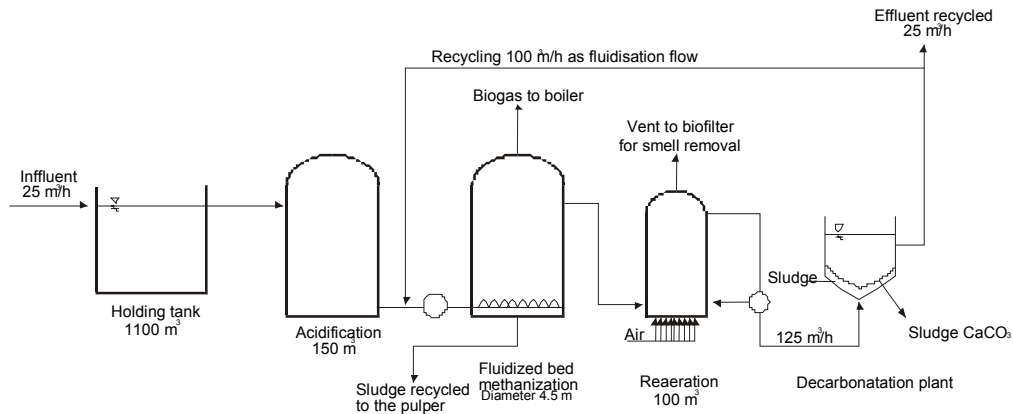


Figure 5.12: Example for an industrial in-line treatment in a zero effluent mill manufacturing corrugated medium [Niovelon, 1997]

Option 2: Anaerobic treatment combined with an activated sludge system and a sand filter.

A partial stream of the process water is cooled in order to bring the water temperature down from 55°C to 35°C.

A buffer tank/preacidification reactor is used for pre-conditioning of the water with nutrients before feeding it into the UASB reactor. This reactor is followed by aerobic treatment in two parallel aeration tanks. After passing a sedimentation tank the treated water is sent to sand filters in order to reduce the concentration of solid substance. The biogas produced in the anaerobic reactors is being scrubbed to remove the H₂S and is then used for steam generation.

A simplified scheme of the process water treatment is shown in Figure 5.13.

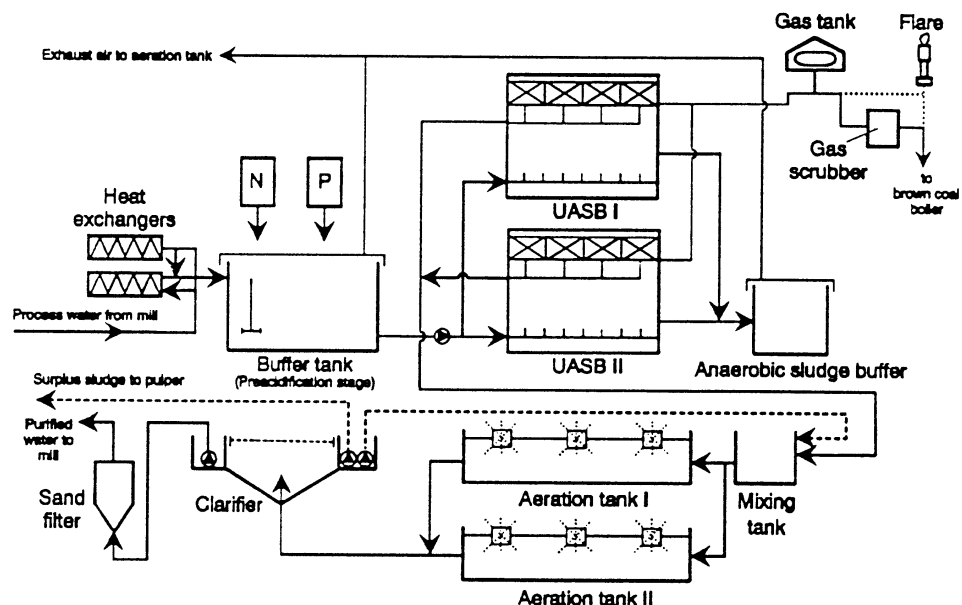


Figure 5.13: Example for in-line treatment of closed water loops, process water treatment system of Zuelpich Papier GmbH, Recycled Paper Europe [Diedrich, 1997]

By in-line treatment it is possible to achieve the desired level of COD in the circuits depending on the flow treated and the size of the plant. The zero discharge option does not imply reaching a high efficiency of pollution reduction corresponding to regulations but only acceptable concentration levels in circuits to give good characteristics to the paper products. When keeping the COD level near 7000 - 8000 mg/l in the closed water circuit, process water quality is similar to mills with a current average effluent volume amounting to about 3 to 4 m³/t.

Applicability and characterisation: Process integrated technique. Closed water loops with biological in-line process water treatment can theoretically be applied at new as well as at existing paper mills. However, there are several reasons, why this technique is not generally regarded as BAT. The main reason is the calcium carbonate precipitation in the process water circuit as well as in the anaerobic and aerobic treatment plants. The control of the calcium concentration in the white water is very complex and not completely understood. Technical solutions for this problem have still to be developed. Additionally, for application of biological in-line treatment in an existing paper mill the total water-fibre-system has to be optimised, which could take a few years or, especially in older mills, could not be performed at all. However, recycling of a part of the water after biological treatment is carried out by a limited number of paper mills in Europe producing corrugating medium.

Main achieved environmental performance: Closed water loops with in-line treatment result in zero emissions to water.

In case of a paper mill already operating an effluent-free process water system, the in-line treatment can be an efficient measure to reduce the pollution of the produced paper and the concentration of odorous compounds in the vapour exhaust of the paper machine.

A German paper mill producing wellenstoff and testliner since 1970 under completely effluent-free conditions (without in-line biological treatment) realised considerable improvements of process water quality, paper quality and emissions of organic substances by the vapour exhaust of the paper machines after start-up an in-line biological process water treatment plant in 1995.

Monitoring of emissions: In zero effluent mills no emissions to receiving waters have to be monitored.

Cross media effects: Anaerobic techniques for in-line treatment reduce the generation of excess biomass. The excess biomass can either be reused for paper production or incinerated for energy recovery. The energy demand of the in-line treatment plant (pumps, aerators, agitators) is completely covered by thermal use of the generated biogas. Compared to the totally closed water system without in-line treatment the concentration of odorous compounds in the process water (e.g. formic acids, acetic acid, propionic acid and lactic acid) can be reduced by 95 %. This results in a significant decrease of emissions of these organic substances in the vapour exhaust of the paper machine. Thus, unpleasant odours can be reduced significantly.

Operational Data: At the German paper mill that has realised option 2, the in-line process water treatment was started up in September 1995. The expected efficiency of the biological treatment was achieved within a few weeks. Since this time the plant has been operating without any significant troubles. Nevertheless, problems caused by precipitation of calcium carbonate in pipes and in the aeration basin have to be solved in future. Measures to reduce calcium carbonate precipitation are still under development.

The hydraulic reliability of the circuit closure involves introducing continuously only 50% of the water flow that is evaporated in the drying section of the paper machine (about 1 m³/t) i.e. internal modification of the circuits have to be applied to decrease water consumption.

The French in-line treatment plant with decarbonisation (option 1) achieved its proposed operating conditions not before March 1997. The process water circuit is completely closed. The runnability of the paper machine and the quality of produced paper are reported not to be affected adversely.

Economics: Anaerobic installations require smaller and less expensive installations than aerobic treatment with lower operating costs and an energy saving through the production of methane. For option 1 an investment cost of 15 million FRF has been reported (including holding tank, acidification tank, anaerobic reactor, re-aeration unit with biological filter). Decarbonation needed additional investments of 3 million FRF [1].

For a German in-line treatment plant that has realised option 2 investment costs of 6 MEuros has been reported (1 MEuros of which were subsidies). The annual total operation costs covering chemicals, disposal of separated sulphur, staff and maintenance amounts to 165000 Euros. Net energy savings of 13000 Euro/a are included. Assuming a paper production of 360000 tonnes/a and an amount of treated process water of 1000000 m³/a, specific operation costs of 0.5 Euros/tonne paper and 0.2 Euros/m³ process water are calculated. The specific costs including capital costs and operation cost total 1.8 Euros/tonne paper and 0.7 Euros/m³ process water respectively [2].

Driving forces for implementing this technique: Paper mills producing wellenstoff and testliner sometimes are located at rivers used for drinking water supply or on small water courses which are susceptible to unacceptable levels of pollution at times of low flow. To guarantee an acceptable quality of the river water, local authorities set stringent discharge standards based on water quality targets defined for the river. In some cases paper mills cannot fulfil these discharge standards with end-of-pipe treatment of wastewater. Therefore, they have to close the water circuit completely. However, the closure of the water circuit has negative effects on paper quality and vapour exhaust of paper machines. To avoid an increase of salt content, water hardness and concentration of odorous volatile fatty acids, the biological in-line treatment of process water can be a suitable measure. Nevertheless, further research is necessary to solve the problem of calcium carbonate precipitation and some other side-problems.

Example Plants: Assi Domaen Packaging Lecoursonnois Paper Mill, Mennecey/France; Zülpich Papier-Recycled Paper Europe, Zülpich/Germany; Tillmann, Germany

Literature:

[Nivelon, 1997], [UBA-Report 7041, 1996], [Diedrich, 1997]

5.3.5 Anaerobic Techniques as First Stage of Biological Wastewater Treatment

This technique has to be considered in the determination of BAT mainly for "brown papers" manufactured from recovered papers. However, anaerobic or combined anaerobic/aerobic wastewater treatment can theoretically also be applied for de-inked grades because the applicability depends mainly on the COD content of the wastewater. But practical experiences are very limited for deinked grades.

Description of the technique: The extensive closure of water circuits in paper mills processing recycled paper causes high concentrations of dissolved organic substances in the process water. Therefore, before being released into receiving waters, the process waters have to be purified by biological treatment. With the combination of anaerobic and aerobic biological treatment, a significant reduction of the organic load of the wastewater can be achieved. A simplified scheme of a combined anaerobic/aerobic wastewater treatment plant is shown in Figure 5.14.

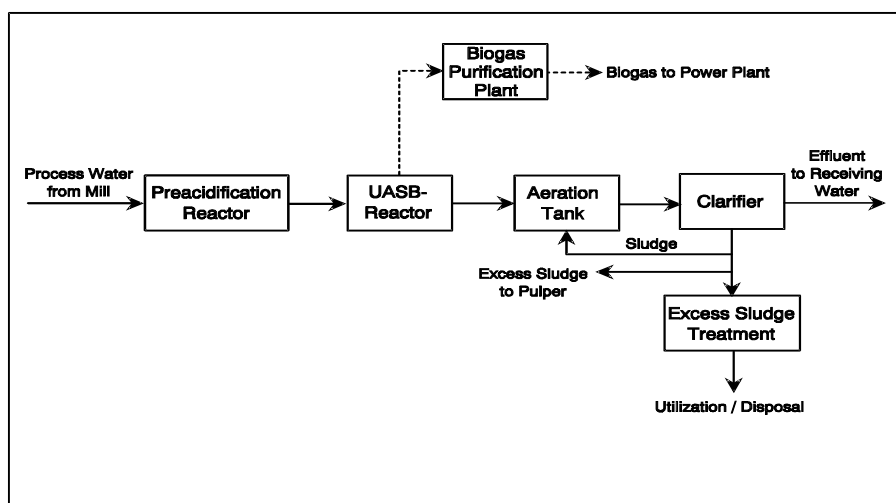


Figure 5.14: Simplified scheme of a combined anaerobic/aerobic wastewater treatment plant [IFP, 1998]

As anaerobic reactors the following systems can be used:

- contact reactor
- UASB-reactor (Upflow Anaerobic Sludge Blanket)
- fixed-bed reactor
- fluidised bed reactor.

The main purpose of the different reactor concepts is to ensure a high concentration of biomass within the reactors. This is achieved either by recycling washed out biomass after settling in an external separator (contact reactor system) or by attaching the biomass to a supporting media within the reactor (fixed-bed reactor, fluidised bed reactor, UASB-reactor). The reactors can be operated as single units or as modular combined units. Reactor systems, which are operating with biomass supporting media, are especially suitable for high COD-loads. Biogas, mainly a mixture of methane and carbon dioxide, which is produced by the anaerobic degradation of process water pollutants, can be used as an energy source after desulphurization. Compared to aerobic wastewater treatment, much less biomass is produced during the anaerobic degradation process.

However, anaerobic treated wastewater does not comply with requirements for final COD and BOD concentration of the treated effluent. Therefore, anaerobic treatment normally is not used as a stand-alone treatment. The effluents of anaerobic systems are always post-treated by an aerobic biological stage.

For an economic application of anaerobic techniques as a first stage of biological wastewater treatment, the COD-load of the process water should not be less than 2000 mg/l. Paper mills producing „brown grades“ at a low level of fresh water consumption are easily reaching this level. Paper mills manufacturing de-inked grades can also reach this level before any treatment. Nevertheless, examples of anaerobic/aerobic wastewater treatment for de-inked grades are very few [Driessen]. The anaerobic degradation process could be disturbed by dissolved sulphate, when the concentration exceeds 1000 mg/l, because during the anaerobic process sulphate is transformed into hydrogen sulphide (H₂S) which is toxic to anaerobic microorganisms. Normally, a toxic level will not be reached.

Application and characterisation: When an anaerobic stage is added before aerobic treatment in an existing plant, the necessary capacity of aerobic treatment facilities can be reduced. In principle, there are no problems to expand an already existing aerobic treatment plant by an

anaerobic pre-stage when the process water composition, the COD-load and the sulphate content are suitable for anaerobic treatment. The retrofitting of an anaerobic pre-treatment stage is a convenient measure when the aerobic stage has reached its maximum capacity and is probably overloaded.

Combined anaerobic/aerobic wastewater treatment plants must first of all be regarded as end-of-pipe techniques. However, considering the efforts to control the application of chemical additives (e.g. cleaning agents, defoamers, slimicides) to papermaking system in order to protect the sensitive anaerobic microorganisms in the treatment plant, the biological treatment can also be (partly) regarded as a process integrated environmental protection measure.

Some paper mills are performing trials to recycle a part-stream of the biologically treated process water back into the water circuit. The main problems they still have to face are the accumulation of chlorides, sulphates and calcium in the process water, causing corrosion and calcium carbonate precipitation and scaling on pipes, wires and felts. The precipitation of calcium carbonate is a complex problem, which needs further research work in the future.

Main achieved environmental performance: Treatment efficiencies in anaerobic reactors depend on plant design and operating conditions. Typical efficiencies are within the range of 60 – 85 % for COD removal and 85 - 95 % for BOD removal. The total efficiency of combinations of anaerobic and aerobic techniques is in the range of 95 – 97 % for COD-removal and 99.0 – 99.8 % for BOD-removal. The organic load in the effluent is reduced to 0.5 – 1.5 kg COD/tonne paper produced and to 0.02 – 0.1 kg BOD/tonne paper produced, respectively.

A German 100% RCF based paper mill (without de-inking) reported an improvement in treatment efficiency by use of combined anaerobic-aerobic treatment compared to a two-stage aerobic treatment. As yearly average values the following values have been achieved:

Parameter	Unit	2-stage aerobic treatment	Anaerobic/aerobic treatment
COD concentration	mg/l	290	190
BOD ₅ - concentration	mg/l	21	12
COD-load	kg/t	0.93	0.68

Table 5.22: Yearly average values of treated effluent of a German 100% RCF based paper and board mill without de-inking

In combined anaerobic/aerobic treatment plants the energy demand related to 1 tonne COD removed (mainly used for pumping and aeration) is about 200 - 300 kWh, whereas in stand-alone and well-designed aerobic plants the energy demand for 1 tonne COD removed amounts to 500 - 600 kWh.

The volume of biogas produced during anaerobic degradation ranges from 400 to 600 m³/tonne COD removed. The methane content varies in the range of 65 – 75 %. Since the calorific value of methane is 35.7 MJ/m³, the energy resulting from the thermal utilisation of biogas in a CHP power plant is in the range of 1900 – 2900 kWh/tonne COD removed, assuming an efficiency of the power plant of 75 %. Energetic utilisation of biogas not only covers the total energy demand of the anaerobic/aerobic treatment plant. A part of the produced energy (about 70 - 80%) can be used for the paper production process.

Monitoring of emissions: The main parameter used to control the performance of anaerobic and aerobic wastewater treatment techniques is the COD, which is mostly analysed on a daily basis. For anaerobic systems the biogas production rate, continuously measured by a gas meter,

is another important control parameter, as well as the continuous measurement of CO₂-, CH₄-, and H₂S-contents of biogas.

Cross media effects: Anaerobic pre-treatment contributes to a significant reduction of the excess sludge production. Compared to stand-alone aerobic treatment of wastewater, in a combined anaerobic/aerobic treatment plant the biomass production is reduced by 70 to 80 %. External depositing of the sludge can be avoided by returning the excess-sludge into the paper production process. However, returning excess sludge into the paper is only applicable in specific cases. The proportion of sludge on the raw materials input is less than 1 %. After desulphurization, the produced biogas can be used as fuel in in-mill power plants, substituting fossil fuels.

Operational data: Combined anaerobic/aerobic treatment plants have been operated since 1990/91. Compared to stand-alone aerobic treatment plants, they have proved themselves to be more stable systems with respect to changing COD-loads and toxic or inhibiting substances in the process water. The availability of the plants is close to 100 %.

Suspended solids in concentrations above 200 mg/l could cause problems in anaerobic systems, especially in fixed-bed reactors. In some UASB-reactors a slow disintegration of the biomass pellets was observed. In this case, the biomass can be replaced by new pellets from other UASB-reactors in order to keep the reactor in effective operation. The anaerobic pre-treatment considerably reduces the tendency for developing bulky sludge in the following aerobic stage. Excess sludge produced in the aerobic stage can be recycled to the paper production process without causing any problem.

Economics: The investment costs for combined anaerobic/aerobic wastewater treatment plants vary in a wide range depending on the specific COD load and the volume of wastewater. Assuming COD loads of 20 to 35 tonne/d, which correspond to an annual production of wellenstoff and testliner of 200000 to 350000 tonne, the investment costs are in the range of 7 to 12 MEuros.

Taking into account the net energy savings by use of the produced biogas as fuel, the annual operating costs including chemicals and operating materials, waste disposal, staff and maintenance are in the range of 0.6 – 1.0 Euros/tonne paper produced.

Driving forces for implementing this technique: The most important reason to install combined anaerobic/aerobic systems for the biological treatment of process water was the improved stability with regard to fluctuations of COD-loading compared to a stand-alone aerobic treatment plant. Another incentive was the production of biogas and its use as fuel in power plants. Energetic use of biogas not only covers the energy demand of the anaerobic/aerobic treatment plant. There is an energy surplus, which can be used in the production process. Finally, the considerably smaller volume of excess sludge produced has to be regarded. By using combined anaerobic/aerobic techniques instead of a one-stage or two-stage aerobic technique, the sludge production is reduced by 70 – 80 %. This fact is of special interest for paper mills which do not have their own facilities for energetic utilisation of excess sludge and do not recycle sludge into the production process, and therefore have to provide for expensive external disposal.

Example Plants: Numerous anaerobic plants are operated as the first stage of wastewater treatment in European paper mills producing testliner and wellenstoff. Approximately 12 plants are installed e.g. in Germany of which 9 are based on the UASB-system, two on fixed-bed reactors and one is equipped with a contact reactor.

Literature:

[Koepp-Bank, 1991], [Hamm, 1991], [Driessen], [IFP, 1998]

5.3.6 Aerobic biological treatment

Refer also to 6.3.9

Description of the technique: Aerobic biological treatment for effluents from recovered paper mills has been used for over 20 years to remove oxygen consuming organic substances and specific organic compounds. These substances are converted by different variants of biological treatment systems into biomass, carbon dioxide and water. Low loaded aerobic activated sludge systems are widely used. The nutrient content in wastewater of recovered paper mills is generally low. Therefore, to ensure efficient operation of the biological system phosphorus and nitrogen controlled addition is necessary. In order to control eutrophication problems, overdosing of nutrients and unnecessary emissions of nutrients should be prevented.

Applicability and characterisation: Applicable to both new and existing mills.

Main achieved environmental performance: Achievable removal efficiency is in the range of 95-99% for BOD₅ and 75 - 90% for COD. Achievable effluent data by low rate activated sludge treatment are summarised in Table 5.23.

Parameter	Achievable concentrations and loads for de-inking recovered fibre mills		Typical removal efficiency [%]
	mg/l	kg/t	
BOD ₅ after treatment	< 20 (down to 5)	0.21	95 - 99
COD after treatment	< 230	2.3	80 - 85
TSS	< 30	0.2	99
Discharge volume	11 m ³ /t		

Table 5.23: Low loaded activated sludge performance data in paper and board production from recovered fibres

[Dutch notes on BAT, 1996] and measured effluent values from German recovered fibre paper mills with de-inking]

Removal efficiencies by use of combined anaerobic/aerobic biological treatment are usually slightly higher (see 5.3.5). The overall treatment efficiency is over 99% for BOD₅ removal and over 95% for COD removal. But up to now, the application of anaerobic treatment is mainly limited to recovered paper mills without de-inking. In the Netherlands, the wastewater of three RCF processing paper mills is treated simultaneously by an anaerobic/aerobic treatment system. One of these mills is a de-inking plant. However, there are some promising trials on laboratory scale to apply combined anaerobic/aerobic biological treatment to de-inking plants, too.

Recycling of a part of the water after biological treatment seems to be possible. At least one newsprint mill using 100% recovered paper as raw materials is using about 10% of the treated effluent (activated sludge + sand filter) in the paper mill without any problems.

Monitoring of emissions: Usually the main effluent parameters are measured daily or at least a few times a week. Additional measurements to control the activated sludge system are necessary as e.g. O₂-content, SVI (Sludge Volume Index), water flow, and analyses of the biomass.

Cross media effects: During aerobic wastewater treatment excess sludge is produced which has to be thickened, de-watered and further treated. A typical value for activated sludge plants is in the range of 0.6 kg excess sludge/kg BOD₅ eliminated (as dry solids) generated during treatment. Thus, depending on the quality of recovered paper and on the process design about 10 kg excess sludge from biological treatment per tonne of paper (on a dry basis) may be expected. For aeration of the active biomass (activated sludge) and for pumps electrical energy is needed.

The specific consumption of energy for degradation/elimination of 1 kg BOD₅ amount to 0.6 - 3 kWh/kg BOD₅ eliminated. If the system is well-designed a value of < 1 kWh/kg BOD₅ eliminated can be achieved [Möbius, 1997]. This value can also be used to compare expected operating costs of different wastewater systems.

Especially during the summer period, the wastewater treatment plant of RCF paper mills may emit annoying odours. If the wastewater treatment is well designed and controlled annoying odours can be avoided.

Operational experiences: Aerobic biological treatment for effluents from recovered paper mills has been successfully used for over 20 years. The phenomenon of bulking sludge has to be controlled.

Economics: Data on costs are only available for an integrated paper mill manufacturing paper based on mechanical pulp. The wastewater treatment system is comparable to the one applied for the treatment of effluent from recovered paper processing. Therefore, the figures on costs

can give a rough picture in which range the cost might be expected. The investment costs for a completely new activated sludge treatment plant are approximately 13.0-15.5 MEuros for a new 1000 Adt/d integrated mechanical pulp and paper mill. These costs include also the necessary primary treatment and sludge handling. The corresponding operating costs are 1.2-1.5 MEuros/a.

Driving force for implementing this technique: Many Member States have set requirements for effluents from paper mills which consider biological treatment generally as BAT on a sector level. As a consequence, most paper mills based on recovered fibres had to build activated sludge systems or other treatment systems with comparable efficiencies.

Example plants: Numerous aerobic wastewater treatment plants are operated in European paper mills producing paper based on de-inked recovered fibres.

Literature:

[Dutch notes on BAT, 1996], [Möbius, 1997b], [CEPI, 1997b]

5.3.7 Upgrading of stock preparation plants with decreased electricity consumption and emissions

The following description applies mainly for recovered paper mills *without* de-inking as e.g. paper mills producing case making material (testliner, wellenstoff). However the basic principles are valid for all recovered paper processing mills. De-inking mills might have additional options in the de-inking process units.

Description of the Technique: There might be different aims for upgrading of stock preparation plant concepts. They depend on the priorities set by a given company such as better removal of smaller impurities and contaminants to improve product quality and efficiency of the paper machine, enhanced recovery of fibres from rejects thus reducing the fibre losses, or energy savings. Another aim can be simplification of the stock preparation system resulting in less energy consumption, less material losses, and less space needed. In order to simplify the stock preparation, especially for brown grades the possibilities for removal of energy consuming dispersion and traditional cleaning stages are discussed. In contrast, extended process concepts with a higher number of process stages might be used to manufacture paper for special purposes or to meet the customers needs (high-quality products).

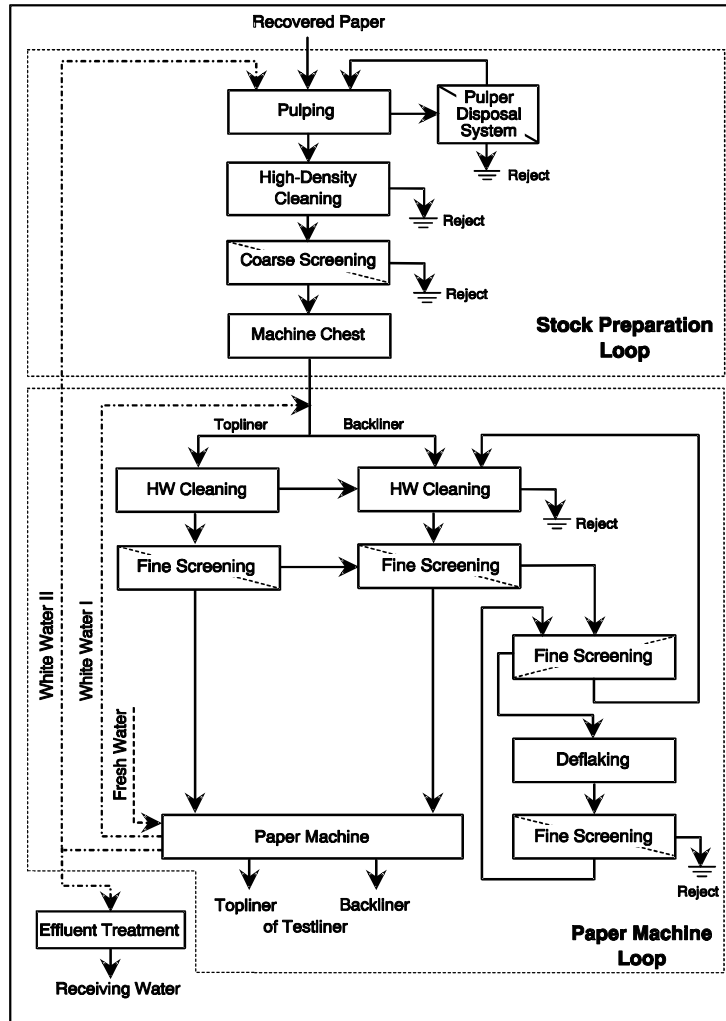
The processing of recovered paper targets first of all the removal of non-fibre components (e.g. plastics, metal, wood, sand) and the elimination of detrimental substances such as stickies, wax or small pieces of undisintegrated paper (flakes) of wet-strength paper. The second goal of pulp processing is the treatment of the fibres themselves to control the quality of the paper to be produced. To achieve this aim, fibres can be fractionated into long-fibre and short-fibre fractions and further treated. For example, low intensity refining improves the bonding ability of the recycled fibres, resulting in increased strength characteristics of the paper produced, and dispersing improves the optical homogeneity of the paper.

For each specific treatment of recycled pulp, special machines are used in various ways. Thus, the screening and cleaning processes must operate in two to four stages in order to reduce the fibre losses in the final stage of each process. To realise an adequate runnability of the paper machine it is also essential to operate additional cleaners and screens in the stock approach flow system. This prevents that deposits released from chest walls or from pipes enter the headbox and the wet-end of the paper machine. These deposits would lead to web breaks and downtime of the machine.

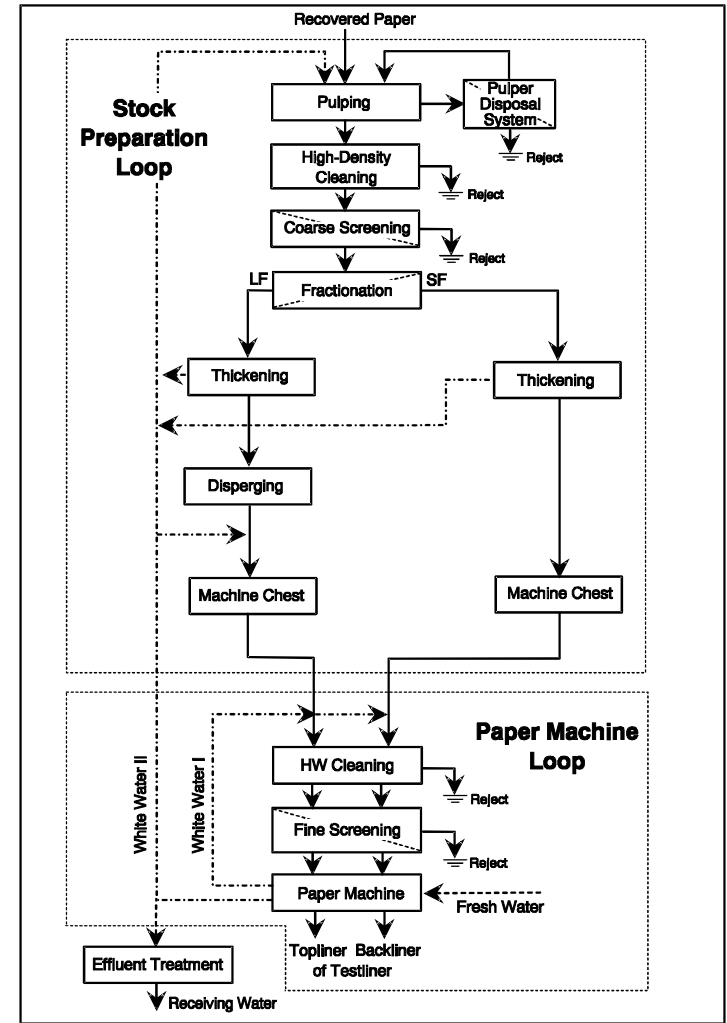
A balance between cleanliness of stock, fibre losses, energy requirements and costs have to be found and are to certain extent depending on the paper quality produced.

In the following some of the different technical options for stock preparation plant concepts are highlighted including their major advantages and drawbacks. Implications for the electricity demand are indicated.

Figure 5.15 shows four examples for stock preparation plant concepts for processing recovered paper for 2-ply testliner. This paper grade is used as an example because of its high importance in tonnage for paper and board mills in Europe and because information was easily available. Table 5.24 compiles for these four options the major characteristics, summarises the electricity demand, and gives some explanations concerning the layout of the stock preparation plant. The figures for electricity demand for the four different systems result from the values for specific energy demand for single process units as compiled in Table 5.25 further below. They should be considered as a realistic approximation. Real mills might have slightly lower or higher values.

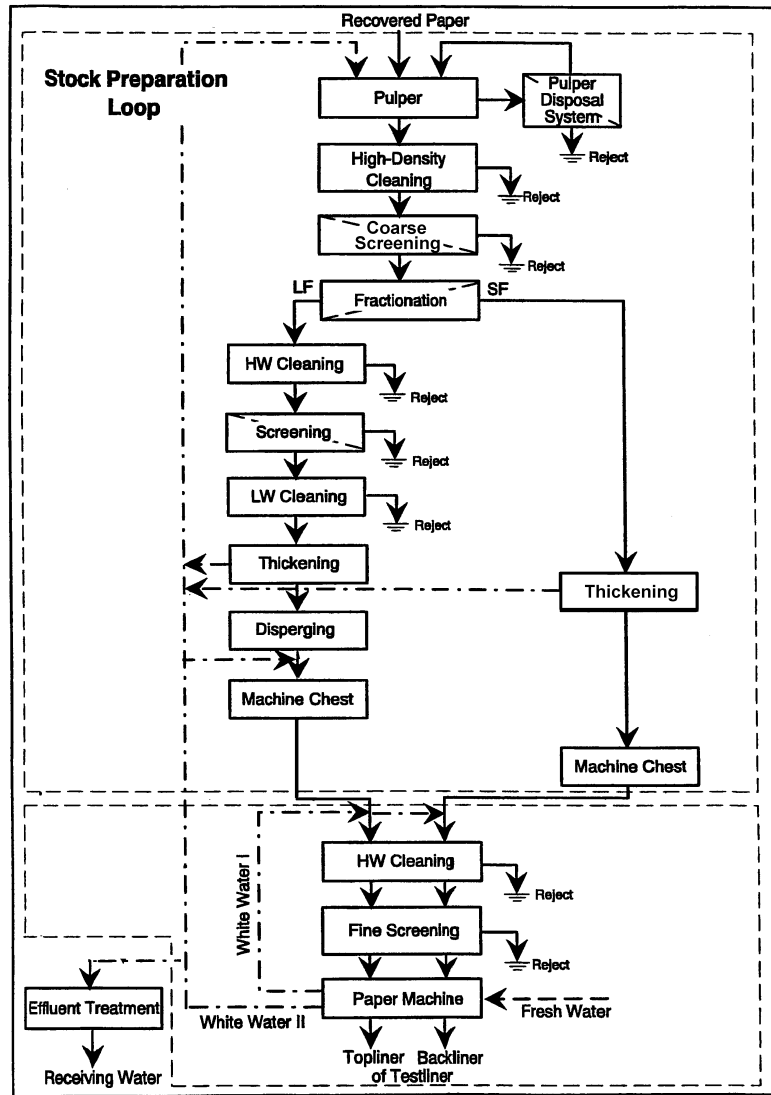


Example 1

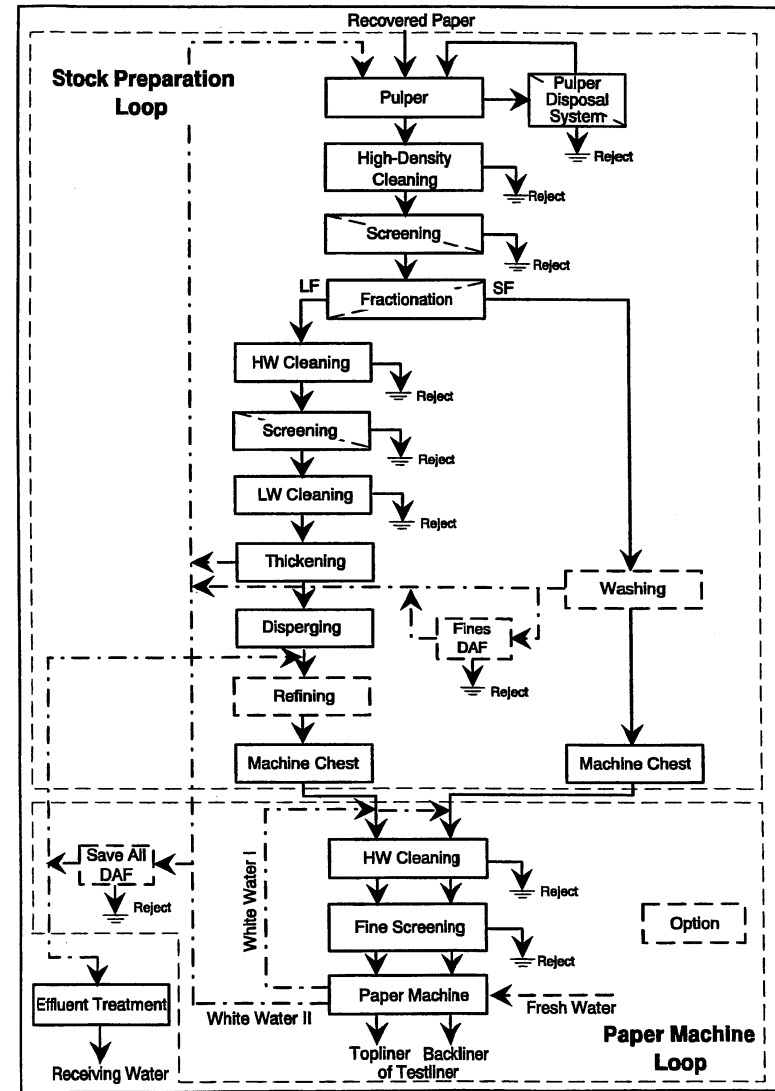


Example 2

Figure 5.15: Four examples for stock preparation plant concepts for processing recovered paper for 2-ply testliner [IFP, 1998]



Example 3



Example 4

Figure 5.15 (cont.): Four examples for stock preparation plant concepts for processing recovered paper for 2-ply testliner [IFP, 1998]

	Major features of the different stock preparation plant concepts	Electric. demand Range (Average)	Explanatory notes
Example 1	Minimised cleaning and screening in the stock preparation plant without fractionation and without further fibre treatment like dispersion and additional cleaning and screening. The stock approach flow system is extended in respect to screening and cleaning in order to achieve sufficient clean recovered pulp	45 - 95 (70) kWh/t	Pulp is split without fractionation and fed into two separate lines for separate cleaning and screening in both lines with different slot widths. The rejects of the topline are introduced into the backliner for further treatment. In the backliner a deflaking process is established to disintegrate fibre flakes into individual fibres for the benefit of final screening efficiency and a reduced amount of rejects
Example 2	Comprises fractionation and dispersion, after fractionation screening, light- and heavy-weight cleaning of the long-fibre fraction is not applied; compromise between minimised energy demand by reduced machinery equipment installations and the requirements of the final product quality	65 - 175 (110) kWh/t	Fractionation is carried out in order to save power of the following energy-intensive dispersing by treating only a part-stream of the recovered pulp (long-fibre fraction). Leaving out screening, light- and heavy-weight cleaning of the long-fibre fraction after fractionation saves energy
Example 3	Additionally to example 2, screening as well as light- and heavy-weight cleaning of the long-fibre fraction after fractionation is applied	75 - 175 (120) kWh/t	Dispersers have to be fed with high consistency pulp (22-32% dryness). Previously, dewatering (thickening) by means of e.g. disc filter, belt press or screw press is necessary
Example 4	Fractionation is extended by additional screening and cleaning (HW and LW), optional refining of the long-fibre fraction, washing of the short-fibre fraction and by two dissolved air floatations (DAF)* in the process water recirculation	110 - 270 (190) kWh/t (with all options)	Washing in combination with a part-stream removal of fines and fillers by a DAF system control the fines and filler content in the paper, resulting in increased strength characteristics of the paper produced. Refining can be performed to improve the bonding ability of the recycled fibres
Explanatory note: * Process water cleaning by DAF of a part-stream treatment of the wash filtrate of the short fibre fraction as well as of paper machine white water II controls the removal of solids (fines and fillers) and to some extent of colloidal substances. The removal of colloidal substances controls the organic white water load (in terms of COD and BOD). More important is the control of fines and fillers in the process water for the benefit of the strength characteristics of the paper produced. Both measures improve the paper quality and the paper machine runnability			

Table 5.24: Major characteristics and electricity demand of different stock preparation plant concepts for processing recovered paper for 2-ply testliner
Some explanatory notes are given where considered helpful [Data derived from IFP, 1998]

Applicability and characterisation: Process-integrated measure. Rebuilds of stock preparation plants as well as of the stock approach flow system can be usually realised in existing mills. A "standard" stock preparation plant typically uses more machines than are required for this "minimised" stock preparation plant system (example 1). To adapt a "standard" system to a "minimised" concept, the shut down of only a part of the equipment is necessary and probably some new pipes and pumps for the connection to the machine chest are required. The stock approach flow system has to be extended. Existing screens from the stock approach flow system or from the stock preparation plant are usually not sufficient, due to the limited capacity when screen baskets with a narrow slot width of 0.15 mm are installed. Therefore, investments of advanced pressurised screens for the approach flow system would be necessary.

Main Achieved environmental performance: The electricity demand for stock preparation and stock approach flow system is between 20 and 40 % of the total power demand of a recovered paper processing mill without de-inking. Therefore, optimisation of the stock preparation plant with respect to savings of electricity is worth considering. Reduced electricity consumption results in reduced air-borne emissions, which depends further on the type of fossil fuel used.

The environmental advantage of the concept 'example 1' is related to savings of electricity for the stock preparation and the stock approach flow system. A system installed in a German paper mill operates with an electrical power demand of 60 kWh/tonne paper produced. For comparison: the mean value of the electricity demand given in the Table 5.25 below results in a power demand between 45 kWh/tonne and 95 kWh/tonne (average 70 kWh/tonne) paper for the system shown as example 1.

In comparison to a concept where screening as well as light- and heavy-weight cleaning of the long-fibre fraction after fractionation is applied (example 3) the energy demand of example 2 is reduced by 10 % to 20 % (65 kWh/tonne – 160 kWh/tonne).

The main positive effect on the environment achieved by "extended" stock preparation plant concepts as example 4 is related to high paper machine efficiency resulting from a very clean pulp with improved strength characteristics.

The electricity demand given in Table 5.24 above results from figures for specific energy demand of unit processes given in Table 5.25 below. As can be seen, the differences in electricity demand between the four options are significant: example 4 (with all options) requires between 110 kWh/tonne and 270 kWh/tonne compared to 65 kWh/tonne and 160 kWh/t consumed by example 2.

However, it has to be born in mind that improved efficiency of the paper machine that is achieved by cleaner pulp results in lower specific electricity and steam demands for paper production, because during breaks the paper machine still uses electricity and steam. In contrast, technologies that are connected with the need for more frequent system washing (downtime) decrease energy efficiency and increase emissions.

Unit Process	Specif. Energy Demand kWh/tonne	Operating Consistency %
Pulping	10 – 20	3 – 6
Deflaking	20 – 60	3 – 6
Screening	5 – 20	0.5 – 4.0
Tail Screening	20 – 40	1 – 4
Centrifugal Cleaning	4 – 8	<0.5 ⇒ 4.5 (<6.0)
Fractionation	5 – 20	3 – 4
Thickening	1 – 10	0.5 ⇒ 5 (10)
Dewatering (Screw Press)	10 – 15	2 – 5 ⇒ 15 – 50
Dewatering (Double Wire Press)	2 – 4	2 – 5 ⇒ 15 – 50
Disperging	30 – 80	22 – 32
Low-Consistency Refining	5 – 25 (per SR* unit)	3.0 – 5.5
High-Consistency Refining	10 – 60 (per SR* unit)	25 – 35
Washing	5 – 20	0.7 – 1.4 ⇒ 5 – 12
Dissolved Air Flotation (DAF)	10 – 20	<0.3 ⇒ 0.01
Storing	0.02 – 0.1	3.0 – 5.5 (12)
Mixing	0.2 – 0.5	3.5 – 4.5
Notes: ⇒ = change of consistency range between inlet and outlet of the equipment concerned *SR = Schopper-Riegler freeness		

Table 5.25: Specific energy demand and operating consistencies for unit processes in the production of Wellenstoff and Testliner [IFP, 1998; data according to a machinery supplier]; data refer to 100% efficiency]

Cross media effects: Paper machines running with increased efficiency have lower electricity and steam demands per tonne of paper. The improved recycled fibre quality results in an improved paper quality.

The rejects from different process stages can be collected separately and used for different purposes. For example, rejects containing high amounts of plastics can be incinerated with the benefit of considerable energy recovery, due to their high heat values. Rejects with high amounts of organic fibre material can be used for composting. The rejects of the high-density cleaner as well as of the pulper disposal system usually are disposed of by landfilling because of their high content of inorganic material (e.g. stones, sands, staples, clips, etc.)

Operational data: World wide a large number of mills are producing testliner with fractionation and dispersion. Sometimes refining is also included in the stock preparation plant. Nevertheless, no exactly identical systems appear to exist.

Example 1 as shown in Figure 5.15 can be regarded as a "minimised" stock preparation plant concept. It is running in one mill producing testliner and wellenstoff (Zülpich Papier – Recycled Paper Europe, Germany). With respect to the achievable paper machine efficiency and local limitations this stock preparation plant concept has to be regarded as an experiment. Because of limited time of experience it is not yet possible to evaluate the success of this energy saving concept. The system seems to result in slightly increased losses of fibres.

Screening in a conventional stock approach flow system has predominantly an insurance against accidental contamination with low demands for maintenance. The maintenance required in the conventional stock preparation does not necessarily contribute to a paper machine shut down because of the pulp storage capacity in available chests. In contrast, if finely slotted screen baskets (with a slot width of 0.15 mm) are applied in the approach flow system in order to achieve sufficient clean recovered pulp (as in example 1) those screens require more extensive maintenance for cleaning. This results in a shut down of the paper machine and lost production. Therefore, the paper machine efficiency with the "minimised" stock preparation is normally poorer than that with a well equipped "standard" stock preparation plant.

Economics: The investment and the operation costs of example 2 are lower compared to the example 3 and 4 and higher compared to the example 1 shown in Figure 5.15. However, increase of costs for the operation of the stock preparation plant has always to be evaluated in the light of improved paper machine efficiency. A lower number of shut downs and web breaks as well as improved paper quality is also important factors.

Besides the higher investment costs for the equipment of "extended" stock preparation concepts (example 4), increasing operation costs in terms of the electricity demand for stock preparation have to be expected.

"Minimised" stock preparation concepts (as in example 1) require relatively low investment costs. Low electricity reduces operation costs also.

Driving forces for implementing this technique: The principal driving force for implementing stock preparation plant concepts with a higher number of process stages is the high quality requirements of the paper to be matched, which has to compete on the market with paper manufactured from virgin fibre. A further incentive is that paper machine runnability should be improved. The driving forces to implement stock preparation plant concepts with "minimised" process stages are lower investment and operation costs mainly savings of electrical power as a result of the fewer machines required.

Example plants: Several mills in Europe are equipped with a stock preparation system similar to example 2 including fractionation and dispersion. However, the equipment installed and the number of process stages varies and no exactly identical system appears to exist. Some mills also have implemented a dissolved air flotation for process water treatment. The combination with washing as shown in example 4 has not been realised for testliner production so far.

Literature

[IFP, 1998]: This report contains many other references.

5.3.8 Generation of clarified water from recovered paper processing with de-inking

Description of the technique: Recycling of larger amounts of white water in recovered paper plant with de-inking is only possible if there is a system for clarification of white water. The systems for water clarification used almost exclusively in the paper industry are based on sedimentation, filtration (disc filter) and flotation. Best available technique at the present time is dissolved air flotation. Anionic trash and fine are agglomerated into physically treatable flocs by using additives. High-molecular, water-soluble polymers or inorganic electrolytes are used as flocculants. The generated agglomerates (flocs) are then floated off in the clarification basin. In Dissolved Air Flotation (DAF) the suspended solid material is attached to air bubbles. These bubbles transport the material to the surface of a circular or rectangular basin where it is scraped off and fed back to the stock preparation. The clarified white water is taken out from the bottom (see Figure 5.16 below).

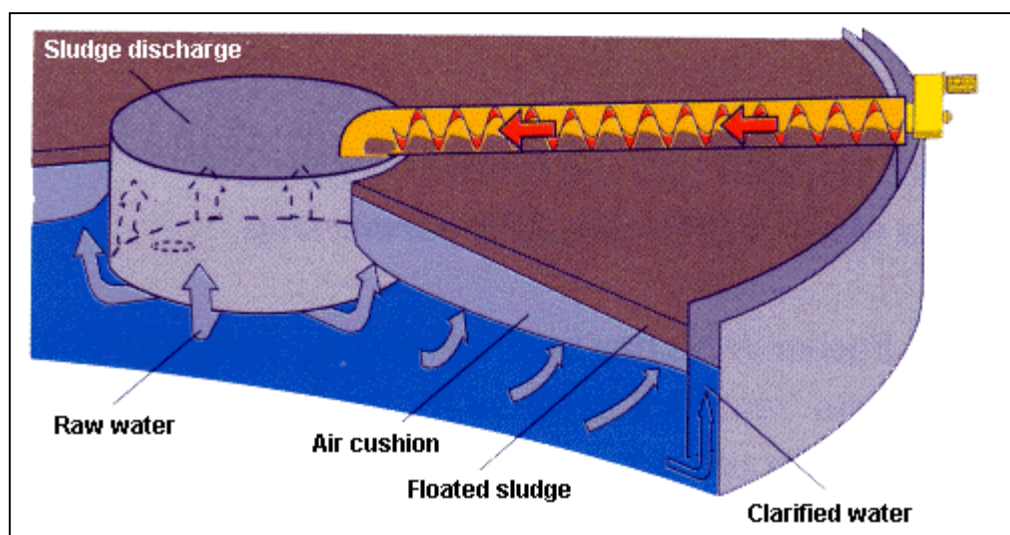


Figure 5.16: Operating principle of a dissolved air flotation (DAF)
[M.Schwarz, 1995]

In a flotation system with a circular basin, the air bubbles are generated by mixing air into the circulation water at high pressure. When the pressure is reduced at the inlet of the basin, microscopic air bubbles are formed. The size of the bubbles is critical. Flocculation agents are usually added to the white water ahead of the flotation to improve separation.

The advantage of flotation is that small-size colloidal material also can be removed. This is a great advantage in the recovered paper plants with deinking, where a large part of the solid material in the process water is colloid. In deinking systems flotation is today the only way to purify the process water for recycling. In a deinking plant the material is pumped to the sludge de-watering instead of being recycled in the process as in paper mills using virgin fibres.

The flotation systems generally give very pure water, but the efficiency is dependent on several factors, which have to be monitored, and controlled as e.g. pH, volume flow, air bubble size and consistency flow. However, at optimum conditions the efficiency is very high. Another

advantage of flotation is that the saturation of air (oxygen) in the process water prevents the forming of anaerobic bacteria.

Applicability and characterisation of the measure: Process-integrated technique. Upgrading of water clarification system is often combined with rearrangements of water loop systems. It can be adopted in new and existing recycled fibre mills.

Main achieved environmental performance: The advantage of dissolved air flotation is that small size colloidal material can be removed. This is a great advantage in the recovered paper plants with de-inking, where large parts of the solid material in the process water is colloid. By use of DAF at the suitable position in the water loops the degree of water loop closure can be continuously adjusted to the requirement of the process water quality depending on the concentration of anionic trash, additives consumption and product quality requirements.

Cross-media effect: Chemicals are needed as flocculants. Electricity is required mainly as pumping energy to saturate part of the untreated water, or a corresponding amount of clarified water, with air after raising the pressure to 7 bar. Floated sludge is generated which have to be de-watered.

Operational experience: Dissolved air flotation systems are mature concepts. All components can be combined on a modular basis for optimal results for different applications.

Economics: No data available.

Driving force for implementing the technique: The driving force for upgrading the water clarification systems with dissolved air flotation in de-inking plants is that it allows optimal water management and adjustment of water loop closure as required (see Figure 5.3 and Figure 5.4).

Example plants: Numerous plants in Europe

Literature:

[CEPI, 1997b], [J. Pöyry, 1994b], [Schwarz, 1995]

5.3.9 Cogeneration of Heat and Power (CHP)

Description of the Technique: Paper industry is a high energy consuming industry. Increased speed of paper machines, more sophisticated recovered paper processing systems, and technological development in general have resulted in higher consumption of electricity in paper mills whereas the specific use of steam remained virtually unchanged.

The energy losses from power generation and from heat production can be reduced by combined generation of both, heat and power (CHP, also called cogeneration). Cogeneration plants raise the conversion efficiency of fuel use from around one-third in conventional power stations to around 80% (or more). Thus, for many paper mills it is possible to increase the overall energy efficiency of the process by making use of the cogeneration thus reducing fuel consumption and air emissions. The energy requirement and the heat-power ratio in the paper and board industry is very appropriate for the use of CHP [Pröger, 1996]. The characteristics of the processes as high and balanced electricity and heat needs, and regularity of operation over the year are also favourable.

Many paper mills have installed different kinds of cogeneration processes. For instance, for boiler houses fired with gas one or several gas turbines prior to the existing supplementary fired steam generator can be installed to reach a higher output of electricity from the plant. If a steam

turbine is already in operation a gas turbine can be installed before the steam generator to generate a higher yield of power.

There are different schemes for combined cycle power plants on the market. Which system is applied depends mainly on the existing power plants already in operation and on local conditions.

As an example, the more modern and most efficient combined cycle gas/steam cogeneration is briefly described. This type is characterised by a very high efficiency and the ability to produce - for the same quantity of heat required in the paper mill - significantly more electricity than the previous steam plants. Where it is practicable this system should be considered as preferable option.

As in normal gas turbine technology air is drawn from the atmosphere and compressed. In the combustion chamber, fuel and air from the gas turbine compressor are mixed and combustion takes place. After combustion, the flue gas is expanded in a turbine, which drives a generator. In combined cycle power plants the thermal energy contained in the gas turbine exhaust gas is utilised in a heat recovery steam generator to produce steam that is used to generate additional electricity via a steam turbine. Plants for co-generation of heat and power convert 80-93% of the energy input into 40-70% heat and 45-20% electricity depending on the specific need of the mills and the system applied. Conventional electricity generation converts somewhat less than 40% of the energy input into electricity. The rest of the energy input is lost.

Applicability and characterisation: Process integrated technique. Cogeneration is a well-known and developed technique. It can be applied to both new and existing mills, if the mill lay out allows it. In existing plants cogeneration can be implemented for instance by repowering existing steam back-pressure units by transforming them into combined-cycle cogeneration plants. The relative small size of most tissue mills can make CHP less viable than for large mills.

Main Achieved Environmental Performance: Emissions per unit of generated heat or power drop significantly as a result of the increased thermal efficiency of CHP. Overall thermal efficiencies can reach 93% thus reducing the carbon dioxide release rate by about 50% compared to conventional power generation combustion systems with an electrical efficiency of about 38%. In contrast, emissions to air on the site will increase.

In Table 5.26 an example of the achieved fuel savings and emission reduction rates for the major pollutants is compiled for a gas turbine in combined cycle applications (GuD). The example represents a cogeneration process that achieves the highest possible thermal efficiency.

In this example, combined co-generation of steam and power (93% fuel efficiency) is compared with conventional electricity generation by coal fired public utility (40% electrical efficiency, example for the German situation) and an on-site steam generation (90% thermal efficiency). It should be noted that the achievable improvements depend on the system compared with.

Example of a combined co-generation designed for 40 t steam/h; production of ca. 20t/h					mg/MJ*
Power Output Combined	MW			9.5	
Process Heat Combined	MW			26.0	
Power Heat Ratio	MW/MW			0.37	
	Utility	Gas Turbine	Supplemental Firing	Total	
Firing Thermal Capacity	MW	14.8	24.4	38.2	
Gas Flow (dry, normal cond.)	m ³ /h			48150	
Emission NO _x *	mg/m ³			160	
Emission CO*	mg/m ³			5	
Emission SO ₂ *	mg/m ³			0	
Mass flow NO _x	kg/h			7.7	60
Mass flow CO	kg/h			0.2	1.5
Mass flow SO ₂	kg/h			0	0
Mass flow CO ₂	t/h			7.6	59.5
* content of oxygen in the waste gas is 3 %					
Electricity by Coal Fired Public Utility 360 MW - Process Steam by Steam Block 40 t/h					
Share of Power Generation	MW			9.5	
Heat Generation	MW			26	
	Utility	Electr. Generation	Steam Generation	Total	
Firing Thermal capacity	MW	25	29	54	
Gas Flow (dry, normal)	m ³ /h	28500	29200	57700	
Emission NO _x	mg/m ³	300	130		
Emission CO	mg/m ³	250	10		
Emission SO ₂	mg/m ³	200	0		
Mass flow NO _x	kg/h	8.6	3.8	12.3	96
Mass flow CO	kg/h	7.1	0.3	7.4	58
Mass flow SO ₂	kg/h	5.7		5.7	44.6
Mass flow CO ₂	t/h	8.27	5.8	14.07	110
Explanatory note: It is assumed that co-generation substitutes base load electricity generation by public utilities. In Germany, the upper base load is generated by coal fired utilities. The comparison is made with a 40% efficiency power plant with modern desulphurisation and denitrification and 2% transmission losses * Calculation for conversion of the figures into specific values: 1 MW x 3600 = MJ; e.g. (9.5 + 26.0) x 3600 = 127800 MJ/h; e.g. the specific NO _x emissions can be calculated as 7700g/h : 127800 MJ/h = 60 mg/MJ					

Table 5.26: Comparison of environmental performance of an operating combined co-generation plant with public utility supply under German conditions
[Example calculated by F.Hutter GmbH Biberach, Germany]

In the case described in Table 5.26, the following reduction rates are achieved by the application of combined co-generation:

- fuel consumption: 29 % reduction,
- NO_x: 38 % reduction,
- CO: 97 % reduction,
- SO₂: 100 % reduction,
- CO_{2, fossil}: 46 % reduction.

Monitoring of Emissions: In bigger co-generation plants NO_x and CO content of the exhaust gas is controlled continuously. Other mills may have periodic measurements of NO_x and CO.

Cross Media Effects: In conjunction with the greenhouse effect, cogeneration power plants based on gas turbines in combined cycle application are regarded as being an important option for the reduction of CO₂ because of their comparatively high thermal efficiency also for relatively small capacity units (from some MW upwards). The high electricity/heat ratio and the high efficiency of the conversion of fuels to power and heat reduces significantly the specific

CO₂ emission per kWh produced compared to conventional power plants. The overall emissions for power generation decrease due to higher thermal efficiency.

Operational Data: Co-generation of heat and power by using different schemes of combined cycles has been applied in a number of paper mills in Europe with good results. No major problems have been reported. Qualified personnel to operate the plant are needed in plants with large capacity.

Economics: The achievable savings and the payback time depend mainly on the price of electricity and fuels within the respective European countries. Investment costs and costs for depreciation and maintenance have to be considered. For the mills that have applied co-generation of heat and power this measure was a cost-effective measure (under the given energy prices). The specific investment for transforming existing steam backpressure units into combined cycle cogeneration plants is in the range of 1000 Euro/kW.

Driving forces for implementing this Technique: It reduces significantly the consumption of fossil fuels, CO₂ emissions (greenhouse gas) and other air pollutant related with power generation by combustion of fossil fuels. Co-generation of heat and power is often an economically viable measure and make mills more independent from external electricity suppliers. If the whole cogeneration potential of a site will be realised, in most cases the production of the plant will exceed the mill's electricity need. A certain amount of electricity generated at high efficiency will be available for the public grid, if the overall market conditions are favourable to it.

It may contribute substantially to the commitments of the Kyoto protocol.

Example Plants: Use of combined heat and power generation is a well-known technique and is applied in numerous paper mills in Europe.

Literature

[Rentz, 1996], [Pröger, 1996], [Data from a German RCF paper mill]

5.3.10 Reject and sludge handling and processing (de-watering) on-site

This technique applies strictly speaking only for "brown papers" manufactured from recovered papers. However, de-watering is an environmental concern for all RCF based paper mills even though they will have different amounts and composition of rejects and sludge.

Description of the Technique: In recovered paper processing, the removal of impurities (mainly in terms of non-paper components) from the pulp slurry is one of the most important process steps. Impurities are removed by multi-stage cleaning and screening at various places of the stock preparation. In the production of wellenstoff and testliner the material loss ranges between 4 and 8 %, depending on the recovered paper grades processed, the stock preparation arrangement established and on the paper quality to be produced. The rejects generated can be subdivided into heavy-weight, coarse rejects and light-weight, fine rejects. Usually these rejects have no material recycling potential and are disposed of by landfilling.

Regardless of the re-use or final disposal, dewatering of the rejects is an essential stage of waste handling. All commonly applied methods for energy recovery and disposal benefit from a high dry solid content of the rejects. Today, the ragger as well as the rejects from pulper disposal systems is mostly not subject to any special dewatering. Due to their material composition, 'draining off' results in a dry content of 60 to 80 %. For dewatering heavy and coarse rejects produced by high-density cleaning and pre-screening, screen spiral conveyors, vibrating screens, screw and rake classifiers are used. Dry solid contents of 60 to 80 % are achievable. The dewatering of light and fine rejects from forward cleaning and fine screening using screens,

endless wires or vibrating screens is followed usually by a further dewatering by means of screw presses. The achievable dry solid content is in the range of 50 to 65 %.

The excess sludge generated in biological wastewater treatment plants in most European paper mills producing wellenstoff and testliner is re-used in paper production. Related to the volume of recovered paper used, the volume of the re-used sludge is less than 1 % by dry weight. Such a small volume can be used as a raw material for paper production without affecting the runnability of the paper machine and the paper characteristics. In this case dewatering facilities are not necessary. Various investigations have shown that the re-use of excess sludge from the biological wastewater treatment plant in paper production does not increase the concentration of detrimental contaminants in the paper produced, since the content of detrimental substances in the sludge itself is very low.

Applicability and characterisation: Process integrated technique. Reject dewatering facilities are common in new as well as in older paper mills. Retrofitting of more effective dewatering systems is possible. The resulting increases of the hydraulic load of the wastewater treatment plant have to be taken into account.

Main achieved environmental performance: Depending on the types of rejects and the reject dewatering system, the water content of rejects can be reduced by 40 to 75 %. In the case of reject disposal in landfill sites, the risk of generating leakage water is minimised. When co-firing rejects in power plants or in cement rotary kilns, the energy demand for the evaporation of water in rejects decreases. This contributes to a higher energy recovery rate.

Monitoring of emissions: Water emissions from reject dewatering facilities are controlled by flow meters. The water squeezed out is generally released in the process water system or to the wastewater treatment plant.

Cross media effects: Reject dewatering results in an increased volume of water to be treated. Because dewatering is generally performed only by mechanical forces, the pollution of squeezed out water is equal to that of the process water. When using screw presses, one has the possibility to heat the rejects by injecting steam, which affects the pollution of squeezed out water. This must be considered especially in cases where the wastewater treatment plant has already approached its maximum capacity. Injecting steam has a cross media effect on energy consumption and air emissions.

Operational data: Reject dewatering processes have been used in paper mills for many years with good results in terms of the increased dryness of the reject and the availability of the machines concerned. To obtain a high dewatering efficiency, most new installations have been screw presses in the last few years.

Economics: Investment costs for reject dewatering – including a dewatering drum as a first stage and a screw press as a second stage – to a dry solid content of 65 % are about 200000 Euro. Annual maintenance costs should not exceed 25000 Euro. The costs correspond to an annual reject volume of 13000 tonnes dry substance.

Driving forces for implementing this technique: The driving force to implement reject dewatering processes was the reduction of waste volume to be disposed of by landfilling. Since co-firing of rejects for energy recovery, e.g. in cement production, has become an alternative for disposal such reject handling is given high priority.

Example plants: Numerous plants in Europe.

Literature:

[IFP, 1998], [Borschke, 1997], [Krieger, 1998]

5.3.11 Environmental sound residue utilisation and disposal

For general aspects of waste management and options for material recycling and energy recovery in paper mills refer also to Section 6.3.14.

The major sources of solid waste in RCF based paper mills are stock preparation, process water clarification and wastewater treatment (refer also to 5.2.2.6). Two major types of processes have to be distinguished:

In recovered paper processing paper mills *without* de-inking (e.g. testliner, wellenstoff, paper board) coarse impurities from the pulper disposal system, rejects from various screening and cleaning stages from the stock preparation plant, and sludge from wastewater treatment are the major waste fractions. The generated rejects amount to about 4 to 10 %, related to the input of raw material. Rejects from the stock preparation plant of brown packaging papers without de-inking have only a limited material recycling potential because they consist of an undefined mixture of non-paper components that are removed from the recovered paper. Commonly, these rejects are dumped in landfill sites. However, due to their high heating value in the range of 22-24 MJ/kg dry substance because of the high proportion of plastics, rejects are suitable for energy recovery, replacing fossil fuels (see below).

Only for rejects from final cleaning and screening stages of the paper machine loop there is a possibility for material recycling because they have a low content of plastics and other impurities. Therefore, in some mills this waste fraction is collected and dewatered separately and used as a co-substrate for composting of biowaste. Especially the current practice of composting varies significantly between Member States. Whereas in some countries composting of sludge from RCF paper mills is encouraged there are others (e.g. Germany) who discourage or ban the composting of waste from paper production.

RCF paper mills *with* de-inking additionally produce high amounts of de-inking sludge and often sludge from process water clarification. The generated rejects and sludge amount to about 15 to 40 %, related to the input of raw material. In DIP plants the de-inking sludge, containing mainly short fibres, coatings, fillers and ink particles, is the crucial waste fraction to be handled. Commonly, most of the sludge is still dumped in landfill sites. In a few countries land spreading in agriculture or composting is practised whereas in other countries this option is discouraged or banned. In bigger DIP plants de-inking sludge together with the sludge from wastewater treatment can be incinerated. There exist different options for the energetic utilisation of rejects and sludge containing organic material (plastics, fibres, and fines):

- incineration in an in-mill reject incineration plant (see example 1 and example 3 further below. Example 1 applies for testliner and wellenstoff, whereas example 3 describes the incineration of rejects and de-inking sludge from DIP plants)
- co-firing in an in-mill coal-fired power plant (see example 2 further below)
- co-firing in the cement industry (is not described here in detail because this option is regulated in the framework of permits for cement kilns. Only some aspects are highlighted in the following)

Rejects can be used as a substitute fuel in the cement industry replacing fossil fuels. Wastes that are fed through the main burner, will be decomposed in the primary burning zone at temperatures up to 2000°C. Inorganic components will be bound in the cement clinker. Waste fed to a secondary burner, preheater or precalciner will be burnt at lower temperatures, which not always is enough to oxidise the organic material completely. The rejects are normally fed at the secondary firing stage at the entrance of the rotary kiln. Feeding rejects and sludge of paper mills in the secondary burner runs a certain risk that emissions of unwanted hydrocarbons (VOC, dioxins) occur. In this combustion zone temperature rises only slowly, which might cause plastics to smoulder. Therefore, operators of cement kilns have to make sure that the use of rejects from paper mills as substitutes for fossil fuels does not result in increased emissions of

VOC or halogenated organic substances. Analyses and control of the composition of the residues to be burned and the resulting emissions to air can avoid this risk. The suitability of waste fractions from paper mills as substitutes for fossil fuels in the cement industry has to be decided case by case. When incinerating the rejects from recovered paper processing mills, the chlorine content of the fly ash can be a limiting factor for the further usage of the ash in case of cement factory.

To obtain a high surface and good ignition behaviour, a pre-treatment of the rejects is necessary. This comprises mainly primary crushing, screening and secondary crushing. Shredding and screening can be combined, e.g. with a magnetic separator and an air separation, in order to recover ferrous metals and to remove impurities that could damage the post-crushing aggregates. Usually, the pre-treatment of rejects is not performed in the paper mills.

So far, no reject utilisation options mentioned above can be regarded as BAT in general. Reject utilisation techniques differ from paper mill to paper mill, mostly depending on local conditions. Because in the near future landfilling as today's predominant disposal option will only be permitted for inertised waste or for waste with a low content of organic compounds, the development of reject utilisation techniques represents a challenge for the European paper industry. Recovery operations are considered as preferred waste treatment options. Possibilities to reduce the amount of waste to be landfilled should be identified and ensured that they happen, where feasible.

Incineration combined with power and steam generation is regarded as an environmentally sound solution. Different technical options for incineration of residues with energy recovery are realised in European paper mills. Three of them are described below including a discussion about major advantages and drawbacks.

Combustion of rejects from RCF mills without de-inking in an in-mill reject incineration plant (example 1) is mainly depending on the size of the mill and the amount of rejects to be incinerated. Co-firing of these rejects in in-mill coal-fired power plants (example 2) is a very recent technique and its applicability depends on the type of fuel used for generation of heat. In this respect it is regarded as a special case and cannot be regarded as a BAT in general either. In contrast, incineration of rejects and sludge in DIP plants is more widely used today in European paper mills and is considered as BAT, where feasible.

Example 1: Energetic utilisation of rejects from RCF mills without de-inking in reject incineration plants

The description of this technique refer to "brown packaging papers" manufactured from recovered papers. However, similar systems are applicable for other recovered paper processing mills (see example 3).

Description of the technique: In most cases, rejects of recycled paper processing in paper mills producing wellenstoff and testliner are disposed of by landfilling. Assuming a proportion of 4 – 10 % of the recovered paper input, the volume of the separated rejects is in many paper mills not sufficient to operate economically a reject incineration plant. Therefore, in contrast to sludge incineration (see example 3), stand-alone incineration plants for rejects from recovered paper processing are installed in only a few modern large-scale paper mills with a high production capacity. Since the early 90s an improved incineration technique has been in operation in a German paper mill. The incineration plant employs multiple hearth combustion and is integrated in the power plant of the mill. It is designed for a reject volume of 14000 tonnes per year. The water content of the rejects is in the range of 45 – 50 %. After shredding and magnetic separation of ferrous material, rejects are fed onto the top hearth, where drying is carried out by upwards-directed hot flue gases. The transport of the rejects to the next hearths is done with the aid of agitators. They transport the rejects through all burning zones, from top to bottom. Flue gas from the furnace top is recycled into the combustion hearths and reheated there. At 800 –

900 °C, the flue gas from the combustion hearths is completely burnt. A separate combustion chamber is therefore unnecessary and the rejects are burnt economically.

The flue gas purification unit is equipped with a two-stage wet scrubber for removal of acidic pollutants, mainly sulphur dioxide and hydrogen chloride. The liquid from the wet scrubbing process is neutralised and treated with precipitation and flocculation agents to remove heavy metals. The heavy metal containing sludge is disposed of in a landfill. For minimising dioxin emissions, a mixture of activated carbon and zeolite is injected into the recycled flue gas stream. The used adsorbents are landfilled. Reduction of NO_x emissions is achieved by selective non-catalytic reduction (SNCR) using ammonia, which is injected into the combustion chamber. Solid particle emission is reduced by an electrostatic precipitator.

Applicability and characterisation: Because the energy content of rejects is used for in-mill energy generation, the incineration of rejects has to be regarded as a process-integrated measure.

Reject incineration in stand-alone waste incineration plants is a rather recent technique that is only used in a few large-scale greenfield or recently expended mills. In many European paper mills, the volume of rejects produced in paper mills may not be sufficient to operate a waste incineration plant under economical conditions. Thus, stand-alone plants are only feasible for bigger mills.

The retrofitting in older paper mills is possible, but it is uncertain whether an incineration plant including the necessary flue gas purification can be operated in an economical way. Taking into account investment costs of about 20 MEuros for a 15000 tonnes/a incineration plant and the fact that the specific costs for smaller plants increase, the economics are doubtful in the case of small paper mills.

For that reason for instance in the province Gelderland, Netherlands, a group of mills operating in a relatively short distance from each other are incinerating residues in a common used fluidised boiler. The composition of the ash will be strictly controlled and used in the construction building industry.¹¹

Main Achievement Environmental Performance: Emission data of the reject incineration plant described above are summarised in Table 5.27. The values shown are average figures for 1997.

Parameter	Unit	Measured values	Limit values (according to German standards)*
Solid particles	mg/Nm ³	3.2	10.0
SO ₂	mg/Nm ³	26.0	50.0
NO _x	mg/Nm ³	195	200
CO	mg/Nm ³	14.1	50.0
HCl	mg/Nm ³	1.7	10.0
HF	mg/Nm ³	0.06	1.0
Total-C	mg/Nm ³	1.4	10.0
Cd, Tl	µg/Nm ³	< 17.0	50.0
Hg	µg/Nm ³	5	50.0
Sb, As, Cr, Co, Cu, Mn, Ni, V, Sn	µg/Nm ³	71.0	500
Dioxins/Furans	ng I-TE/Nm ³	0.097	0.1
Notes:			
* According to the Seventeenth Ordinance on the Implementation of the Federal Immission Control Act (Ordinance on Incinerators for Waste and similar Combustible Material), of 23 Nov 1990, values are referred to standard temperature and pressure (0°C, 1 bar, dry) and to an oxygen content of 11 % per volume			

Table 5.27: Emission data of reject incineration in a multiple hearth combustion plant compared to German Legal Standards [IFP, 1998]

¹¹ N.V. AVIRA and CDEM Holland BV, MER Thermische Conversie-installatie Duiven, 1997.

Monitoring of emissions: Solid particles, SO₂, NO_x and CO are measured continuously, the other parameters by individual sample analyses.

Cross media effects: Incineration of rejects save landfill capacities. The resulting ashes are suitable for reutilization, e.g. for the use in road construction. Fossil fuels for energy generation can be substituted. Emissions to air are released from the incinerator and have to be treated. Achievable emissions can be found in Table 5.27 above. In contrast, potential emissions from landfill gases are reduced. Wastewater is generated when wet scrubbers are used for waste gas treatment.

Operational data: In 1997 the operational efficiency of the incineration plant concerned was about 85 % and it operated satisfactorily. Maintenance and inspection did not exceed the expected periods of time.

Economics: In 1991 investment costs totalled to about 20 MEuros. Specific operation costs are not available. The total costs for incineration of 1 tonne rejects (50 – 60 % dry substance) were around 100 Euros. These costs include capital and operation costs as well as savings of natural gas, which is the energy source of the mill concerned.

Driving forces for implementing this technique: In the case of the reference plant, it was obvious 10 years ago that landfill capacity near the paper mill would become inadequate, resulting in increasing costs for landfilling.

Example plants: SCA Packaging Industriepapier GmbH, Aschaffenburg/Germany

Literature: not available

Example 2: Co-Incineration of rejects from RCF mills without de-inking in coal-fired power plants including flue gas treatment

This technique applies strictly speaking only for RCF based mills manufacturing corrugating medium. However, it may be worth to investigate case by case whether a similar system might be applicable for other recovered paper processing mills.

Description of the Technique: Because of their inhomogeneous composition commonly rejects from RCF mills without de-inking are dumped in landfill sites. However, due to their high heating value in the range of 22 – 24 MJ/kg dry substance caused by the high proportion of plastics, rejects are suitable for energy recovery, replacing fossil fuels (see also example 1).

Table 5.28 shows the composition of rejects as averages from 18 analyses performed in different German paper mills producing wellenstoff and testliner.

Compound	Unit	Value
Plastic	weight-%	26.0
Fibres	weight-%	27.0
Glass and stones	weight-%	0.1
Metals	weight-%	0.9
Other organic material	weight-%	1.0
Water	weight-%	45.0
Heating value (100 % dry substance)	MJ/kg	23.8
Heating value (55 % dry substance)	MJ/kg	12.0
Chlorine content of plastic fraction	weight-%	5.5
Chlorine content of rejects	weight-%	1.4

Table 5.28: Composition of rejects from manufacturing of testliner and wellenstoff [IFP, 1998]

In paper mills firing solid fuels such as brown coal or hard coal in their power plants, the co-incineration of rejects is feasible. The installation of a drying and gasification chamber connected with the combustion chamber of the power plant is necessary. In the drying and gasification chamber the rejects are gasified by oxidation of the carbon-containing material with air. The gases generated during gasification are after-burned in the combustion chamber of the power plant. Proper combustion conditions ($>850^{\circ}\text{C}$ and an oxygen level $>6\%$) have to be ensured to avoid problems with VOC and soot. As a control parameter CO can be monitored ($<50\text{ mg/Nm}^3$).

Before drying and gasification, the rejects require the following treatment: In a first step, a classification in a drum screen is performed. Rejects with a size of more than 50 mm are shredded. Ferrous material is then removed by magnetic separation. A travelling grate is used for feeding rejects to the drying and gasification chamber. A simplified scheme of the described technique is shown in Figure 5.17.

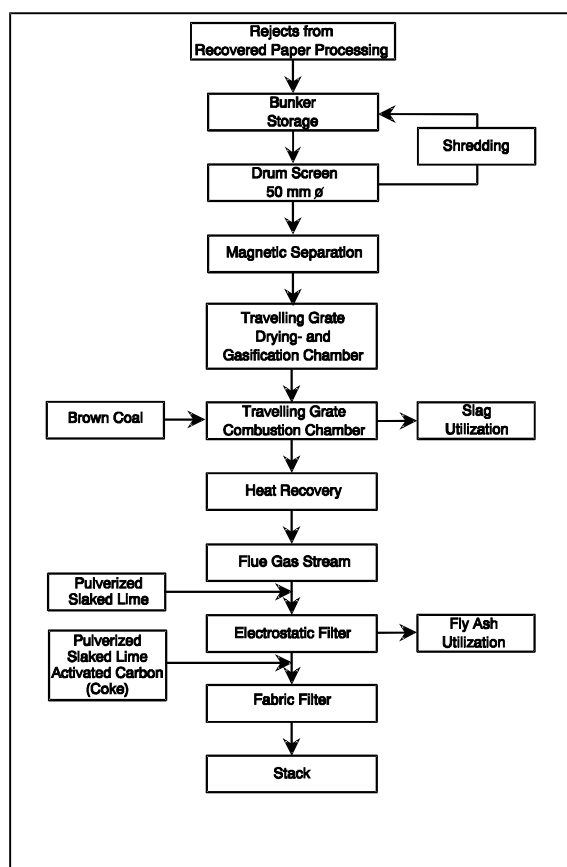


Figure 5.17: Simplified scheme for co-incineration of rejects in a brown coal fired power plant [IFP, 1998]

Applicability and characterisation: Because the energy content of rejects is used for in-mill energy generation, co-incineration of rejects must be regarded as a process-integrated measure. In principal all existing power plants fired with solid fuels (brown coal, hard coal) should be suitable for co-incineration of rejects. However, most of the large-scale European producers of Wellenstoff and Testliner use natural gas as fuel for their power plants. Therefore, co-incineration of rejects is restricted to small and often older mills.

Main achieved environmental performance: Co-incineration of rejects in existing power plants requires additional measures for flue gas purification. Normally, this flue gas treatment has to meet stringent requirements. To remove HCl that is caused by the high chlorine content of the rejects, pulverised dry slaked lime (calcium hydroxide) is injected into the flue gas stream. By injection of dry lime in the right temperature zone HCL, HF, and SO₂ can be minimised. Generally achievable emissions levels are HCl < 30 mg/Nm³, HF < 5 mg/Nm³, and SO₂ < 200 mg/Nm³. Lower values are possible depending on the adsorbent dosage. The waste gases are subsequently treated in a an electrostatic precipitator and additionally in a fabric filter. The solid particle concentration in the purified flue gas will not exceed 10 mg/m³. The removal of dioxins from flue gas is achieved with activated carbon or coke. Generally achievable emission levels are dioxins/furans < 0.1 ng I-TEQ/Nm³. Lower values are possible, depending on the dosage of activated carbon. The waste gas is subsequently treated in the dedusting facility mentioned above. Due to the fact that existing co-incineration plants were started only recently (1997), no reliable data are available.

Monitoring of emissions: The concentration of HCl, solid particles and O₂ in the purified flue gas is measured continuously.

Cross Media Effects: Co-incineration of rejects is considered to have a positive balance concerning achieved environmental performance compared to landfilling. When using rejects for energy generation, fossil fuels can be substituted. 1 tonne rejects with a water content of about 45 % replaces about 0.7 tonne brown coal. Because the proportion of CO₂-neutral fibres in the rejects is in the range of 50 % related to solid substances, the resulting fossil CO₂ emission will be decreased. Co-incineration of rejects is an effective method to minimise waste normally disposed of by landfilling. In this case, the resulting ashes are suitable for reutilization, e.g. in recultivation of brown coal mines. In other cases, dust, particle bound heavy metals and the above mentioned adsorbents are collected and have to be disposed of.

Operational data: Co-incineration of rejects is a very recent technique. Start-up of drying and gasification chambers took place at the end of 1997. Therefore, it is not possible to give sufficient information practices and availability of the incineration plants.

Economics: Investment costs for a co-incineration plant including facilities for reject pre-treatment, drying and the gasification chamber for a reject volume of maximum 3 tonnes/h are in the range of about 2.5 MEuros. Assuming costs for landfilling of 50 Euros/t, there results an annual saving of 0.6 MEuros. The substitution of brown coal saves 0.3 MEuros/a. Costs for maintenance cannot be specified at this time. The costs for depreciation and interest are not taken into account because they are not available.

Driving forces for implementing this technique: Depending on the location of paper mills, costs for landfilling could be very high at present time and will further increase in future. The two mills applying co-incineration of rejects in coal-fired power plants are operating in Germany. Bearing in mind that after 2005 in Germany it will not be allowed to dispose of waste with a content of organic material higher than 5 % on landfill sites, it is clear that the implementing of this technique is an investment for the future.

Example plants: Zülpich Papier-Recycled Paper Europe, Zülpich/Germany
Schöllershammer Industriepapier, Düren/Germany

Literature: not available

Example 3: Incineration of residues (rejects and sludges) from DIP-plants combined with power and steam generation

Differing from example 1 and 2, the example given below refers to DIP plants or those using a mixture of de-inked pulp (DIP) and mechanical pulp.

Description of the technique: Incineration of different kinds of sludge and rejects is widely used today in the pulp and paper industry including rejects, deinking sludge, sludge from wastewater treatment etc. The following two options for incineration of rejects and sludge are available:

- Co-combustion with bark in bark boilers (only for paper mills using a mixture of raw materials as e.g. a mixture of de-inked pulp and mechanical pulp where debarking is applied): For co-combustion, particularly of rather low dry solid sludges, the fluidised bed boiler is presently predominant for new installations. This can be run with 100 % sludge, although the use of a support fuel, such as natural gas, coal or oil is common. The need for the support fuel depends on the sludge dry solids and ash content. Generally, at least 35-40 % dry solid content is required for self-supporting combustion (see Figure 6.19)

- Separate sludge incineration

To be suitable for burning in a boiler, the sludge from recovered paper production has to be first dewatered (see Section 5.3.10). The dewatering filtrates shall be treated in the mill's WWTP. Currently some mills handle and reuse the predewatering filtrate after microflotation in the pulping process.

De-inking *sludge* from the flotation cells can be burned without pre-treatment after being dewatered. Dewatered excess sludge from the biological wastewater treatment can be added but has only a small share of the whole sludge volume (around 5 %). To ensure high temperature (> 850°C) normally gas or bark is also burned in the solid fuel boiler (fluidised boiler). There are mills that burn the sludge only, whereas others burn all residues including rejects or bark.

In case that DIP *rejects* are also incinerated they have to be processed first to be suitable for burning in a fluidised bed boiler, (see also example 2, Figure 5.17). The main purpose of pre-treatment of the rejects from a deinking plant is to separate the incombustibles and crush the fuel particles to proper size to obtain a high surface and a good ignition behaviour. After primary crushing and screening, the combustibles shall be led to the fuel bin of the boiler. The remaining rejects shall be separated into iron rejects and other incombustible rejects.

The pre-treatment of these rejects may consist of the following stages:

- *Prescreening 1* in order to separate large iron particles
- *Primary crushing* that will reduce the particles to a suitable size for the following screening stages
- *Prescreening 2* that will remove the rest of the iron
- *Screening* that will separate the incombustibles (metals, stones, glass etc.)
- *Secondary crushing* that will cut plastic ribbons, strips and ropes that may have passed the primary crushing.

Applicability and characterisation of the measure: Incineration of residues (rejects and sludge) combined with power and steam generation can be applied in most new and existing mills. However, the applicability depends on the type and capacity of boiler in each case. For instance, small mills cannot apply this technology. They have often only very simple oil or gas boilers with limited capacity or technical feasibility to burn solid materials. The higher chlorine content of the rejects needs special attention (corrosion, waste gas treatment).

When applied, fluidised bed boilers are generally more appropriate and can be retrofitted with less additional costs than grate fired boilers. On the operating point of view the fluidised bed boilers have many benefits, among others lower sensitivity to fuel quality or quantity variations and in most cases lower emissions, over the grate fired units.

Main achieved environmental performance: The main achievement is the reduction of the amount of material to be landfilled by about 80-90 %. Additionally a change in quality is achieved i.e. the organic materials are nearly completely eliminated. For the final disposal or use of the ashes there are different options depending on the ash qualities achieved. In some cases ash will be landfilled, others use them in building industry or other add-value purposes.

Emission data of incineration plant for de-inking sludge and sludge from biological wastewater treatment are summarised in Table 5.29. The values shown are average figures for 1998.

Parameter	Unit	Measured values in 1998 *	Limit value daily average*	Installed emission abatement techniques
Dust	mg/Nm ³	4.8	10.0	- Use of bag filters (teflon)
SO ₂	mg/Nm ³	1.1	50.0	- S-content in the sludge is very low
NO _x	mg/Nm ³	185	200	- SNCR (injection of ammonia)
CO	mg/Nm ³	16.3	50.0	- fluidised bed ensures good combustion
HCl	mg/Nm ³	3.5	10.0	- injection of an adsorbent (mixture of calcium and activated carbon) before the bag filters
Total-C	mg/Nm ³	1.1	10.0	

Note:
* The measured values and the emission limits are referred to an oxygen content of 11 % per volume. Heavy metals and dioxins are well below the limit values. They are measured periodically.

Table 5.29: Emission data of de-inking sludge (+ about 5% excess sludge) incineration in a fluidised bed combustion plant in Germany compared to German Legal Standards [1998 Simplified Environmental Statement, Sachsen mill]

Energy recovery may be a secondary target to apply this technique. After dewatering there is a slight positive energy balance in the range of 4-5 MJ/t referred to incineration of dewatered sludge (at 58% dry solids). However, for some paper mills applying wash de-inking (e.g. RCF tissue mills) sludge incineration result in a net consumption of energy. This is typically due to high ash content and thus lowered energy value of sludge.

Cross-media effect: Emissions to air are released from the incinerator and have to be treated. Achievable emissions can be found in Table 5.29 above. In contrast, potential emissions from the landfill gases are reduced. Normally, the purification of waste gas from incinerators generates a certain amount of waste that has to be disposed of. In case of wet waste gas treatment wastewater is generated.

Operational experience: The incineration of *sludge* combined with power and steam generation is used in many modern mills. However, the incineration of *rejects* is much more difficult and involves potential emission and corrosion problems. The possibilities in practise are dependent on the capacity and type of the boiler. Technology can be applied in a limited extent in smaller paper mills.

The devolatilized chlorine from fluidised bed combustion will, besides as HCl, also be as potassium chloride (KCl) and sodium chloride (NaCl). These substances are known to condense on the tube surface with a tendency to increase the possibility for molten phase corrosion. This type of corrosion can be encountered in superheaters when the steam temperatures are above 500°C.

Economics: Investment costs for a new sludge and reject incinerator are about 7-9 MEuros and operating costs 0.7 - 0.9 MEuros/a corresponding a pulp production of 700 ADt/d.

Driving force for implementing the technique: The area required for landfilling can be significantly reduced by incineration of residues depending on the organic content of the materials to be burned. In many Member States the landfilling of waste with high organic content is discouraged.

Reference plant: Some DIP plants in Europe for newsprint and tissue have installed fluidised bed incineration systems as e.g. Sachsen Papier Eilenburg, newsprint (DE), Tela Papierfabrik AG, tissue (CH), Haindl Papier Schwedt, newsprint (DE), WEPA Giershagen, tissue (DE).

Literature:

[CEPI, 1998b], [Finnish BAT Report, 1997], [StoraEnso, 1999]

5.4 Best Available Techniques

5.4.1 Introduction

In understanding this chapter and its contents, the attention of the reader is drawn back to the preface of this document and in particular the fifth section of the preface: “How to understand and use this document”. The techniques and associated emission and/or consumption levels, or ranges of levels, presented in this chapter have been assessed through an iterative process involving the following steps:

- identification of the key environmental issues for the sector; for integrated RCF processing paper mills the major concerns are water use, wastewater discharge (COD, BOD, suspended solids, N, P, AOX), energy consumption (steam and electricity), solid waste such as rejects, sludge and ash, air emissions from energy generation (SO₂, NO_x, CO₂, dust), noise, waste heat to water and sometimes odour; the latter three stand for local impacts;
- examination of the techniques most relevant to address those key issues;
- identification of the best environmental performance levels, on the basis of the available data in the European Union and world-wide;
- examination of the conditions under which these performance levels were achieved; such as costs, cross-media effects, main driving forces involved in implementation of this techniques;
- selection of the best available techniques (BAT) and the associated emission and/or consumption levels for this sector in a general sense all according to Article 2(11) and Annex IV of the Directive.

Expert judgement by the European IPPC Bureau and the relevant Technical Working Group (TWG) has played a key role in each of these steps and in the way in which the information is presented here.

On the basis of this assessment, techniques, and as far as possible emission and consumption levels associated with the use of BAT, are presented in this chapter that are considered to be appropriate to the sector as a whole and in many cases reflect current performance of some installations within the sector. Where emission or consumption levels “associated with best available techniques” are presented, this is to be understood as meaning that those levels represent the environmental performance that could be anticipated as a result of the application, in this sector, of the techniques described, bearing in mind the balance of costs and advantages inherent within the definition of BAT. However, they are neither emission nor consumption limit values and should not be understood as such. In some cases it may be technically possible to achieve better emission or consumption levels but due to the costs involved or cross media considerations, they are not considered to be appropriate as BAT for the sector as a whole. However, such levels may be considered to be justified in more specific cases where there are special driving forces.

The emission and consumption levels associated with the use of BAT have to be seen together with any specified reference conditions (e.g. averaging periods).

The concept of “levels associated with BAT” described above is to be distinguished from the term “achievable level” used elsewhere in this document. Where a level is described as “achievable” using a particular technique or combination of techniques, this should be understood to mean that the level may be expected to be achieved over a substantial period of time in a well maintained and operated installation or process using those techniques.

Where available, data concerning costs have been given together with the description of the techniques presented in the previous chapter. These give a rough indication about the magnitude of costs involved. However, the actual cost of applying a technique will depend

strongly on the specific situation regarding, for example, taxes, fees, and the technical characteristics of the installation concerned. It is not possible to evaluate such site-specific factors fully in this document. In the absence of data concerning costs, conclusions on economic viability of techniques are drawn from observations on existing installations.

It is intended that the general BAT in this chapter are a reference point against which to judge the current performance of an existing installation or to judge a proposal for a new installation. In this way they will assist in the determination of appropriate "BAT-based" conditions for the installation or in the establishment of general binding rules under Article 9(8). It is foreseen that new installations can be designed to perform at or even better than the general BAT levels presented here. It is also considered that existing installations could move towards the general BAT levels or do better, subject to the technical and economic applicability of the techniques in each case.

While the BREFs do not set legally binding standards, they are meant to give information for the guidance of industry, Member States and the public on achievable emission and consumption levels when using specified techniques. The appropriate limit values for any specific case will need to be determined taking into account the objectives of the IPPC Directive and the local considerations.

Manufacture of paper from recovered paper is not a single process but a series of unit processes, often linked and inter-dependent. Therefore, it is always a suitable combination of techniques that constitutes BAT for a RCF processing paper mill. The order of priority and the selection of the techniques or combinations of techniques depend on the local circumstances.

Best available techniques given below are, if not stated otherwise, applicable to new and existing plants. In paper mills, the applicability of a technique is less driven by the fact whether a mill is new or existing. Paper mills are characterised by the fact that machinery is rebuilt rather than replaced whole-scale. The modular rebuilding and development of plants means that each site is a unique product of its location and history. On the other hand, papermaking is a series of unit processes, which are common in all countries.

Criteria to be considered in the determination of BAT in the specific cases are rather than specific costs for smaller mills are relatively higher (economies of scale). Other factors to consider are limitations of space, which some older mills might face, or unsuitable material or lay out of older equipment, which does not fit for a higher degree of water closure. More water system closure usually is combined with higher complexity of the system that needs to be monitored, controlled and understood. Smaller mills might sometimes not have the knowledge available which would be necessary to run and control more complex process solutions most efficiently.

5.4.2 BAT for recovered paper processing paper mills

For recovered paper processing mills the following techniques are considered as BAT. The following list of BAT is not considered exhaustive and any other technique or combination of techniques achieving the same (or better) performance can also be considered; such techniques may be under development or an emerging technique or already available but not described in this document. For integrated recovered paper mills it is refer to Section 6.4 where further details on BAT for papermaking is given. If not stated otherwise, the data refer to yearly average values.

General measures

1. Training, education and motivation of staff and operators. Paper mills are operated by people. Therefore, training of staff can be a very cost-effective way of reducing water consumption and discharges of harmful substances as for instance accidental releases of chemicals.
2. Process control optimisation. To be able to reduce different pollutants simultaneously and to maintain low emissions, improved process control and measurement are required.
3. To maintain the efficiency of the technical units of paper mills and the associated abatement techniques at a high level, sufficient maintenance has to be ensured.
4. Environmental management system which clearly defines the responsibilities for environmentally relevant aspects in a mill. It raises awareness and includes goals and measures, process and job instructions, check lists and other relevant documentation.

Measures for reducing emissions to water

Reduction of fresh water consumption and thus wastewater flows can be achieved by application of a combination of different techniques such as:

1. Separation of less contaminated water from contaminated one and recycling of process water. Separation and reuse of clean cooling waters and recycling of sealing and process water from pumps for vacuum generation are ways to reduce fresh water consumption.
2. Optimal water management (water loop arrangement), water clarification by sedimentation, flotation or filtration techniques and recycling of process water for different purposes
3. Reduction of fresh water consumption by strict separation of water loops and counter-current flows
4. Generation of clarified water for de-inking plants (flotation)

Water pollution abatement is strongly related to recovery and recycling of process water in order to reduce fresh water consumption. Increased process water closure will result in smaller and more concentrated discharges, which in general can be treated more efficiently. Decrease of process water flows will also increase the applicability of advanced technologies. Therefore, reduction of the intake of fresh water can result in decreasing discharges to surface waters. The intake of fresh water is mainly determined by product requirements, paper grades and the design of the water system of the paper mill (condition of the mill). The water consumption is dependent on the amount of water required for showers. Furthermore, amount of fresh water consumption depends on the knowledge about water management and the motivation of the whole staff to support the vision of running a paper mill using as less water as necessary. Excess white water and other polluted process water is purged from the system and is treated biologically.

5. Installation of an equalisation basin and primary treatment.
These measures are applied at nearly all paper mills and are rather considered as good practice. They are a pre-requisite for well and stable performing biological wastewater treatment plants. For RCF processing paper mills they are not considered as BAT as a stand-alone technique.
6. Aerobic biological treatment. This is the preferable option for de-inked grades and depending on the conditions also for non-de-inked grades. There are a lot of different treatment options available that achieve good results in reducing the organic load to the recipients. The choice of the treatment option is mainly governed by the initial concentration, the wastewater characteristics and the removal efficiency to be achieved. Proper design and maintenance of the treatment plant is a prerequisite for good performing biological systems. Dependent on the initial concentration and the treatment system chosen, pollution load removal efficiencies associated with BAT are the one presented in Section 6.3.10 and 5.3.6. Common treatment of wastewater from a paper mill or a consortium of paper mills in the municipal biological wastewater treatment plant is also considered as BAT when comparable removal efficiencies are achieved by this common treatment.

7. Combined anaerobic and aerobic biological treatment. This is the preferable option for non-deinked grades. They have usually to treat higher polluted wastewater either because of higher degree of water circuit closure and/or larger amounts of organic substances dissolved in the stock preparation. There are a few good experiences for anaerobic treatment of wastewater from DIP plants also. Anaerobic treatment is never used as stand-alone biological treatment but is always followed by aerobic treatment. Compared to aerobic treatment only the combined treatment generates significantly less excess sludge (see measures for reducing solid waste further below).
8. Partial recycling of treated water after biological treatment. The possible degree of water recycling is depending on the specific paper grades produced. For non-deinked paper grades this measure is considered BAT. However, the advantages and drawbacks need to be carefully investigated and will usually require additional polishing (tertiary treatment)
9. Treating internal water circuits.
This includes techniques which should be considered when equipment has to be replaced or in areas where stricter environmental requirements have to be met. Usually only partial streams of the whole water will be treated having specific substances to be reduced. Although closed water loops with in-line biological treatment of process water is running at a few full-scale applications in Europe for non-deinked grades it is not yet considered as BAT. This is because problems caused by precipitation of calcium carbonate in pipes and the aeration basin of the activated sludge plant are still waiting for a satisfying technical solution.

It is difficult to present reliable figures on wastewater loads before biological treatment because it is rare that those emissions are reported transparently. For instance, it is often not clear which process-integrated techniques are applied to achieve reported emission levels with primary treatment only. Emissions to water before treatment depend to a large extent on the quality of raw materials used (recovered paper, chemical additives) and process lay out (consistency, temperature, alkaline treatment, and water loop design). The mills are not considered to represent BAT but stand for some real-world examples that might give an indication of releases to water when no biological treatment is applied. Consequently, the values in Table 5.30 all refer to water discharges with primary treatment only.

Examples of RCF paper mills	Reported achieved emission levels after primary treatment only			Production '97 [Adt/a]	Remarks
	COD [kg/t]	BOD ₅ [kg/t]	Flow ³⁾ [m ³ /t]		
De-inking mills *					
Haindl Papier Schongau, DE	20.2 (2500 mg/l)	10.1 **	8.2	500000 newsprint, 40000 SC paper, 47000 DIP	data for 1997, 84% DIP, 16% TMP
Haindl Papier (Schwedt), DE	23.0 (1500 mg/l)	11.5 **	15.2	250000 newsprint	data for 1997, 100% DIP
Lang Papier Ettringen, DE	15.9 (2100 mg/l)	7.9 **	7.7	129000 newsprint, 123000 SC paper, 5100 DIP	data for 1997, 88% DIP, 12 % GW pulp
Sachsen Papier Eilenburg, DE	18.1 (1600 mg/l)	9 **	11.4	284000 newsprint, 47000 DIP	data for 1997, 100% DIP, 1998: 10 m ³ /t, 13 kg COD/t
Mill 1, RCF tissue, DE	47	23.5 **	10	n./a.	Lower quality recovered paper grades as raw material
Mill 2, RCF tissue, DE	20	10 **	10	n./a.	Medium quality recovered paper grades as raw material
Mill 3, RCF tissue, DE	37	18.5**	11	n./a.	Medium quality recovered paper grades as raw material
Mill 4, RCF tissue, DE	17.8	9**	17	n./a.	Higher quality recovered paper grades as raw material
Without de-inking					
COD value from [Dutch note on BAT, 1996]	20-30	10-15** (estimated value)	0 - 5	n./a.	No data from real world examples available
Notes: n./a. = no information available					
* The data for the DIP plants are taken from [Pfitzner, 1999]; data for the RCF tissue mills are taken from [Zippel, 1999]					
** The BOD ₅ value is estimated assuming that COD = 2*BOD ₅					
It adds no value to give value for nitrogen and phosphorus before biological treatment because N and P is added to the paper mill wastewater in order to feed the biomass of the biological wastewater treatment plant					

Table 5.30: Examples of yearly average emission levels to water after primary treatment only of some integrated RCF paper mills with and without de-inking

The list of mills is a selection of mills where data were available and is therefore not intended to be complete

Because of a lack of transparency whether or not (and too which extent) the mills without biological treatment have applied BAT no emission levels associated with the use of BAT with only primary treatment are proposed.

Table 5.31 shows achievable emission levels of some integrated RCF paper mills in Europe. It can be assumed that they have applied a suitable combination of BAT, but not necessarily all, and biological wastewater treatment as well.

Examples of RCF processing paper mills	Reported achieved emission levels after biological treatment						Type of treatment
	COD	BOD ₅	tot-P	TSS	Flow [m ³ /t]	Production '97 [Adt/a]	
De-inking mills							
Mill 1, newsprint, DE	300 mg/l (2.1 kg/t)	10 mg/l (0.07 kg/t)	0.4 mg/l	14 mg/l (0.09 kg/t)	7	100000	Activated sludge
Mill 1, newsprint, DE	335 mg/l (5 kg/t)	19 mg/l (0.3 kg/t)	0.4 mg/l	n./a.	15	233000 (data: 1996)	Activated sludge
Sachsen Papier, newsprint, DE	200 mg/l (2 kg/t)	4 mg/l (0.04 kg/t)	0.3 mg/l	n./a.	10	355000 (data: 1998)	Trickling filter + activated sludge
Mill 4, RCF tissue, DE	100 mg/l (0.9 kg/t)	10 mg/l (0.09 kg/t)	n./a.	n./a.	9	64000	Activated sludge
Without de-inking							
Fiskeby board mill, SE	90 mg/l	5 mg/l	0.1 mg/l	5 mg/l	n./a.	123000	High load submersed biofilm (Kaldnes) + activated sludge
Industriewater Eerbeek, (Consortium of 3 RCF processing mills), NL	85 mg/l	5 mg/l	0.4 mg/l	9 mg/l	n./a.	450000 (15% DIP, 5% GWP)	Anaerobic/aerobic (activated sludge)
Mill 1, (mostly corrugating medium + less special paper, DE)	94 mg/l (0.9 kg/t)	4 mg/l (0.04 kg/t)	0.6 mg/l	17 mg/l	9	120000 corrugating paper	Anaerobic/aerobic (activated sludge)
Mill 2, Fine board, DE	65 mg/l (0.32 kg/t)	5 mg/l (0.02 kg/t)	0.65 mg/l	n./a.	5	650000	Trickling filter + activated sludge
Mill 3, corrugating medium, DE	168 mg/l (1.1 kg/t)	9 mg/l (0.06 kg/t)	1 mg/l	25 mg/l	7	38000	01-8/97: Activated sludge; then: Anaerobic/aerobic tr.
Mill 4, corrugating medium, DE	140 mg/l (0.6 kg/t)	5 mg/l (0.02 kg/t)	0.9 mg/l	4 mg/l	4.2	300000	Anaerobic/aerobic (activated sludge)
Mill 5, corrugating medium, DE	0	0	0	0	0	40000	in-line (zero effluent) anaerobic/aerobic
Mill 5, white testliner & folding box boards, DE	90 mg/l (0.6 kg/t)	13 mg/l (0.09 kg/t)	1.1 mg/l	n./a.	7	120000, data: 1998	Anaerobic/aerobic (activated sludge)

Table 5.31: Examples of achieved annual average emissions to water after biological treatment of some RCF processing paper mills in Europe (reference year: mostly 1997)

The list of mills is a selection of mills where data were available or provided and is therefore not intended to be complete. The data are derived from TWG members and from personnel communication. The method of analysis is the one used in the respective country. In Sweden the values for BOD are given as BOD₇

Assuming adequate design and capacity of the wastewater treatment plant and appropriate operation and control by skilled operators, emission levels associated with a combination of BAT are considered to be those given in table below. The effluent loads include pulping, bleaching, for de-inked grades, and papermaking.

In spite of the huge number of different kinds of paper products manufactured from recovered paper it can be stated that paper mills that have implemented BAT achieve relatively similar emissions to water. Therefore, as regards the discharges after suitable wastewater treatment from the various paper production categories, further significant differences between paper grades were not identified.

Parameter	Units	Without de-inking ⁴	With de-inking ¹	RCF based tissue
BOD ₅	kg/t of paper	<0.05-0.15 ⁵	<0.05-0.2 ⁵	<0.05-0.5 ⁵
COD	kg/t of paper	0.5-1.5	2.0-4.0	2.0-4.0
TSS	kg/t of paper	0.05-0.15	0.1-0.3	0.1-0.4
AOX	kg/t of paper	<0.005	<0.005	<0.005
Total P	kg/t of paper	0.002-0.005 ²	0.005-0.01 ²	0.005-0.015 ²
Total N	kg/t of paper	0.02-0.05 ²	0.05-0.1 ²	0.05-0.25 ²
Wastewater Amount	m ³ /t of paper	<7	8-15	8-25 ³

Explanatory notes:

- 1) A mixture of other fibre types (such as GWP, TMP or CTMP) might be used as different shares ranging from 0-30 % of the fibre furnish
- 2) Emissions of N and P depend on the optimised dosage of these nutrients to the biological wastewater treatment plant. To achieve low emissions a certain fine-tuning of the added nutrient feed is required
- 3) For tissue production there is a number of factors that might lead to somewhat higher specific water consumption: lower basic weights of paper produced (down to 12 g/m²), higher cleanliness of the product, frequent changes of grade or colours, lower speeds of the paper machines, and the use of processes that need higher amounts of high pressure showers. Therefore, for tissue a process water demand of 8 – 25 m³/t is regarded as BAT.
- 4) Coated cartonboard manufacturing requires some more water than e.g. testliner, wellenstoff or uncoated cartonboard production (7-15 m³/t). Therefore, the upper end of the emission range associated with BAT is valid for coated cartonboard.
- 5) The lower end of the BOD emission range indicates an almost complete removal of biodegradable organic matter. It should be understood as such and not be taken as a precise figure.

Table 5.32: Yearly average emission and consumption levels associated with the use of BAT for integrated RCF processing (> 50% RCF) paper mills with (e.g. newsprint, copy paper, folding boxboard in a few cases) and without de-inking (e.g. white topline/testliner/wellenstoff/fluting mills)

The emission data refer to integrated RCF processing paper mills. However, there are an increasing number of mills in Europe that use different kinds of fibre furnish. A part of the furnish might consist of recovered fibres, a part is provided by mechanical pulp production on site, another part might consist of purchased chemical pulp. BAT emission levels for this kind of mills are presented in Sections 4.4 and 6.4.

Emissions to water are presented only for three different groups: paper grades without de-inking; de-inked grades and RCF based tissue mills. Concerning emissions to water the differences between different types of paper are not very significant. For instance, RCF processing mills manufacturing printing and writing paper can achieve similar ranges of emissions as RCF based newsprint mills.

In Europe, within the non-de-inked group the biggest group comprises mills manufacturing case making materials (testliner, wellenstoff, and fluting). Other mills are producing carton board based and folding box board from recovered paper. The latter use different recovered paper qualities and stock preparation processes for the different layers of the multi-layer board. Some mills use to a certain extent purchased bleached kraft pulp. Some layers might consist of DIP. However, the emission levels to water associated with the use of BAT of these mills are in the same range than the emissions of RCF paper mills without de-inking mentioned in Table 5.32. On the other hand, consumption of water could be a little higher, especially when paper and board is manufactured in mills that produce different paper qualities on the same machine. There are examples of RCF board mills producing folding boxboard that apply de-inking processes to reach on the basis of lower quality waste paper grades the product quality to be achieved. For those mills, as for any other board grade produced by de-inking, the techniques to be considered are those for de-inked paper class.

A big number of tissue mills are also using recovered fibres as major fibre source. They might use different mixtures of recovered fibres and virgin fibres. If they use mainly DIP they often

use better qualities of recovered paper as raw material. As can be seen from the table above emissions to water are comparable to other de-inked grades. However, for tissue production there is a number of factors that might lead to somewhat higher specific water consumption.

The table above should be read together with the following additional explanations:

BOD: In well designed treatment plants BOD is removed almost completely (95% + removal) from RCF processing paper mill wastewater when the carbon-phosphorus-nitrogen ratio and oxygen supply is maintained sufficiently and well controlled. BOD₅ levels will usually be well below 25 mg BOD₅/l and can reach values down to 5 mg/l i.e. almost completely removal. BOD levels around 5 mg/l are hardly to measure accurately and reproducibly. They should be read as values close to the detection limit. Depending on the water flow these performance levels corresponds to <0.05 kg BOD₅/t and 0.3 kg BOD₅/t respectively.

COD: De-inking processing results in higher COD emissions than emissions caused by processing without de-inking. Factors such as raw materials used, paper grade manufactured, applied process-integrated and external measures, and water flow per tonne of product, have an influence on the final pollution load. Concentrations between below 100 mg/l up to 200 mg COD/l (without de-inking) and 200 mg/l to 300 mg/l COD (with de-inking) are achievable when BAT is applied.

TSS: Under normal operation conditions, the water from the secondary clarifier is fairly clear. The content of suspended solids is in the range of below 10 to 30 mg/l. This corresponds to discharges of 0.1 - 0.3 kg TSS/t. The values depend on the surface load of the secondary clarifier and the characteristics of the biomass.

AOX: Nowadays, discharges of chlorinated organics are very low as the chlorine content in original paper that is recovered has decreased over the years. In paper mills using virgin fibres, normally either ECF or TCF bleached pulp is used which is also reflected in the lower AOX emissions discharged from RCF processing paper mills. Activated sludge treatment result in a further AOX reduction between 30 and 50 %. However, this reduction is partly achieved by stripping of these compounds during wastewater treatment. Depending on the type of recovered paper and chemical additives used RCF processing paper mills normally discharge chlorinated organic compounds below 0.3 mg/l or below 0.004 kg/t.

N and P: Mineral nutrients are usually added to the biological treatment plant to keep the balance C : P : N which is of crucial importance for the growth of active biomass. To find and keep a balance between biodegradable carbon, nitrogen- and phosphorus-compounds a certain fine-tuning of the added nutrient feed is required. Usually, phosphorus is added as phosphorus acid and nitrogen in form of urea. When the system is well optimised nutrients discharge well below 1 mg tot-P/l and 5 mg total N/l are achievable. The corresponding loads are 0.005-0.01 kg P/t and 0.05-0.1 kg N/t respectively with de-inking and somewhat less for mills without de-inking because of lower water flows.

Measures for reducing of emissions to air

Air emissions in RCF based paper mills are mainly related to the power plants installed for the production of heat and the generation of electricity. Saving of heat and electricity corresponds therefore with reduction of air emissions. The power plants are usually standard boilers and can be treated like any other power plants. Therefore, generally acknowledged BAT are mentioned only briefly in this section. To decrease air emission the following measures are available:

1. Co-generation of heat and power
2. Improving existing steam boilers by installation of low NO_x technology and by using low sulphur fuel or controlling S emissions
3. Using renewable sources like wood or wood waste to reduce the emissions of fossil CO₂ (only applicable in RCS paper mills that are operating a virgin pulp production line).

Emission levels associated with BAT from auxiliary boilers incinerating own biofuels and/or different fossil fuels are given in Table 5.33. It has to be noted that auxiliary boilers within the pulp and paper industry are of a very variable size (from 10 to above 200 MW). For the smaller only the use of low-S fuel and combustion techniques can be applied at reasonable costs while for the larger also control measures. This difference is reflected in the following table. The higher range is considered BAT for smaller installations and is achieved when only quality of fuel and internal measures are applied; the lower levels (in brackets) are associated with additional control measures like SNCR and scrubbers and are regarded as BAT for larger installations.

Released substances	Coal	Heavy fuel oil	Gas oil	Gas	Biofuel (e.g. bark)
mg S/MJ fuel input	100 - 200 ¹ (50 - 100) ⁵	100 - 200 ¹ (50-100) ⁵	25-50	<5	< 15
mg NO _x /MJ fuel input	80 - 110 ² (50-80 SNCR) ³	80 - 110 ² (50-80 SNCR) ³	45-60 ²	30 -60 ²	60 -100 ² (40-70 SNCR) ³
mg dust/Nm ³	10 - 30 ⁴ at 6% O ₂	10 - 40 ⁴ at 3 % O ₂	10-30 3% O ₂	< 5 3% O ₂	10 - 30 ⁴ at 6% O ₂
Notes:					
1) Sulphur emissions of oil or coal fired boilers depend on the availability of low-S oil and coal. Certain reduction of sulphur could be achieved with injection of calcium carbonate.					
2) Only combustion technology is applied					
3) Secondary measures as SNCR are also applied; only larger installations					
4) Achieved values when electrostatic precipitators are used					
5) When a scrubber is used; only applied to larger installations					

Table 5.33: Emission levels associated with the use of BAT for different fuels

For coated paper grades a careful choice of coating colour recipes is considered BAT. By this measure the emission of volatile organic carbons and of some single substances of concern as e.g. acrylonitrile or formaldehyde that can occur in the exhaust air of coating machines can be avoided or reduced. Especially coating colour recipes that contain carcinogenic compounds should be avoided.

Local nuisances due to annoying odour can be largely avoided by process engineering measures or, if the biological wastewater treatment plant is the major source of odours, by well-designed and controlled plants.

Measures for reducing solid waste

To reduce the amount of solid waste to be landfilled the following measures are considered as BAT:

1. Minimisation the generation of solid waste and recover, re-use and re-cycle re-usable materials as far as possible.
2. Separate collection of waste fractions at source and, if necessary, intermediate storage of residuals/waste, to allow for a greater proportion to be reused or recycled rather than land-filled.
3. Optimising the fibre recovery by upgrading of stock preparation plants
4. Optimisation of the amount of cleaning stages in the stock preparation
5. Dissolved air flotation (DAF) to recover fibres and fillers and to clarify process water. In the design of stock preparation plant concepts (as mentioned in item 3 to 5) a balance between cleanliness of stock, fibre losses, product quality, energy requirements and costs have to found.
6. Anaerobic biological pre-treatment of waste water
Compared to stand-alone aerobic waste water treatment combined anaerobic/aerobic treatment generates considerably less excess sludge

7. Efficient reject and sludge handling on-site (de-watering) to enhance dry solids content in order to improve the incineration properties. After de-watering of rejects and sludge, the dry solid content achieved depends mainly on the characteristic of the sludge and the technical equipment for de-watering. Higher dry solids usually mean less transport requirements and higher calorific value of the sludge that is especially interesting in case where the residues are burnt.
8. Reduction of the amount of waste to be landfilled. Identification of possibilities for recovery operations and - if feasible - utilisation of waste for material recycling or incineration of rejects and sludge with energy recovery, if feasible. Produced ash can often be used as raw material in the building materials industry. Different options for incineration of rejects and sludge are available. The applicability is limited by the size of the mill. In some cases (e.g. tissue mills), supporting fuels or adding of residues with higher calorific value (e.g. bark, wood waste) are required when the amount of land-filling is reduced by combustion techniques.

Depending on the quality of recovered papers used for production and the product properties to be achieved the amount of solid waste will vary. Both the processing of lower qualities of recovered paper and the manufacturing of higher paper qualities from similar raw materials result in an increase of rejects. Generally, the production of non-de-inked grades produced less amount of solid waste than the production of de-inked grades. Within de-inked grades relevant differences occur. For instance, for the manufacturing of printing and writing papers from recovered paper normally higher amounts of solid waste are generated than for newsprint, especially if wash-de-inking is necessary. For graphic papers, there is a trend to use better recovered paper qualities. For RCF based tissue production there is a need to wash out the fillers and fines by wash-de-inking. This process generates significant higher amounts of waste to be handled and further treated than for other de-inked paper grades.

No BAT associated levels of the amount of waste to be landfilled are presented because they depend mainly on the degree of utilisation, the treatment options chosen and the quality of the recovered paper used as fibrous raw material. Additionally, there is little detailed and reliable information available on achievable amounts of solid wastes from RCF processing paper mills. There is a lack of comparable statistical data and various terms for different waste fractions are used in Europe.

Energy saving measures

In general in this sector BAT is considered to be the use of energy efficient technologies. A lot of options for energy saving in many stages within the manufacturing process are available. Usually these measures are linked with investments to replace, rebuild or upgrade process equipment. Because of economies of scale, smaller mills are less able to invest in new energy efficient technologies. It should be noticed that energy saving measures are mostly not applied only for energy saving. Production efficiency, improvement of product quality and reduction of overall costs is the most important basis for investments. Energy saving technologies can therefore be regarded as techniques that are incorporated into many other aspects of papermaking.

To decrease energy consumption the following measures are available:

1. Implementation of a system for monitoring energy usage and performance. Based on reliable energy performance information appropriate action can be taken. Energy management includes setting, controlling, reviewing and revising energy performance targets.
2. Upgrading of equipment. When replacing equipment less energy consuming equipment with possibilities for automated process control instead of conventional manual systems. Automated controlled systems are more efficient to control and can result in more accurate processing and energy savings (see also Section 6.3.8)

- Application of anaerobic wastewater treatment. Energy consumption is 10 times less than for aerobic treatment and generated methane gas can be used a fuel. Anaerobic treatment is not always applicable. The wastewater has to meet minimum requirement as mentioned in Section 5.3.5.

For further measures to reduce energy consumption that are generally applicable to paper mills it is referred to Section 6.3.18. Major possibilities for improvement discussed in this section, are e.g. optimisation of the de-watering at the wire section by installation of a wide nip press (see Section 6.3.17) and use of energy efficient technologies. Also the reduction of direct use of steam by careful process integration by using pinch analysis is mentioned there.

In many European countries, information on energy balances of paper mills is poorly available in public. Different reporting schemes, if any, for energy consumption are used. Energy demand also depends on the product quality (especially in tissue mills) and partly on local conditions. Therefore, it is difficult to present energy consumption values associated with the use of BAT. The ranges of energy consumption of paper mills shown in Table 5.34 should only be taken as an indication about the approximate need of process heat and power at energy efficient paper mills. Further examples of energy efficient paper mills including the specific conditions might be possible to add in a reviewed version of the BREF.

Type of mill	Process heat consumption (net) in GJ/t ¹⁾	Power consumption (net) in MWh/t ¹⁾
RCF based testliner and wellenstoff, without de-inking	6.0 - 6.5	0.7 - 0.8
RCF based cartonboard or folding boxboard, without de-inking	8.0 - 9.0	0.9 - 1.0
RCF based newsprint, de-inked	4.0 - 6.5	1.0 - 1.5
RCF based tissue, de-inked	7.0 - 12.0 ²⁾	1.2 - 1.4
Explanatory notes: The units can be converted from MWh to GJ according to 1 MWh = 3.6 GJ and 1 GJ = 0.277 MWh 1) All data from [J. Pöyry, 1998] 2) In tissue mills the energy consumption depends mainly on the drying system used. Through air drying and re-creping consume significant additional energy. Tissue mills use primary fuel instead of steam in drying (most hoods are direct gas fired).		

Table 5.34: Indication for heat and power consumption associated with the use of BAT for different types of recovered paper production per tonne of product

Noise attenuation

BAT is the reduction of noise levels audible in the vicinity of paper mills. The measures applied will depend to a large extent to the specific noise problem of a mill and the targets set. Usually they will be much stricter when the mill is located adjacent to a residential area.

Chemical usage

In general BAT for chemical usage is considered to be:

- Ensure the availability of a database for all used chemicals and additives containing information on the chemical composition of the substances, degradability, their toxicity for men and environment and potential of bio-accumulation.
- Application of the principle of substitution i.e. less hazardous products are used when available.

3. Measures to avoid accidental discharges to soil and water from handling and storage of chemicals.

Design and operation of facilities in such a way those dangerous substances cannot escape.

5.5 Emerging Techniques

In this paragraph a number of techniques are mentioned which are not (yet) applied at industrial scale. Other techniques have reached a more advanced stage of development but are still not considered as available.

5.5.1 Advanced effluent treatment with a combined process of ozonation and fixed bed biofilm reactors

Description: Secondary treatment of wastewater from paper mills is applied in numerous mills in Europe thus reducing emissions to water significantly. However, present developments in the industry are trying to further reduce releases of organic substances and waste heat by combining process-integrated measures with external measures. Advanced treatment of remaining pollutants after biological treatment is aiming at a further reduction of COD, AOX, colour and other matters.

Effective advanced effluent treatment - unless partial flows can be successfully pre-treated - is normally downstream the biological stage. A treatment process was developed during the last five years to improve the treated effluent quality in view to stronger environmental regulations and the possibility for the reuse of treated effluent in the process. This tertiary effluent treatment consists of a combination of ozone with fixed bed biofilm reactors and results in a significant elimination of COD, colour and AOX with a minimum of ozone dosage. A typical scheme of this process is shown in Figure 5.18.

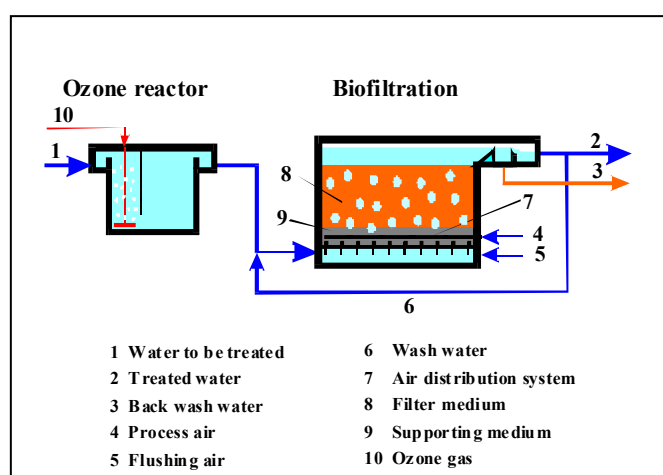


Figure 5.18: Combined process of ozonation and fixed bed biofilm reactors

The treated effluent has a low content of disturbing matters so that the reuse of tertiary treated effluent in the process seems to be an interesting option. That means, the ozone treated water can be either discharged or re-used in production.

The chemical analyse of tertiary treated effluents shows that apart from the elimination of organic matter (measured as COD) other substances are also drastically reduced or eliminated such as colour, AOX, heavily degradable optical brighteners and chelating agents, bacteria and spores.

Status of development: Ozone treatment of biologically purified wastewater for further reduction of residual COD and to improve colour stripping have been tested over some years in laboratory and pilot-scale. These laboratory trials [Öller, 1997 a +b] and investigations on half-technical scale [Möbius, 1996] have shown that ozone treatment can significantly reduce COD and colours depending on the amount of ozone applied. The process can be considered as in a

developed stage. In full-scale applications only the removal efficiency and ozone capacity (kg ozone/h) have to be determined in laboratory or pilot tests.

Generally, it can be expected that this kind of technique will be first applied at mills located at sensitive recipients or by mills which intend to increase significantly capacity and simultaneously have no permit for increasing the load of effluent to the river. In this cases the specific load of substances have to be decreased.

In 1999, the first full-scale treatment consisting of a one-stage combined ozonation and biofiltration will be put into operation (Fa. Lang, Germany).

Environmental implications: The efficiency of ozone treatment depends strongly on the quality of the individual water to be treated and the specific lay out of the treatment system. Therefore, no general statement on the achievable environmental performance is possible. In effluents meeting certain boundary conditions in terms of COD and BOD₅/COD ratios, the bioavailability can be enhanced to allow additional biological treatment. The ozone treated water can then be either discharged or re-used in production.

The main focus of this process however is the transfer of persistent organic compounds (residual COD, AOX, and colour) into biodegradable fractions (only partial oxidation i.e. limited and controlled oxidation of organic carbons). This results in a significant increase of the BOD/COD- ratio. The results of pilot tests with paper mill effluents after biological treatment show that further COD removal efficiencies up to 90 % (referred to COD concentration after secondary clarifier) can be achieved with specific ozone consumption of 0.7 - 1.0 kg O₃/kg COD_{eliminated} after the biofilters. Removal efficiencies of about 50% or more are achieved by one-stage ozonation-biofiltration. COD removal efficiencies of well above 50 % up to 90 % are achieved when the process is operated in two stages. After the first ozonation stage a biofilter degrades partially oxidised organic matter. The second stage consists of another ozonation step followed by a biofilter. This process lay out avoids full oxidation of organic matter by ozonation thus reducing the amount of required ozone and optimising the operation costs. The target of this lay out is not to consume ozone for readily biodegradable matter.

With the exception of the small amount of biological excess sludge produced in the biofilters polluting substances are really eliminated and not only separated. Therefore, this treatment does not generate a concentrate that calls for further treatment, as it is the case when membranes or evaporation are used.

Negative cross-media effects are energy consumption for ozone generation that is in the range of 10 - 13 kWh/kg ozone and a smaller amount of energy consumption for production of pure oxygen.

Economic considerations: Cost estimates have revealed that in comparison to current advanced treatment techniques such as flocculation/precipitation, ozone treatment provides an economically viable alternative under certain conditions.

The specific treatment costs for a one-stage process with biofiltration following ozonation typically amount to under 0.5 Euros per m³ of treated effluent. This covers total investment and operating costs (ozone generation, pumps, etc.) and includes oxygen supplied as liquid oxygen. Ozone treatment can also give a more or less complete colour stripping at reasonable costs.

Literature/References: [Öller, 1997 a +b], [Möbius, 1997 a], [Möbius, 1999], [Helble, 1999], [Kaindl, 1999]

5.5.2 Membrane bioreactor for end-of-pipe or (partly) in-line treatment

Description: Membrane bioreactors (MBR) are combined separation-oxidation processes. They have two main functions:

1. Enhanced biological oxidation (decomposition of organic material). Enhanced because the conditions in a membrane bioreactor are such as to encourage biomass adaptation (long sludge age and absolute retention of biomass (no clarifier acting as a biomass selector)).
2. Separation of solids and liquid by use of a membrane process.

This new generation of membrane bioreactors is using immersed shell-less membranes instead of external modules as shown in the figure below.

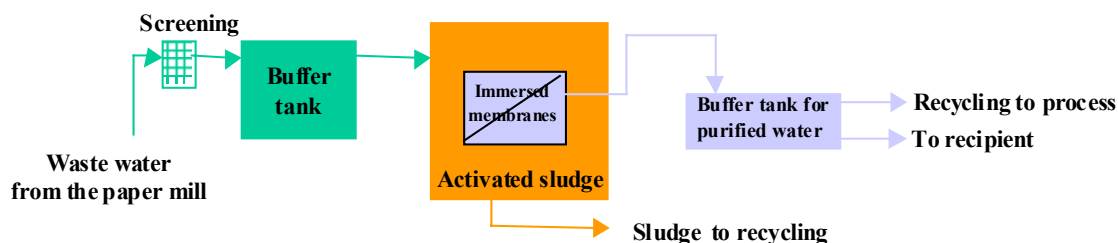


Figure 5.19: Membrane bioreactor using immersed membranes in an activated sludge reactor

The membranes are immersed directly into the biomass of the activated sludge plant and operated at very low transmembrane pressures (0.2 bar typically). The energy consumption of this process is only 0.2 kWh/m³ for the filtration (including pumping, and membrane aeration for turbulence promotion) compared to 4 to 8 kWh/m³ for external loops MBRs (figures are referring to the conditions of the so-called BIOSEP reactor).

Status of development: The first full-scale application went into operation in 1999 at a French cardboard mill (Papeterie du Rhin). In the case of this cardboard mill the sludge will be reinjected in the pulper. The design flow rate is relatively small (900 m³/day). The operators of the mill will slowly try to increase the fraction of the treated water recycled back to the mill.

Environmental implications: For some types of mills, which could not meet discharge limits (e.g. when they have slightly higher concentration or loads) an MBR could allow them to reach their discharge limits. But the process could also be used as pre-treatment for downstream separation/concentration processes such as nano-filtration (NF) or evaporation. This application might be interesting for operators of paper mills who think to use MBRs in their mill-water circuit closure plans, allowing e.g. to use cheaper NF configurations and to meet more stable operating conditions.

Membrane bioreactors can produce a lot less sludge (up to half) than a conventional biological treatment, because of the specific characteristics of the active biomass growing in those MBR applications.

Economical considerations: No data available

Literature/References: There are different suppliers of submersed membrane bioreactors.

5.5.3 Recovery of boiler ash and carbon dioxide gas to produce recycled mineral fillers for use in paper.

Description: A new chemical process utilises both ash which results from the combustion of de-inking residue and carbon dioxide generated during combustion to produce a type of recycled mineral filler precipitated calcium carbonate (RMF PCC) for use in paper. The new process is one that derives from the chemistry used to produce pure precipitated calcium carbonate (PCC), a commonly used mineral in papermaking. Precipitated calcium carbonate is

chemically identical to natural calcium carbonate (ground limestone or chalk), but generally is more pure. The main advantage to the papermaker, however, is that the chemical process of their production allows individual PCC particles to assume a variety of shapes and sizes (morphologies). Careful selection of size and shape can maximise PCC functionality over a wide range of papermaking applications. These advantages are also imparted to the paper when RMF PCC is used as the filler.

The process to produce a recycled mineral filler PCC (RMF PCC) can be described by the following equation:

Materials	Boiler Ash	+ Ca(OH) ₂	+ CO ₂	=> Ash/CaCO ₃	+ H ₂ O
Quantities	5-50g	37-70g (fresh lime)	22-43g	100g (Recycled Mineral Filler)	9-18g

The ash resulting from the combustion of paper mill residuals or deinking sludge contains mainly compounds rich in calcium, silicon and aluminium. These result from the minerals contained in the waste, mainly calcium carbonate (CaCO₃) and kaolin clay (H₂Al₂Si₂O₈-H₂O).

It has been discovered that the calcium aluminosilicate minerals in boiler ashes are suitable for nucleation and growth of PCC. It has also been discovered that these ashes can replace up to one-half the lime (CaO) that is used to produce calcium hydroxide slurry. Individual particles of RMF PCC are composites of PCC and boiler ash. The reaction is controlled, so that PCC of a particular morphology precipitates on and covers the surface of an ash "core". The process has been patented (U.S. 5,759,258) and is supplied by Speciality Minerals Inc (SMI), one of the leading suppliers of precipitated calcium carbonate (PCC) to the European Paper Industry.

Status of development: A German paper mill (Haindl Schongau) is carrying out pilot test to adapt the existing plant for production of pure PCC to the production of recycled mineral filler PCC. Development work on the use of PCC for coating is also underway.

Environmental implications: The process reduces significantly the amount of solid waste to be deposited from deinking plants. Utilisation of boiler ash as a raw material in the production of precipitated calcium carbonate (PCC) reduces consumption of fossil fuels for production of CaO from limestone quarry (CaCO₃) by up to 50%, and thus reduces emissions of CO₂ by a corresponding amount. If paper mills that generate large quantities of deinking residuals reduce the amount of solid waste from the deinking process by incineration, CO₂ is emitted to air, and ash must still be disposed. A process to produce RMF PCC can partly or completely consume ash and CO₂ generated at these mills. This is in addition to reductions at the limestone quarry in both fossil fuel consumption and CO₂ emissions. The main principle of the process itself and the major benefits are summarised in the illustration below.

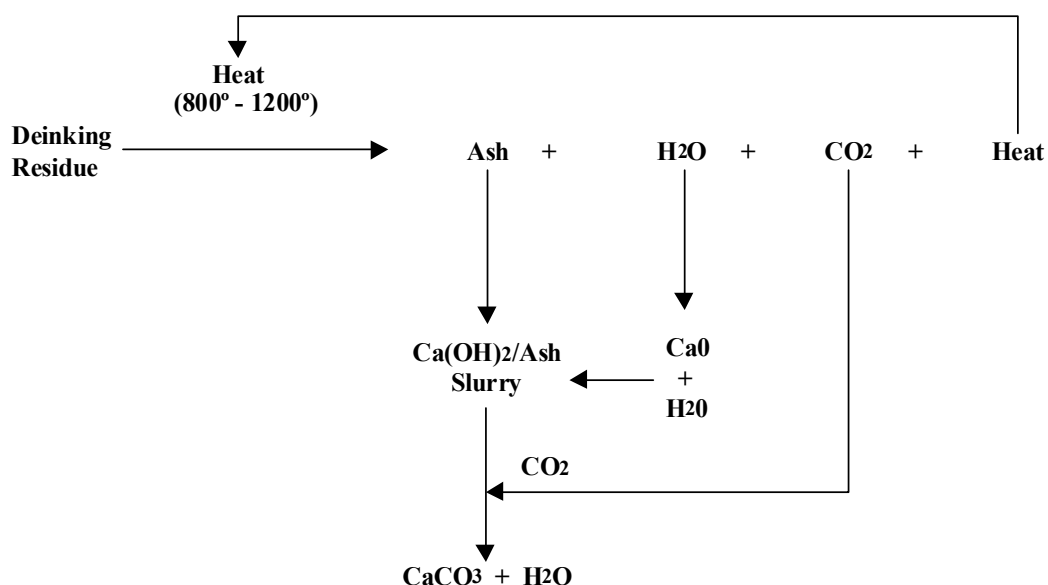


Figure 5.20: The main principles of the RMF PCC process

Reproduced from "Recycling of Mineral Fillers from the Residue of a Paper Deinking Plant", Sohara et. al., U.S. 5,759,258, 1998

Economical considerations: In countries where cost of landfill is high and rising the option of handing over de-inking ash as a raw material for production of precipitated calcium carbonate (PCC) is appealing since it makes both economic and environmental goods. However, the brightness of Recycled Mineral Filler PCC, based on a realistic mixture of one third ash, and two thirds of pure PCC, is 90% and thus lower than pure PCC (96%). It might also raise abrasivity. On the other hand RMF PCC has better opacity properties than pure PCC. The economics of recycled mineral filler PCC depend very much on the quality of the recovered paper from which the de-inking residue is produced (high amounts of calcium carbonate fillers are beneficial). The higher the calcium contents in the recovered paper, the better for the operation of this process.

A prerequisite for the implementation of recycled mineral filler PCC is the presence of a boiler combustion of de-inking residue. Normally, the plant producing pure PCC is adapted for recycled mineral filler PCC production. Step by step, lime is replaced by de-inking ash.

Literature/References: [Roberts, 1998]

5.5.4 "Kidney" treatment - Techniques for further circuit water cleaning

Refer also to Section 6.5.1.

Description: A low wastewater load can be achieved by a combination of a suitably designed process water system and internal wastewater purification. Process water in the paper industry is used for a number of different applications, with different water quality requirements. Hydraulic separation of different process units creates relatively small internal water circuits, which can be treated more efficient.

Water circuit closure is currently restricted by various contaminants (disturbing substances) in the process water, which have a disruptive effect on either the technology or the product. Separation of process units from each other (e.g. by use of thickeners) makes it possible to remove disturbing substances inside the process unit in which they are generated in order to prevent contaminants travelling through the whole papermaking process. The contaminants in

the separated water loops can be (partial) removed from the water circuit in question to a desired level, in order to fulfil the process water quality requirements set for that specific process unit. This approach results in complex concepts that require a lot of knowledge for control of the system.

There are basic differences between the furnish, technologies and requirements of finished paper depending on whether graphic grades ("white grades") or packaging papers ("brown grades") are involved. In principle, the configuration of systems for packing papers is always simpler than for white grades. For brown grades manufactured from recycled fibres it is possible to control completely closed circuits by integrating a biological treatment stage (see Section 5.3.4). There are even paper mills that manufacture brown grades operating with closed water systems (zero emissions to water) without internal treatment.

With "white" graphic papers, the wastewater load can be minimised by internal treatment of process water by use of membrane filtration, ozonation plus biofilter or alternatively by evaporation technology, so-called "kidney" treatment. However, the suitability of such technologies in continuous operation needs to be carefully tested before they are put into industrial production. These techniques can also be applied as advanced external treatment following common biological treatment (refer to Section 5.5.1 and Section 5.5.2).

Status of development: Advanced treatment of partial flows of process water ask for treatment and water management methods that are not yet spread in paper mills. However, a lot of development works for treatment of process waters has been carried out in most European countries. A lot of smaller testing plants and a few full-scale applications are already in operation. However, especially for "white grades" there are still open questions concerning the chemistry of closed water circulation and the separation of individual compounds in separation processes. Further experimental research, modelling, new water quality measurements and control methods are required.

The optimum plant configuration has always be determined carefully on a case-by case basis taking all relevant aspects into considerations (such as product properties, costs, market demands, costs for water supply and treatment, the requirements by the legislation, site specific considerations etc.).

Environmental implications: The recycling of treated water reduces the consumption of fresh water and also the volume of effluents. By selecting the most appropriate partial process water flow for the internal treatment it is possible to reduce the total discharge to water. However, the impact of closed water circulation on the energy and material balance of the whole mill should always be carefully assessed. In some cases the internal water treatment concept ("kidney strategy") can lead to better efficiencies for the whole mill (e.g. energy savings, reduced consumption of chemicals). In other cases it might only lead to reduced emissions to water.

Economical considerations: No specific data available. Expanding of the external effluent treatment system with a tertiary stage is often not considered economical at high water consumption levels. Internal water treatment has the advantage that water can be treated where it is used. Furthermore, different waters can be treated separately only to an extent that is actually needed. On the other hand, these measures demand a change in process management and require relatively large investments.

Literature/References: [Borschke, 1997], [Proceedings, 1997 a]

5.5.5 The Continuous Batch Fibre Recovery System to processing recovered paper in a complete system

Description: This technology, the Continuous Batch Fibre Recovery System (the so-called "Tunnelwasher") has the potential to improve the competitiveness of smaller mills and paper

machines because it can economically process recovered paper materials in quantities as low as 3 t/d. The primary aim is to provide mini recycling mills close to the source of recovered paper. The equipment is not intended to be the basis for a large RCF mill. The CBFRS combines a pulper, a washer and a coarse screen in one machine. It is based on ideas developed in the industrial laundry business.

The system consists of cells within units that can be extended and added to depending on the end product required. Ideally two four cells units would be joined together giving a capacity of 7 - 8 tonnes per day of RCF. Recovered paper is loaded into the first cell. The cells are divided within a rotating drum with a defined sequence. The first load is transported to the next cell while the first cell receives a new load. This continues until the accepted fibres, in the form of pulp, are discharged through an extraction plate at the bottom of the final four cells.

Status of development: There is one installation at a paper mill in North America, the IPMC Paper Mill in Detroit, Michigan. The mill produces 175 tonnes per day of speciality grades of paper and has installed a 25 t/d line to process recovered paper generated within Michigan. A second system for production of 20 - 25 t/d recycled fibres from drink boxes was installed in Mexico. Other applications are planned to start in the near future.

Environmental implications: The benefit of the CBFR system is that it combines the effects of several traditional components that are commonly used in recovered paper processing. Thus, it eliminates the need of several process equipment (as e.g. deflaker, washing, flotation, dispersion, kneader) resulting in saving of energy and investments.

As in conventional systems process water is counter-flowing in the system. The benefit is that it reduces the volume of process water requiring. The wastewater can be treated by dissolved air flotation giving water that is clean enough to be reused. Process water consumption of less than 4.5 m³/t is expected.

The system processes also more difficult materials (such as milk cartons, drink boxes, wax-coated corrugated etc.) that contain high quality fibre but are typically not sorted because they are generated in small volumes and are not regarded as economically to recycle. The operator can take a more local or regional approach to locating recovered material.

The system can also be applied to treat fibre containing rejects of conventional systems on line. The recovery of fibres leads to a higher yield in recovered paper processing thus reducing the rejects to be landfilled.

Economical considerations: No specific data available. The supplier states that the system can economically process recovered paper materials in quantities as low as 3 t/d because of comparably lower costs for investments.

Literature/References:

[Regenex, 1996], [Braeuer, 1998]

6 PAPERMAKING AND RELATED PROCESSES

This section describes paper and board production of the major grades being manufactured in European paper mills.

During the production of different paper grades either virgin fibres (chemical or mechanical pulps) or recycled fibres are used as main raw materials. In Europe, there are also a big number of mills manufacturing papers with a mixture of fibrous materials. Today, the composition of the raw material used for paper is influenced more than ever before by the cost of the individual components. The composition of raw materials used for paper manufacturing (e.g. fibrous material, mineral fillers, coating) has a major effect on the total production costs, the product quality and the environmental impact of the process. The manufacturing of fibres used for papermaking has been described in the previous Chapters 2 to 5. In the following, paper and board manufacturing is described independent from pulp manufacturing. This approach is considered to be reasonable because the same unit processes around the paper and board machine are required in every paper mill. The description of papermaking as part of integrated pulp mills would increase the complexity of the technical description. Finally, in numbers, most paper mills in Europe are non-integrated mills.

Although there is a big variety of paper products and different process lay outs in paper mills almost all types of paper and board-making processes have the following basic units:

- Stock preparation
- Approach flow system
- A paper and board machine consisting of
 - Head box introduces the suspension of fibres to the wire and creates a uniform dispersion of fibres across the total width of the wire belt
 - A wire section drains paper web to around 12 - 20% solids
 - A press section removes more water out of the web by pressing down to about 50% moisture content
 - A drying section removes rest of moisture by heating the web with drying cylinders
 - A reeler reels the paper web into a roll
- Depending on the paper and board grade there are additional process units (optional) like calenders, coaters, a coating colour kitchen, winders, rewinders and a roll wrapping station.

In the following the basic units of paper manufacturing are described. The main papermaking additives and chemicals are included in these descriptions. Their environmental properties are discussed more in details separately in Annex I. Because papermaking is a sector that requires large amounts of water a paragraph about water circuits is included. Coating and important finishing processes are also covered.

6.1 Applied Processes and Techniques

6.1.1 Stock Preparation

Stock preparation is conducted to convert raw stock into finished stock (furnish) for the paper machine. The pulp is prepared for the paper machine including the blending of different pulps, dilution and the addition of chemicals. The raw stocks used are the various types of chemical pulp, mechanical pulp, and recovered paper and their mixtures. The quality of the finished stock essentially determines the properties of the paper produced. Raw stock is available in the form of bales, loose material, or, in case of integrated mills, as suspensions. Stock preparation consists of several process steps that are adapted to one another as fibre disintegration, cleaning, fibre modification and storage and mixing. These systems differ considerably depending on the raw stock used and on the quality of furnish required. For instance, in the case of pulp being pumped directly from the pulp mill, the slushing and deflaking stages are omitted.

Stock preparation is based on the removal of impurities, the conditioning of the strength properties of the fibres (refining) and the addition of chemicals to aid the process and affect the final quality of the paper sheet (resins, wet strength agents, colours, fillers). In non-integrated mills the fibres are received dry. They are suspended in a pulper to create a suspension that can be pumped. Then, undissolved impurities are removed from the slurry by screening (screens) and cleaning (centrifugal cleaners). The objective of screening is the removal of interfering substances from the fibres. The fibre suspension is passed through a screen with apertures in the form of slots or round holes, and the impurities to be separated are rejected by the screen. Cleaning is the separation of impurities from the fibre suspension in a centrifugal field. Cleaning is carried out in centrifugal cleaners. A distinction is made between heavy-particle and light-particle cleaners, depending on the purpose of separation. Most cleaners are multistage systems (up to 5 stages).

To improve the bonding ability of the individual fibres of the finished paper refining may be carried out (optional).

The refining has the purpose of conditioning the fibres to create the required properties of the finished product. Refining is carried out in refiners equipped with e.g. a rotating disk that is pressed on a stator. The electrical energy used in refining as part of the papermaking process is usually in the range between 100 and 500 kWh/t for most papers but can be up to 3000 kWh/t for speciality papers. Thus for a non-integrated paper mill using chemical pulp, refining will represent the largest use of electrical energy (drying being the large use of heat). Practically all of the energy input to this refining will be turned into heat and there is no option here for energy recovery although this heat generated contributes to the elevated temperature sought in the process.

Complete stock preparation for a paper machine usually consists of several lines, in each of which different raw stocks are prepared. The processing of broke from the paper machine is also part of this process (see Section 6.1.4). Finally, the pulp is pumped to the storage chests or mixing chests. These chests serve as a buffer between the stock preparation and the actual paper machine, to promote process continuity. In the mixing chests, prepared stocks are mixed in proportions appropriate for producing a particular grade of paper, the required additives are added and the correct fibre consistency is adjusted.

6.1.2 Paper Machine

In the paper machine the paper is formed and most of the properties of the paper are determined. The paper machine is actually a large de-watering device consisting of a head box, a wire section, press section and dryer section. The most common machine design still to recent times is the Fourdrinier process in which the sheet is formed onto a continuous wire or fabric onto

which the suspension of fibres is introduced from the headbox. Recently twin wire formers have been used for web formation and they have become the state-of-the-art design. In twin wire formers, the fibre suspension is led between two wires operating at the same speed, and is drained through one or both sides. There are different types of twin wire formers (e.g. gap formers. In gap formers the diluted stock is injected directly into the gap between the two wires) and combinations of Foudrinier and twin wires (hybrid formers).

Figure 6.1 shows the key features of a paper machine.

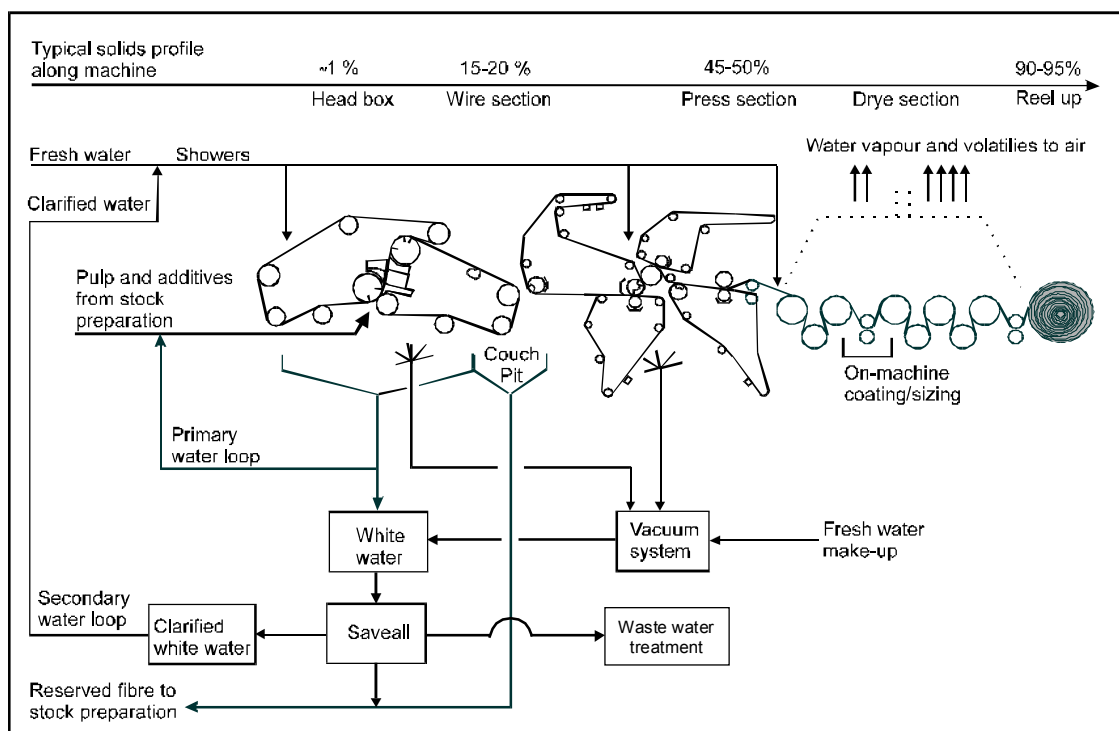


Figure 6.1: Key features of a twin wire paper machine

Paper is made by introducing a dilute suspension of fibres, and possibly fillers, dyes and other chemicals, on a fine mesh through which the water drains, leaving the web of fibres and fines and fillers settling on the mesh. The fibre slurry, which at the wet end of the paper machine is typically between 0.2 and 1.5% consistency, is conveyed to the wire section via the head box. The task of the head box is to create a uniform dispersion of fibres across the total width of the wire belt, in order to achieve uniform paper formation. By the time the paper web has drained to around 10 - 20% solids on the wire the web is self-supporting and can be led away from the mesh onto subsequent pressing and drying stages. The water drains through the wire aided by so-called dewatering elements. Examples of those are rolls, foils and vacuum boxes below the wire, so that after typically 10 m the web of paper is formed. In a twin wire former dewatering pressure is formed as well by the fabric tension over a curved surface of blades or a roll. Machine speeds vary considerably with the web on the fastest machines, typically newsprint, travelling at 1500 m/min with a web width of 10 m. Tissue machines, although generally of narrower deckle, now run at speeds in excess of 2000 m/min. Some machines incorporate a number of wires for making multi-ply papers or boards.

The paper web passes into a press section supported on felts between rollers and through vacuum sections to remove more water (normally down to 60-55%, in some cases down to about 50% moisture content) and then through the drying section. The drying is normally done using steam heated cylinders enclosed in a hood. In the dryer section the web is dried to the final dry content of 90 - 95%. Practically all the heat used for drying ends up in the hood exhaust air. The temperature of the exhaust air is normally 80 - 85 °C and humidity 140 - 160 g_{H2O}/kg_{dry air}. A

part of the moisture (about 1 - 1.5 m³/t of paper) is driven off to the atmosphere. For economic reasons, all paper mills have installed heat recovery systems. Figure 6.2 shows a schematic picture of the drying and heat recovery section of a paper machine.

In the first heat exchanger of the heat recovery system heat is recovered to incoming supply air. The next heat exchanger is for the heating of incoming fresh water. In some cases heat is also recovered to wire pit water to compensate for the heat losses in the wet end. The last heat exchanger is for circulation water. The circulation water is used to heat the incoming ventilation air. The supply air and shower water are heated to their final temperatures (90 - 95 °C and 45 - 60 C respectively) using steam.

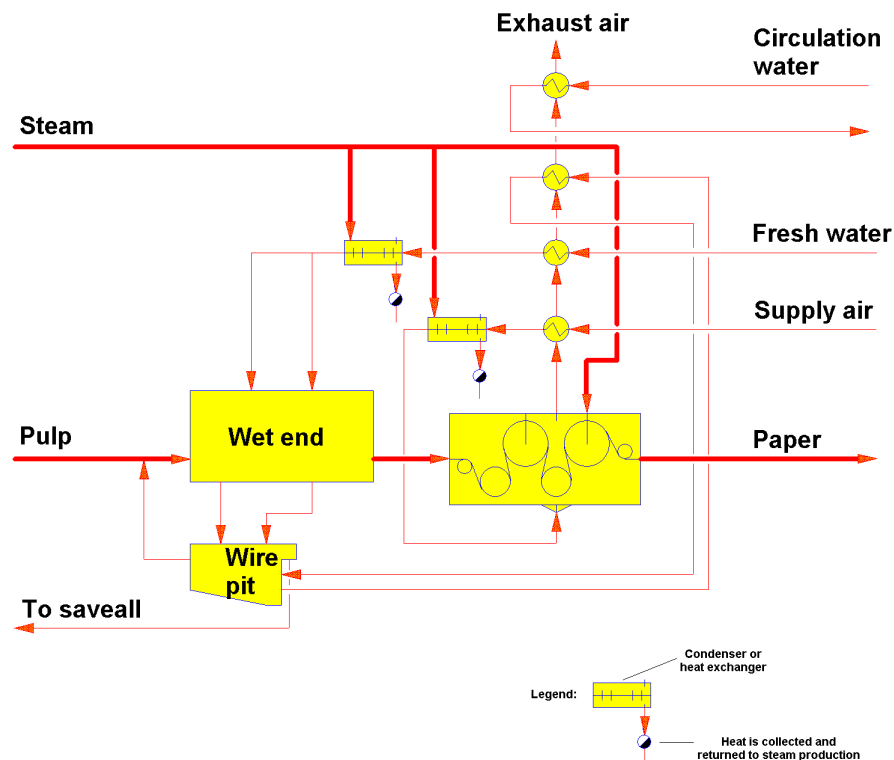


Figure 6.2: Paper machine heat recovery system

Table 6.1 shows an example of heat flows in a typical large and modern paper machine. The production capacity of the machine is 240120 t/a (667 t/d). The dry content of web entering dryer section is 44.5% and that of product 91%. The temperature of exhaust air is 82 °C and humidity 160 g_{H₂O}/kg_{dry air}. The values are for Scandinavian winter conditions. In warm climate the share of circulation water decreases or disappears and the exhaust to atmosphere correspondingly increases.

Locations for heat recovery	Destination of heat flow from the drying section [MW] and [MJ/t]	Distribution of heat [%]
Supply air	1.8 MW or 233 MJ/t	6
Wire pit water	3.6 MW or 466 MJ/t	11
Fresh water	5.5 MW or 712 MJ/t	19
Circulation water	8.0 MW or 1036 MJ/t	27
Exhaust to atmosphere	10.8 MW or 1399 MJ/t	37
Total (Exhaust air from hood)	29.7 MW or 3847 MJ/t	100

Table 6.1: Example for heat recovery and heat losses of a paper machine with a production of 667 t/d [data from Valmet]

Values are referring to Scandinavian winter conditions. In countries with warmer climate there is no need for heating of circulation water that is used for machine room heating

One variation for the production of light-weight machine-glazed paper or conventional tissue is the usage of a large heated "Yankee" cylinder on the machine. The drying of the paper web is carried out during the rotation of the cylinder.

In a simple machine the paper may then be reeled and sent for cutting and finishing. In other cases a variety of different stages are incorporated within the machine. A size press is a section of the machine where starches and other chemicals are applied to the surface of the paper by dipping or spraying, with residual water being removed in a short after drying-section.

In most applications the edges of the web are continually trimmed with cutting water jets, into the couch pit, as it leaves the wire. Whenever the web breaks that can happen a number of times per day, there is a considerable loss of paper. Similar losses occur on routine start-ups. All of this paper, termed "broke", is re-pulped and returned to the stock chests in the stock preparation area. Losses of dry paper may be re-pulped immediately or stored and re-introduced to the system at a later date. Coloured or coated broke is recycled if possible but sometimes needs to be bleached or chemically treated first (see Section 6.1.4).

There is a continuous need to prevent the build up of solids on any of the fast moving wires, felts or rollers as these would quickly lead to web breaks. The showers or sprays for this purpose are the primary consumers of fresh water and/or cleaned water in the system. Vacuum systems can also consume substantial amounts of fresh water.

Retention of both solids (fibre, fines and fillers) and solubles (added chemicals, organics from the pulp etc) into the paper web, rather than passing through the mesh and remaining in the water circuit, is an important concept. It clearly affects the likely destination of any substance - either to the product or to effluent. On-line consistency monitoring is often used to stabilise retention. The wire retention of solids can be raised by the addition of retention aids (chemical improving retention), and it is a normal practice on most paper grades. However, this is constrained on some grades by product quality.

6.1.3 Water circuits and fibre recovery

There are three process water circuits in a paper mill: the primary circuit, the secondary circuit, and the tertiary circuit. A scheme of the water circuits in a paper mill is shown in Figure 6.3.

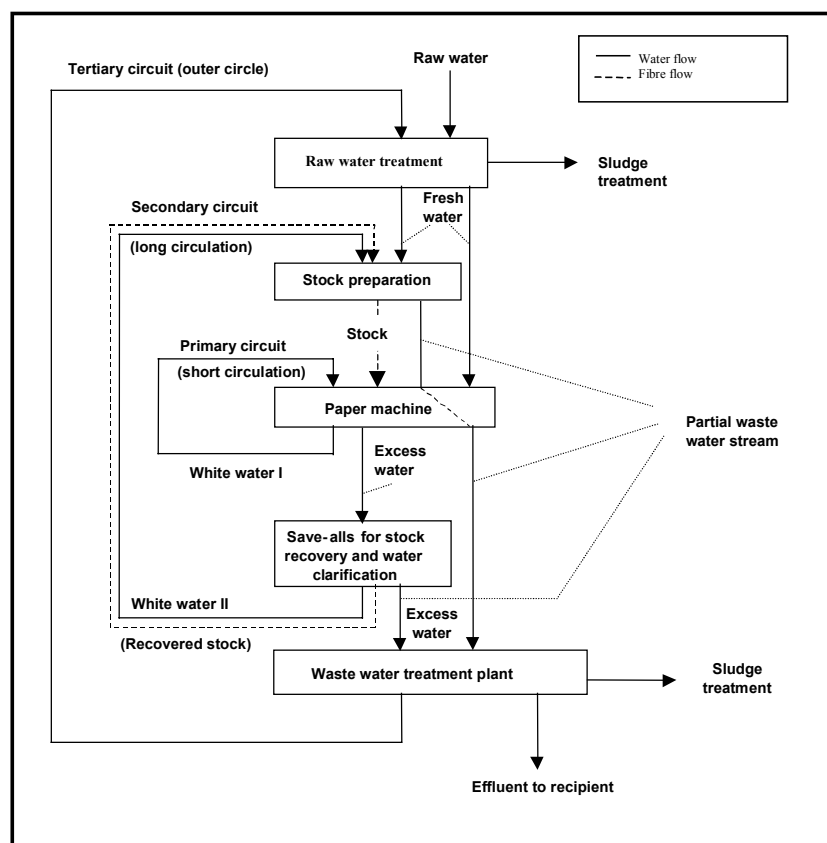


Figure 6.3: Simplified scheme of water and stock streams in a paper mill

In the primary circuit (short circulation), the fibre, fines and filler-rich water obtained in the sheet-forming zone of the wire section (white water I) is recycled for stock dilution in the stock approach flow system. The primary circuit is maintained as closed as possible.

Excess water from the sheet-forming section, suction and press water, as well as cleaning water is called white water II and is circulated in the secondary circuit (long circulation). The white water draining from the wire is typically treated through a so-called save-all, which may be a sedimentation or flotation plant or a filtration unit as a drum or disc filter. This water is then called clarified water.

A precoat disc filter conditioned with raw pulp produces stocks with highest consistency (10-30%) and is designed to achieve a three (or four) way separation of the white water into fibre, a first draw of cloudy water and subsequent draws of clear and super-clear filtrate. The cloudy filtrate is usually recycled back to the filter as dilution water, but can also replace fresh water in the process or be used for the dilution of the stock. A higher recycling rate of cloudy filtrate back to the disc filter results in a cleaner filtrate. The concentration of suspended solids in the clear filtrate (fines and fillers) is usually about 10-150 mg/l for virgin pulp or 100-400 mg/l with recycled pulp.

Flotation systems are also used as save-all. At optimum conditions, the efficiency of flotation systems for solids removal is often almost 100% resulting in concentration of suspended solids of 10-50 mg/l (for virgin pulp). The consistency of the floated sludge is between 3 and 10%. Flotation plants consist of a clarifying basin with sludge removal, aeration equipment for a partial stream of clarified water, and a dosing plant for the flotation chemicals. The advantage of flotation is that small-size colloidal material also can be removed (if suitably flocculated prior to flotation). This is a great advantage in recovered paper plants (see Section 5.3.8 with de-

inking, where a large part of the solid material in the process water is colloidal (in a de-inking plant the floated sludge is pumped to sludge de-watering instead of being recycled to the process).

Sedimentation installations are suitable for the clarification of filler-loaded process water but necessitates large volumes and therefore a large space requirement.

The fibre stream that is recovered in save-alls is returned to the stock chest and the different quality waters are returned to different use relevant to their quality where it replaces fresh water.

The tertiary circuit contains excess water from the secondary circuit and, in addition all other process water which is not, or is not directly reusable because of its degree of contamination. It is treated in chemo-mechanical and/or biological wastewater treatment plants. Up to now re-use of purified water is not fully applicable for all paper grades. In some cases purified water is partially returned to the process depending on product quality and local conditions. Closed water circuits are only realised in a few paper mills producing corrugating medium based on recovered paper processing (see Section 5.3.4) or board.

From this description, it can be seen that a very large quantity of water is involved at the wet end of a paper machine and there is usually a high degree of water recirculation in different water loops. About 1 - 1.5 m³/t of paper is usually evaporated in the dryer section of a machine and lost from the process. "Dry" paper product in equilibrium with a normal atmosphere is around 6 to 10% water.

6.1.4 Broke system

The term "broke" refers to any formed paper from the beginning of the papermaking process to the finished product that is never shipped to the customer. Broke will exist in many forms and varying quantities and it will always be generated by the papermaking process.

The main goal of a broke system is to return the paper fibre back to the process with no disruption to the uniformity and quality of the stock flowing to the paper machine. Every paper machine is different. There are no two paper machines that are exactly the same even the machines producing the same paper grades. It follows therefore, that no two broke systems are alike (in chemical point of view).

The amount of broke produced during papermaking is normally 5 - 20 % of the machine capacity. Sometimes it can reach even amounts of 50 % of normal production.

Depending on the particular case, machine broke will be generated at the different locations. Broke is produced during web breaks. Wet broke is generated even during normal operation in the form of edge trimming at the wire section, and dry broke is produced in finishing operations. The broke pulps originating from the wet and dry ends of the paper machine are not identical in terms of their papermaking characteristics.

On coated paper machines the broke system needs different storage towers for wet (uncoated) and for dry (coated) broke (see Figure 6.4). The figure shows a possible lay out of a broke system of a paper mill manufacturing coated paper.

Broke pulp is pumped from the storage towers to the thickeners where excess water is removed. Thicker broke is fed to the broke dosage chest, where the coated and uncoated broke are mixed together. After the broke dosage chest the broke is cleaned in several stages to minimise the waste broke which can not be recirculated to the process. The cleaned broke is discharged to the

main line mixing chest, from where the final papermaking furnish is pumped through additional cleaning to the paper machine.

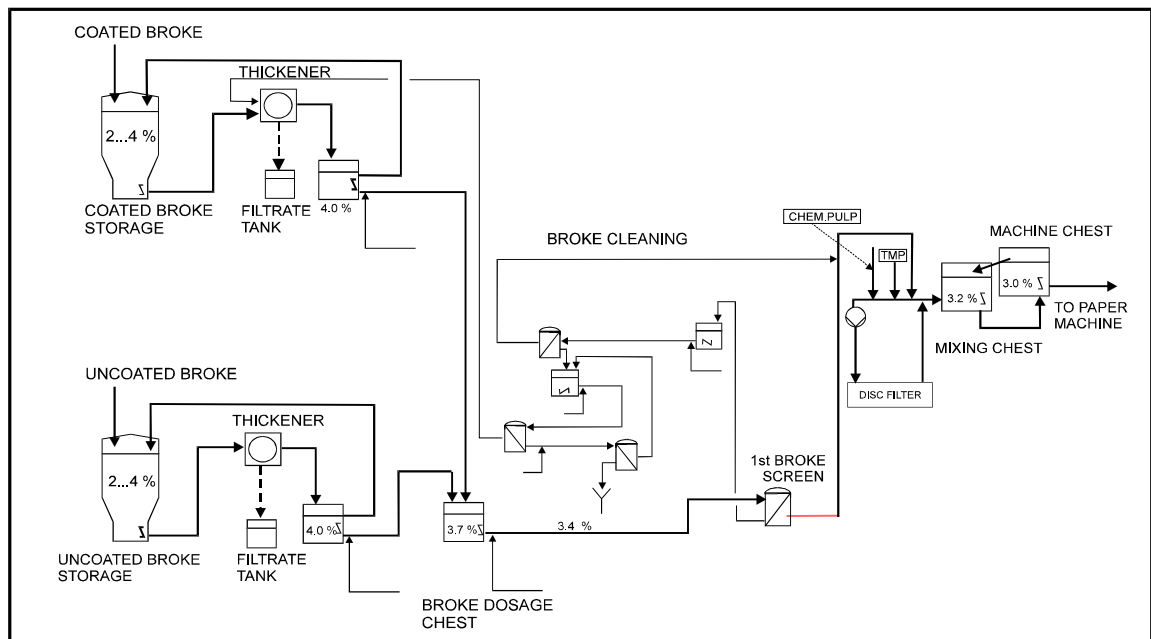


Figure 6.4: Possible lay out of a broke system of a paper mill manufacturing coated paper
Uncoated and coated broke are stored in separate tanks

6.1.5 Sizing (optional)

Usually sizing means wet end sizing where starch or synthetic sizing agents are added direct to furnish to reduce the natural suction capacity of the paper. In sizing, starch or other sizing agents are applied to the fibre matrix to increase the strength of the base paper web and to modify the surface properties with respect to liquid uptake during writing, printing or coating. Wet end sizing is applied for instance to fine paper (copy paper) and some special paper grades.

The potential environmental impact of size application is mainly the releases to water. If sizes are added to the paper stock significantly higher concentrations of COD in the water circuits can be measured. Also the re-pulping of sized broke increases somewhat the COD in the water circuits. For instance, the re-pulping of starch-coated broke is one of the main sources of BOD in the writing and fine paper sector.

Sizes may also be applied to the surface of the paper sheet (surface sizing) to avoid dusting (linting) of the paper in offset printing process. Surface sizing increases also surface strength of the paper. In surface sizing, the web is passed through the sizing liquor pond, which is located above a roll nip that presses on the web (size press). As a result the paper web absorbs the sizing liquor. The amount of size taken up depends on the dry content of the web that can reach 98% before the size press.

Size press technology has advanced over recent times with film size press becoming the norm in preference to the older technology that effectively flooded the sheet at a nip between two rolls. Film size presses involve the application of a controlled amount of water based size mixture evenly to the paper sheet by first creating a uniform film thickness on an adjacent roll and then transferring the film onto the paper sheet as if printing the size film onto the paper. The water applied in the size press is evaporated in the after-dryer section. Size presses are mainly used for printing and writing papers and packaging grades made from recycled fibre.

If size is applied by a size press only relatively small amounts of concentrated size have to be discharged when operation conditions are changed.

Although size press treatment is a form of paper coating to improve its surface properties, the term "coating" is usually reserved for the application of a pigmented slurry to the surface of the paper in order to improve its printability or for other specialist applications.

6.1.6 Coating (optional)

Paper, composed of individual fibres has a relatively rough surface. Since this roughness has a negative effect on printing, a large amount of paper and board is coated in order to attain a smooth surface for printing. The term "coating" describes the application of a mixture of water, white pigments, binder, and various additives to one or both sides of the surface of the paper in order to create specific surface qualities. Paper may be coated either on equipment that is an integral part of the paper machine (on-machine) or on separate coating equipment (off-machine). The coated sheet is dried by a short steam-heated cylinder section, by infra-red radiation, by hot air or a combination.

The composition of the coating colour is largely determined by the demands made on the surface of the paper by the particular printing process. Coatings can be complex mixtures of ingredients and usually require preparation before use. The coating colour preparation is carried out in the so-called coating kitchen where the coating chemicals are mixed and adjusted. The finished coating colour is screened before entering the coating machine. Some raw materials may be received wet for easier handling and to avoid any dust problem. All coatings will contain some sort of binder. Starch may be used for added stiffness but will typically be cooked prior to use. Stearates (Ca and NH_4) are used to provide lubrication during application and surface texture. Pigments will be used such as fine clay, talc, or calcium carbonate, as will colours, brighteners and other low volume speciality chemicals.

Coating machines consist of an unwinder, a coating station or stations (coating application unit), a drying section (infrared, hot-air and heated cylinders are used) and a reel. For optimal operation various control measurements are installed.

Nearly all coatings are water based applied with roller, air knife, size press, blade and bar coating systems all with the objective of laying down a consistent thickness of coating material to the paper sheet. Air knives work at about 30 - 50% solids, others about 50 - 70 %. The coating slurry is generally recirculated through the system with constant filtering to remove fibres and other contamination in order to maintain the slurry quality. These filters will be cleaned at regular intervals thus generating a concentrated waste stream.

There are different grades of coated paper and boards to be distinguished. However, the classification of coated grades has not yet been standardised. Certain terms for describing the major types of coated paper and board are used throughout Europe. They are shortly described below.

Art Paper. The term refers to wood-free or slightly wood-containing paper that is coated on both sides. The weight of the coating exceeds 20 g/m^2 per side, resulting in the complete disappearance of the fibre structure of the raw paper. Up to three coats are applied to each side to obtain the high quality required. This paper is used for high quality printed products.

Machine-Coated Papers. This grade includes both wood-free and wood-containing papers with a coat weight up to 18 g/m^2 per side. Higher weights are often obtained by applying a double coat. The coating formulations are normally simpler than those for art paper. Machine-coated papers are used mainly for printing purposes.

Lightweight Coated (LWC) Papers. These papers are highly wood-containing and generally have coat weights in the range 5-12 g/m² per side. They are mass papers and are used for the production of catalogues, magazines, advertising pamphlets etc. The weight ranges has been extended below (ULWC = Ultra-LWC) and also above (MWC = medium weight coated and HWC = high-weight coated) these limits. Today the heavy grades are often provided with a double coat and are, consequently, grouped with machine-coated grades.

Folding Boxboard and Chromoboard. In these grades of board, the white topline is coated on the board machine. The remaining layers of board can consist of bleached or unbleached pulp or of recovered paper. The coating weight is in the range 12-33 g/m² and the coat is normally comprised of a precoat and a topcoat. More recently, three coating layers have also been applied. The board is rarely coated on the reverse.

Depending on the operation of the coating kitchen, coating application and the measures in place for recovery or separate treatment of coating-colour containing effluents relevant releases to water can occur (see 6.3.5 and 6.3.6). In some applications somewhat increased concentrations of volatile organic compounds (VOCs) can be measured in the exhaust gases of the drying hood.

Potential releases to water can be caused by either spill of concentrated coating components (\cong 50% consistency) from coating kitchen or coater station or diluted coating components from washing water of tanks and piping. The concentrated discharges can be collected in tanks or mobile containers for solid waste treatment. The diluted streams are collected in tanks, from which they are led to the effluent treatment. Usually, effluents from coating require a separate pre-treatment in a flocculation plant (see 6.3.6). Otherwise, coating wastewater may cause disturbances in the performance of the biological wastewater treatment plant. In recent years the membrane filtration technology described in Section 6.3.5 has produced good results in coating colour recycling. In applications in Finland, Sweden, France and Germany the recovered coating colour is recycled back to the coating kitchen where it is proportioned to the fresh coating colour. Coated broke is normally re-pulped so that some of the coatings are returned to the water circuit

6.1.7 Dyeing of paper (optional)

Coloured papers are obtained by dyeing the paper stock or the paper surface (size press, paper coating). Optically brightened papers can be produced in the same manner.

Stock dyeing is the most widely used type of paper dyeing. Dyes, pigments, and optical brighteners are added either batchwise in the pulper or mixing chest or introduced continuously into the stock flow. Continuous addition has the advantage of a shorter zone in the stock line that must be cleaned when the colour is changed. However, because of the lower contact time compared to batch addition a lower colour yield is obtained for intensely coloured papers and more complex equipment is required for this dyeing process.

When the surface of the paper is coloured in the size press the dyes are added to the size press liquor. Surface dyeing has gained acceptance only in individual cases because uniform dyeing of the paper is difficult to achieve. However, this process has the advantage of the absence of dyes in the water circuits.

Surfaces of papers can also be coloured by coating. In normal coating (see 6.1.6), the surface of the paper or board is covered with a pigment coating. In the case of coloured coatings, the starting material is the white coating mixture, and the desired shade is attained by adding a dispersion of an organic or inorganic pigment.

Depending on the fibrous material to be dyed and the intended purpose of the paper different types of pigments and dyes are used as basic dyes (cationic dyes), direct dyes, acid dyes. Additionally fixing agents and other additives are used to improve dye fixation and to obtain better dyeing results. As pigments either inorganic pigments or organic pigments (e.g. azo and phthalocyanine types) and carbon black are used for paper dyeing.

The potential environmental impact of colouring is mainly the releases to water. Especially in mills with several changes of tints or shades per day the water circuits have to be cleaned after a certain time. Usually, the paper mills work in campaigns producing first the paler tints changing step by step to the deeper tints. The coloration of the water has then just to be re-adjusted. However, when for instance deep green is reached, the water system has to be washed. The coloured wastewater is sent to the water via wastewater treatment plant. Several times per month the piping is subjected to a chemical attack to eliminate deposits and colour in the piping. In some mills for this chemical treatment elemental chlorine and hypochlorite are used.

6.1.8 Addition of chemicals

Apart from the main raw materials, i.e. fibrous material and fillers papermaking requires the use of various admixtures of chemical additives and auxiliaries. One part serves as a mean to achieve certain paper properties (e.g. sizing agents, wet strength agents, dyestuffs, coating colours); the other part improves operations in the production process (e.g. retention agents, anti-foaming agents, cleaning agents, and slimicides).

Chemical additives may be delivered to site ready for use or prepared on site - typically low volume speciality chemicals will be delivered ready for use whereas the higher volume chemicals may be either. This holds true for coatings as well as those added to the paper stock. Chemical additives can be added at the wet end with the dilute feedstock or sprayed onto the wire, whereupon it is formed into the body of the paper, or at the size press or coating end of the machine, where it is added to the surface. In the former case all of the chemical which fails to be retained within the paper web will remain in the water circuit probably passing to effluent. The chemicals remaining in the water circuit may hinder the process of closing up the water cycle and may have a negative impact on the waste water treatment plant also. However, it depends on the type and quantity of applied chemicals.

Adding chemicals to the surface by spray or by dipping is potentially more controlled and need only involve water for washing out and cleaning. However, this is only possible for a few applications. In those few cases any wash-water could be segregated for separate treatment. For example, liquid residues from coating can be treated separately in a precipitation step or by use of ultra-filtration (see Section 6.3.5 and Section 6.3.6).

The main papermaking additives and their environmental properties are discussed in more detail separately in Section 6.2.2.3 and in ANNEX I.

6.1.9 Calendering (optional)

The objective of calendering is to produce a smooth paper surface that meets the printing and writing requirements for the intended use. In calendering, the web is fed through counteracting press rolls and in this process the surface roughness is influenced by the action of pressure and very often temperature. Machine calender consists of two or more chilled cast-iron rolls with very smooth surfaces that are arranged one on top the other as shown in Figure 6.5.

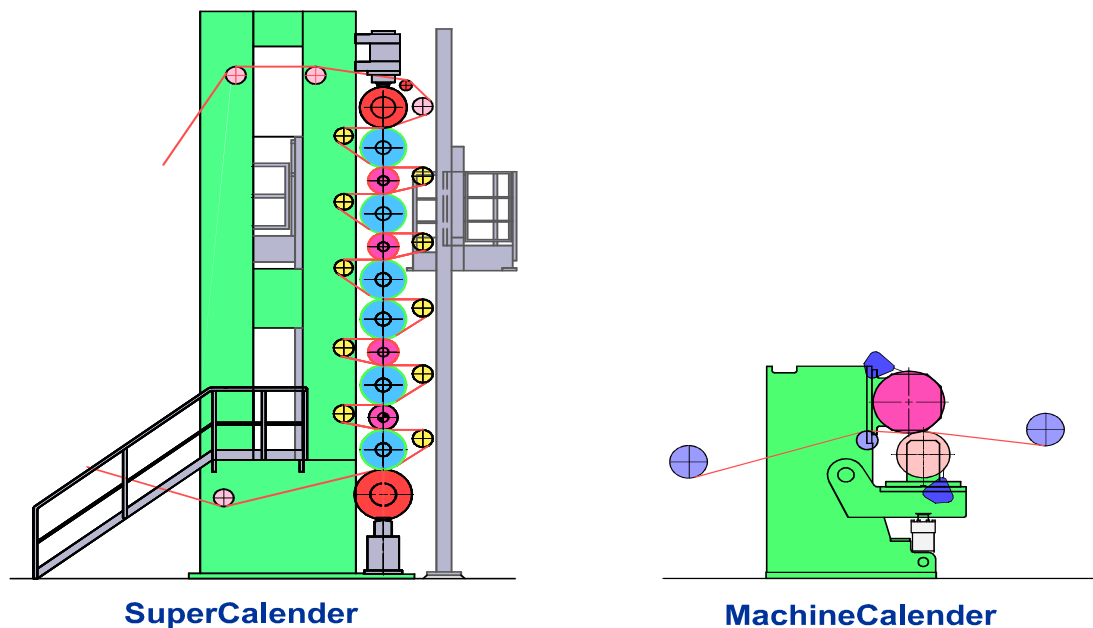


Figure 6.5: Example of two different calenders: supercalender and machine calender
[Figure provided by Valmet]

The web is passed through the nips of these rolls (hard nips). Nowadays, calenders have a heated cast-iron roll combined with a roll with a soft plastic cover (soft nip). Two or more of these are arranged one behind the other. The rolls are heated internally with hot water, steam or heating oil.

The paper web that has been made in the paper machine or coater is often subjected to a further finishing treatment called supercalendering (Figure 6.5). A uniform, high surface smoothness is produced in this process, which is carried out independently of the paper machine, usually in supercalenders. This treatment also improves the gloss. Supercalendering increases printability that is necessary in case of picture printing. Before supercalendering, the web is on some grades checked in rewinders for possible defects. Defective parts are eliminated and the ends of the web are spliced together again. The supercalendering system consists of the reel-off stand, the actual supercalender, and the reel-up stand.

The environmental impact of (super)calendering is mainly the energy consumption needed for running the machine and heating the rolls

6.1.10 Reeling / cutting / despatch

The final paper product will be made to customer specifications in terms of roll or sheet sizes, paper weight, colour and finish. Most paper machines will produce large rolls of paper where the width of the paper web has been determined by trimming the sides of the web at the wet end of the machine. It is usual to finish products with sharp rotary knives and guillotines off machine by trimming rolls to exact widths and cutting to sheets before wrapping for dispatch. There may also be a stage of conditioning the paper product to a specified moisture content so it is consistent throughout, dimensionally stable and fit for intended use such as printing or packaging.

The environmental consequences of these operations are relatively small, but there is the potential for dust generation in cutting. Involved processes consume little energy. Waste is generated of trimmed paper, which is normally recycled as broke back to the papermaking process.

6.1.11 Examples of non-integrated paper mills in Europe

Paper and board manufacturing processes can take place at the same site with pulp production (integrated mills) or separately at a site of its own (non-integrated mills).

In 1993 there were operating 830 non-integrated paper mills in Western Europe with a total capacity of about 30 million tonnes/a. This corresponds to an arithmetical average production capacity of about 35000 t/a. There is a high share of non-integrated paper industry in countries like Italy (211), Germany (161 mills), Spain (114 mills), France (107 mills) and United Kingdom (81 mills) [J. Pöyry, 1994 b].

Different paper and board grades are manufactured from different raw materials with machines that are designed for each paper and board grade. However, until now there is no common understanding in Europe which paper grades have to be distinguished from an environmental point of view to describe achievable emissions of paper mills which have implemented BAT. The classification systems of trade statistics (e.g. National statistics, CEPI statistics) are not the same as those used by the Member States for setting legal requirements for the paper industry. The classification of paper mills varies from country to country. As a consequence, there is no existing classification that can just be adopted.

In Europe, the biggest number of non-integrated paper mills is manufacturing fine paper, tissue or speciality papers. However, it has to be born in mind that in some countries these paper grades are also produced in integrated mills. For instance, in the Nordic countries the fine paper mills have in most cases been built adjacent to a pulp mill. Tissue is also either produced in integrated (mainly using recovered fibres) or non-integrated paper mills.

6.1.11.1 Uncoated woodfree printing and writing papers

Printing and writing papers includes products like wood-containing magazine printing papers (see Chapter 4) and wood-free natural printing papers.

Wood-free natural printing papers consist almost exclusively of bleached hardwood and softwood chemical pulp. 10 - 20% fillers may be used. These uncoated papers are usually sized and further upgraded by surface sizing and calendering. Wood-free printing papers do not yellow to any appreciable extent and have a high strength.

During the cleaning and screening of the stock only small quantities of rejects are purged, as the raw materials are largely pure. During refining the fibres are shortened and fibrilled. During fibre fibrillation a small part of the organic material is dissolved.

Other wood-free paper products consisting primarily of chemical pulp include amongst others products as tissue, cellulose wadding, filter paper, decorative paper, base paper for lamination or parchment base paper. They also include those products where size is added to the mass to reduce the natural suction capacity of the fibre web as e.g. poster paper, carbon paper, kraft papers and drawing papers. Sizing increases the organic substances in the water circuits and during re-pulping of the broke most of the additives can be re-dissolved (e.g. converted native starch).

6.1.11.2 Coated woodfree printing and writing paper

Coated printing papers represent the largest group within the printing and writing papers. The largest part of this group - wood-containing, coated printing papers - is described in Chapter 4.

The base paper for wood-free, coated paper consists predominantly of chemical pulp. A layer of coating colour is applied to both sides of the paper web. These papers may be additionally calendered to supply them with a dull or glossy surface. Besides printing paper and art paper the production of chromo-board (the white topline of board) is also included in this group.

During the stock preparation process only small quantities of rejects are purged, as the raw materials are largely pure. Coated paper is dried two times, in the usual drying section and again after application of the wet coating. Depending on the paper type produced additional additives are added in the mixing chests which can result in wastewater contamination. Coating and finishing consists of both surface sizing and application of coating colour (one or several coats on one or both sides). The preparation of the coating colour and the re-pulping of the broke result in additional wastewater contamination, consisting of undissolved substances as well as dissolved oxygen consuming substances.

6.1.11.3 Tissue paper

Tissue is usually a product where the single layers produced in the paper machine are combined to a multi-layer product after the paper machine in a separate unit. This is because of its low basis weight sheet (down to 12 g/m² on the wire). The main product properties are softness and smoothness, cleanliness, high absorption capacity and strength. Converting into finished products is often integrated with the tissue production i.e. tissue mills often sell their products to the end-consumer (including packaging).

Tissue is predominantly made of bleached chemical pulps or de-inked recovered fibres (see Chapter 5). In case of using recovered paper, the fillers and fines (very small fibres unsuitable for tissue manufacturing) have to be removed. A mixture with different shares of virgin and recovered fibres is also frequently used. If recovered fibres are used the mills are integrated or partly integrated respectively. In recovered paper processing mills much water is used to remove fillers and fines from the stock. These substances appear as increased sludge to be handled and dealt with. For the processing of recovered paper with de-inking it is referred to Chapter 5.

For tissue manufacturing different drying technologies for different products are used as e.g. the conventional Yankee dryer or the significantly more energy consuming Through-Air Drying process (TAD) where huge amounts of air have to be heated. TAD dried products tend to be bulkier and softer which result in a significantly lower fibre consumption for a given product compared to ordinary dried creped tissue.

During the stock preparation process there are only small quantities of losses of fibrous material (1 - 2%). Air emission depends mainly on the energy supply and the lay out of the drying process. Tissue mills tend to use somewhat higher volumes of fresh water on showers than other papers because the cleanliness of wires and felts are crucial for the very lightweight sheet formation. Many tissue machines make frequent changes of grade and/or colour for different products reducing somewhat the efficiency of the use of raw materials, water and energy. This phenomenon is more evident for small mills with only one paper machine. Depending on the product properties additives are added which may result in wastewater contamination. As an example, the use of organic halogenated resins for wet strength improvement leads to higher levels of AOX in wastewater.

6.1.11.4 Speciality paper

Paper and boards for technical and speciality uses cover a wide range of grades. Speciality papers often require fibrous materials or specific fibre processing that are otherwise too expensive to be used. For instance, document paper, banknotes and identification papers contain not only synthetic fibres, but also cotton and jute pulp from rags.

This group comprises highly comminuted paper consisting of pure chemical pulp. Specific characteristics, such as transparency and grease impermeability are achieved by intensive refining. Amongst others, the following paper types are manufactured: accounting parchment, electric insulation paper, capacitor tissue paper, uncoated tracing paper, glassine, parchment replacement, cigarette paper etc. Only small quantities of unsuitable materials are lost during the cleaning and screening process stages, as the raw materials are largely pure. During refining the fibres are shortened and strongly fibrilled. During fibre fibrillation a part of the organic material is dissolved. Depending on the paper type chemical additives are added which may partly end up in the wastewater. The specific wastewater flow varies strongly between 40 and 300 m³/t depending on the product and the specific production conditions. The possibilities for closing up the water circuits are limited by the production technology for this product group (increased heat because of intensive refining) and by the qualitative demands placed on the individual paper types (e.g. electric conductivity, transparency, sensory characteristics).

Special papers for technical, medical, pharmaceutical and other applications are produced in small batches with more than one change of type per day and paper machine as an yearly average. The pulp composition for individual products can vary considerably and includes pre-treated annual plants, bleached and unbleached chemical pulp, chemical and mineral fibres.

The pulp used varies considerably in type and quality. The following paper types are manufactured amongst others: test strip paper, photographic base paper, filter paper for laboratory use, special paper for clinical use, oil filter paper, dust filter paper, impregnating base paper, base paper of vulcanised fibres, electrical laminating paper, sealing paper, calendar rolls paper (e.g. for embossing rolls), carbonless paper, thermal paper, label paper, cast-coated paper, etc. For the production of speciality papers water can only be re-circulated to a limited extent because of the exactly defined quality demands on these special papers. As a result and because of the frequent change of types the specific water consumption may exceed 100 m³/t. The organic load of the wastewater is low. Depending on the quality criteria to be achieved a change of paper type may result in a more or less complete emptying of stock and water system.

6.2 Present Consumption and Emission Levels of Paper Mills

6.2.1 Overview of input/output

An overview of raw material and energy input and the output of products, residues for further utilisation and major releases (emissions, waste etc.) of the manufacturing of paper is presented in Figure 6.6.

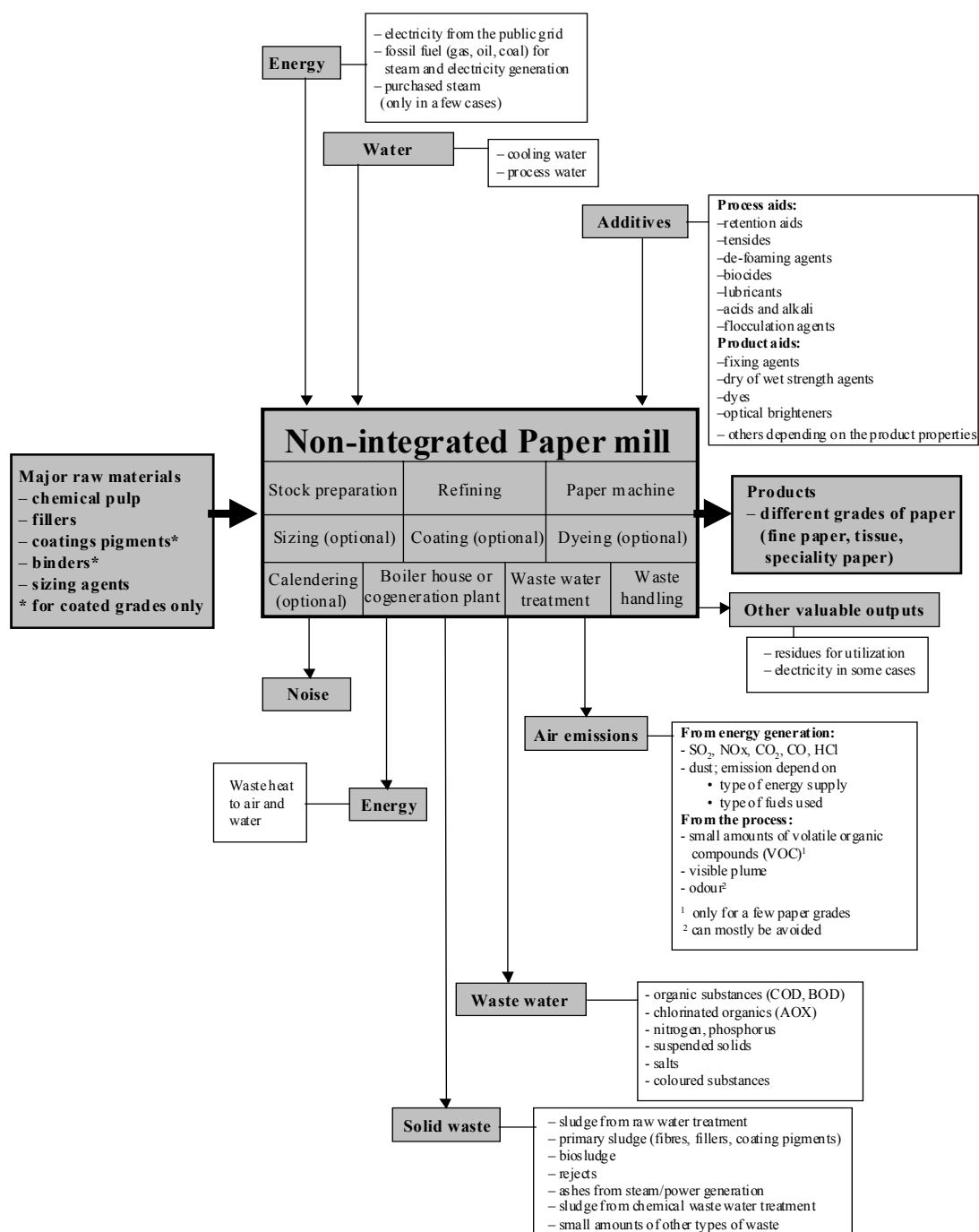


Figure 6.6: Mass stream overview of a paper mill

The presence of some substances depends mainly on the paper grade and properties to be achieved and the type of energy supply

Using the mass stream overview, specific raw material consumption and specific emission per tonne of product can be calculated. Table 6.2 shows data from the biggest fine paper mill in Europe because no other data were available. This example stands for a mill having achieved best performance levels. In Table 6.3 below data for typical tissue mills are given.

Input			Output		
Raw materials	Value	Unit	Product	Value	Unit
Chemical bleached pulp (5% moisture)	610.03	kg/t	Fine paper (coated & uncoated)	1000	kg
Fillers (CaCO ₃), 73% DS	209.28	kg/t	Emissions		
Coating pigments (CaCO ₃ and kaolin, 73% DS)	210.18	kg/t	CO ₂ ³⁾	298	kg/t
Starch, dry	40.33	kg/t	CO _{2, regenerative}	-	kg/t
Binders, dry	29.34	kg/t	NOx ³⁾	0.2	kg/t
Sizing agents, 20% DS	6.36	kg/t	CO ³⁾	0.02	kg/t
Other additives and dyes	15.35	kg/t	SO ₂ ³⁾	negligible	kg/t
Energy			Dust ³⁾	negligible	kg/t
Natural gas for steam generation	5217	MJ/t	Noise: at 2 points of measurement ⁴⁾	47.4 (600m) 39.8 (1200m)	dB (A) dB (A)
Gas for fork lift trucks	0.002	MJ/t	COD	0.44 (97)	kg/t (mg/l)
Gas for shrink ovens	15.4	MJ/t	BOD ₅	0.11 (24)	kg/t (mg/l)
Purchased electricity ²⁾	611.8	kWh/t	Suspended solids	0.14 (30)	kg/t (mg/l)
Total energy consumed	2065	kWh/t	AOX	0.0007 (0.15)	kg/t (mg/l)
Total primary energy ¹⁾	3136	kWh/t	N _{inorganic}	0.041 (9.2)	kg/t (mg/l)
			P _{total}	0.003 (0.8)	kg/t (mg/l)
			Water vapour	1.5	m ³ /t
			Wastewater flow	4.5	m ³ /t
Water demand			Residues		
Raw-/fresh water	6	m ³ /t	Sludge (utilised in brick industry)	12.7 (at 100% DS)	kg/t
			Other waste	5.1	kg/t

Notes:

- 1) The contribution of purchased electricity to the specific primary energy consumption is calculated assuming an energy yield of the electricity generating companies of 36.75%, i.e. purchased electricity of 1 kWh corresponds to primary energy of 2.75 kWh. In this case 611.8 kWh/t corresponds to 1682.45 kWh/t primary energy (e.g. coal). Conversion factor: 1 MJ = 0.2778 kWh and 1 kWh = 3.6 MJ.
- 2) Consumption of power includes delivery of raw water pumps
- 3) Air emissions from purchased electricity are not included. Steam is produced on-site in a gas fired steam boiler. Air emissions from non-integrated paper mills depend mainly on the type of fuel used.
- 4) The distance from the paper mills to a commercial area is about 600 m; the distance to a residential area 1200 m.

Table 6.2: Annual average input/output data from the biggest non-integrated wood-free fine paper mill in Europe (coated and uncoated grades) manufacturing about 1018450 t/a (1997)¹²
The data to emission to water represent the situation after 2-stage biological treatment (high-load trickling filter plus activated sludge)

Table 6.2 refers to a very big paper mill. However, it should be noted that smaller mills often have higher specific energy consumption values and also higher water consumption than bigger mills. Reasons for differences in environmental performance between bigger and smaller paper mills are for instance:

- fresh water needed for continuously trimming the edges of the web is the same for wider and narrower machines. Thus, paper machines with a larger width use relatively less water for that purpose.

¹² Environmental Declaration '98 Nordland Papier AG, UPM, Postfach 11 60, D-26888 Dörpen, Germany.

- Bigger machine produce usually bulk grades. That means, less changes of grades are necessary that cause higher water consumption and increase pollutant load when the system has to be washed
- The economies of scale facilitate investments in clean technology for bigger mills
- Bigger mills have more financial and human resources for research and development

In Table 6.3 consumption and emission levels for tissue mills are compiled. The main difference between virgin and secondary fibre mills is solid waste. While virgin fibre mills generate 10-40 kg waste/t of paper (100% dry solid) amounts of 400 - 1000 kg waste/t of paper result from recycled fibre processing (see Section 5.2.2.6).

Input			Output		
Raw materials	Value	Unit	Product	Value	Unit
Chemical bleached pulp	1010-1020	kg/t	Tissue	1000	kg
Wet strength resins	0-80	kg/t	Emissions		
Starch, dry	0-30	kg/t	CO ₂ ⁴⁾	300-1800	kg/t
Colour agents	0-2	kg/t	CO _{2, regenerative}	-	kg/t
Other additives	0-20	kg/t	NO _x ⁴⁾	0.5-5	kg/t
			SO ₂ ⁴⁾	0.07-10	kg/t
			Dust ⁴⁾	n/a.	kg/t
Energy				before	after treatment
Fuel for steam generation	5000-25000	MJ/t	COD	n/a.	2 -6 kg/t
Total electricity consumed ¹⁾	1000-3000 ³⁾	kWh/t	BOD ₅	n/a.	1 - 2 kg/t
Total energy consumed ²⁾	2000-10000	kWh/t	Suspended solids	n/a.	1 - 3 kg/t
			AOX	n/a.	5 - 15 g/t
			N _{total}	n/a.	5 - 100 g/t
			P _{total}	n/a.	1 - 30 g/t
			Water vapour	1	m ³ /t
			Wastewater flow	6 - 100	m ³ /t
Water demand			Residues		
Raw-/fresh water	7-100	m ³ /t	Solid waste	10 - 40 (at 100% DS)	kg/t

Notes:

- 1) No allowance is made for efficiency of electricity generating companies.
- 2) The specific primary energy consumption can be calculated from this figure by taking into account the energy yield of the electricity generating companies. Conversion factor: 1 MJ = 0.2778 kWh and 1 kWh = 3.6 MJ.
- 3) The upper end of the range refers to tissue mills using through air drying (TAD) or re-creping techniques. To operate TAD enormous volumes of air need to be moved by large fans.
- 4) The emissions include all fuel types for generation of steam. Emissions do not include purchased energy.

Table 6.3: Consumption and emission levels for typical tissue mills [ETS data]

Emissions to water are given as typical values before and after treatment. Apart from data ranges for solid waste there is no significant difference between consumption and emission levels for virgin and recycled fibres

6.2.2 Consumption and emission levels

The following aspects associated with paper manufacturing are of concern:

- Consumption of raw materials
- Water use
- Use of additives
- Energy demand
- Wastewater emissions

- Solid waste generation wastewater
- Air emissions from paper machines
- Air emission from energy generation
- Odour from vapours and from wastewater treatment plant (local)
- Noise from paper machines (local)

Low frequency vibration and emission of visible plumes can also be a local aspect of concern. No information was provided on this issue and therefore it is not further described here.

As for the reported emission and consumption figures, it should be borne in mind that, due to the use of some different measurement methods in the various Member States, data are not always strictly comparable from country to country. (See Annex III for more information on this issue but the different methods used do not alter the conclusions drawn in this document).

6.2.2.1 Consumption of major raw material

Paper is made from fibres, water and chemical additives. The consumption of raw materials in papermaking depends strongly on the paper grade manufactured and the final product properties and qualities to be achieved. In Table 6.4 examples of raw material used are compiled. Some product characteristics are also given.

Paper grade	Major raw materials used	Some product characteristics and product examples
Newsprint	No added new fillers; few added chemicals; sometimes pigments added; Very little colour; Uses mechanical pulp or RCF	Narrow weight range 40 - 50 g/m ² a) 100 - 70% RCF based + 0 - 30% TMP b) mainly TMP + 0 - 50% DIP
Kraft Wrapping	No added fillers, coloured; Uses mainly unbleached kraft pulp	High strength product; 70 - 100 g/m ²
Kraftliner or Testliner	No added fillers; Uses unbl. kraft pulp and RCF or RCF only	Heavier weight; 110 - 160 g/m ² Testliner: 90-100% RCF
Board	Often different compositions in different ply; mostly multi ply sheet; all fibre types including RCF;	Higher basis weights, 175 g/m ² + (up to 2000 g/m ²);
Writing and Printing	All grades of fibre, mainly bleached; Fillers, sizes, colours, brighteners; may be coated; Wide range of basis weights;	Precise specification for user; specific weight from 30 g/m ² to 50-60 g/m ² (LWC) up to 90-120 g/m ²
Tissue	No added fillers; wet strength additives; Uses chemical pulp + RCF in different mixtures	Lightweight product ¹ e.g. Handkerchiefs: 15 g/m ² (for three sheets) Napkins: 20 g/m ² (for two sheets)
Speciality papers	Specific fibre processing; The pulp used can vary considerably in type and quality	This group covers a wide range of grades;
Notes:		
1. The sheet made on a tissue machine rarely exceeds 40 g/m ³ . The higher basis weights of tissue products are achieved by plying up in converting.		

Table 6.4: Examples for major raw materials used for manufacturing of different types of paper

6.2.2.2 Water use

In paper mills fresh water is mainly used:

- As cleaning water for the paper machine called shower water. The function of showers is to lubricate and to clean forming fabrics and wet press felts to maintain satisfactory dewatering performance: 5 - 20 m³/t
- As sealing water and confining in stuffing boxes, suction boxes, vacuum systems and cleaners: 1 - 6 m³/t
- As a solvent and dispersant for fillers and additives: 1.5 - 3 m³/t.
- For some paper grades: Make-up water in stock preparation
- Cooling of process equipment: 3 - 10 m³/t. These waters are often re-circulated and used as process water. Other mills discharge it separately. Therefore, this water is normally not included when water consumption of paper mills is reported
- Power plant: 2 - 3 m³/t. This water is normally not included when water consumption of paper mills is reported.

The simplified scheme in Figure 6.7 shows by use of an example the major positions where fresh water is used. It assumes that cooling water is re-used in the process. Paper mills discharging cooling water would need correspondingly more fresh water. When comparing figures on water consumption in paper mills one has to make sure that the compared figures include the same positions for water consumption.

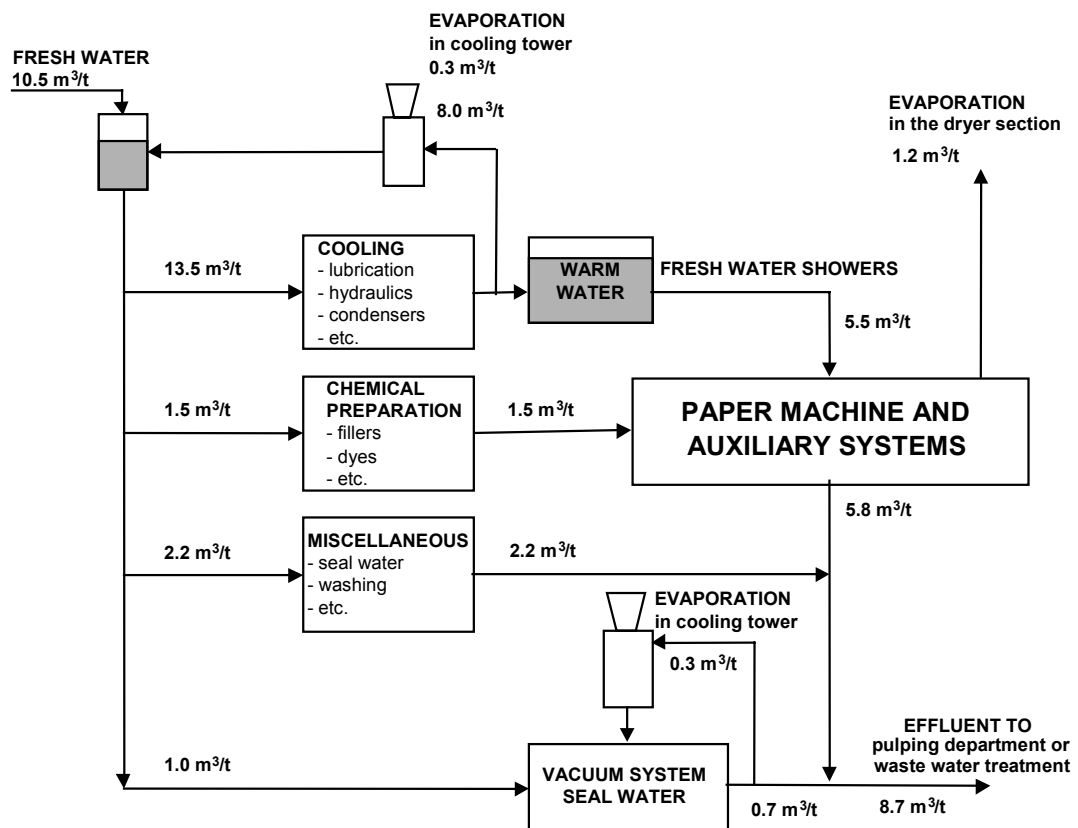


Figure 6.7: Positions of fresh water demand in a paper mill

Example of a paper mill using 10.5 m³/t fresh water. Cooling water is re-circulated by use of cooling towers. The circulated water from the vacuum pumps are not shown (the flow might be in the range of 6-8m³/t). The figure shows only the net water flows (input/output) under continuous operation. Unbalances of the water flows during e.g. start-ups where usually a bigger amount of water is used are not taken into account. "Miscellaneous" is a somewhat "grey area" but is not negligible

Fresh water is normally introduced in the papermaking process mainly through paper machine forming section and press section showers after which, it is fed upstream to various washing and diluting processes in the mill.

In the stock preparation units typically there is no demand for fresh water i.e. fresh water is usually not required for dilution of incoming fibre raw material. If different qualities of white water are available, the water with the highest fibre content (cloudy filtrate) could be used in pulping units. However, most of the cloudy filtrate is used in the short circulation for adjusting the consistency of the incoming fibre slurry. The need for fresh water is limited to dilution of chemicals and to sealing water for some of the equipment. Most chemicals must be diluted with fresh water before entering the paper machine system because otherwise quality problems may arise and the dosages have to be increased. For the dilution of fillers it is sometimes possible to replace the fresh water with clarified water if there is no risk of anaerobic biological activity.

As fibre passes through a pulp or paper mill, different consistencies are required at different stages of the process. Each increase in fibre consistency creates an effluent at that point with the amount and type of contamination depending on the particular unit operations upstream. The ability to recycle that water to another point in the process may be constrained by the chemistry at different stages.

The amount of fresh water use in paper production varies depending on the paper grade produced, the nature of raw material used and the final quality level within each paper grade. Typical ranges for water consumption in the manufacture of a number of paper types are given in Table 6.5.

Paper grade	Water discharge [m ³ /t]	Remarks
Tissue	10 ¹ - 50	For RCF based tissue: includes RCF processing
Printing/writing, uncoated	5 ¹ - 40 ²	may include water used in pulp processing
Printing/writing, coated	5 ¹ - 50	may include water used in pulp processing
Paper board	0 ¹ - 20	includes water used in pulp processing
Speciality paper	10 - 300 ³	
Notes:		
1 the lower end of the range is changed by EIPPCB according to current performance data		
2 the higher end of the range is changed by EIPPCB because the given figure of 90 m ³ /ADt seems to be unrealistic high		
3 the higher end of the range is changed by EIPPCB because the given figure of 400 m ³ /ADt seems to be unrealistic high		

Table 6.5: Water discharge in European paper mills
[J. Pöyry, 1994 b]. For non-integrated paper mills no data are available

In calculating the specific fresh water consumption, fresh water used as cooling water is not taken into account provided that it had no contact with fibrous materials and additives.

Some additional explanations on specific water consumption for tissue mills

In considering fresh water use there are two main factors to bear in mind with regard to tissue mills. One is the need for high levels of cleanliness of both the product itself (hygienic use) and the tissue machine clothing. The other one is the very low production rates due to the light basis weight products made (down to 12 g/m² on the wire compared to 40 - 50 for newsprint, 50 - 100 for writing papers and several hundred for packaging grades).

Although the absolute volume of water used at a tissue mill may not be significantly higher than some other mills, these two factors can combine to make the specific water consumption appear high.

In a tissue mill there are a number of areas where fresh water is required; shower water to keep the felt surface free from contaminants, high pressure shower water for cleaning the wire, and miscellaneous. The latter will vary from machine to machine depending on operator's activity, white water arrangements and storage volume and degree of automation and information available for the operator. Miscellaneous includes uses such as chemical make up, lubrication showers (inside pressure rolls, on Yankee cylinder edges etc.), vacuum pumps etc. Some of these such as chemical make up may be proportional to production rates.

In a mill applying BAT all other uses of water should be suitable for using clarified water rather than fresh.

There are some machines, especially those making heavy weight, low quality grades, where cleanliness of clothing and product is less important, that can achieve lower figures for water consumption down to 10 m³/tonne or lower. Lightweight, high quality grades that need a very high degree of cleanliness generally have higher specific water consumption.

Where there are grade changes, colour changes, machine shuts, several machines in one mill etc., figures on specific water consumption will be increased. These influences are site specific but could increase water consumption by 25% or more. Generally, in mills that manufacture less variety of products, less colours, less wet or dry strength agents, on large machines, the water consumption will be lower and the other way round.

To summarise: Even on the same machine a change of basis weight and speed of the paper machine can have a significant effect on the specific water consumption. Tissue machines generally run much greater ranges of basis weight and speed than most other paper machines. The same machine can make a basis weight range that varies by a factor of 4, e.g. from 12 g/m² to 48 g/m², and could run at speeds from 500m/min to 1200 m/min. Throughout this range the specific water consumption may vary significantly.

It can be stated that there are no fundamental differences in the water reduction measures in use at tissue mills and other paper mills. However, because of the large variations possible on a tissue machine, the main difference is in the degree to which tissue mills can reduce their specific water consumption.

6.2.2.3 Use of additives

Introduction

Depending on the type of paper produced a very large number of chemical additives might be used in papermaking. However, for the production of the bulk paper grades as packaging papers, some printing and writing papers, newsprint, and hygienic papers the use of chemicals is limited to about 10 to 20 different groups of additives. On the other hand, for production of some fine papers and especially of speciality papers a much higher number of chemicals may be used because of the variety of product properties to be achieved. In all, around 1300 products involving around 800 substances are used [Swedish EPA, 1997]. Besides the intended positive effects on production efficiency and product quality some additives may have potential harmful environmental consequences.

Virgin fibrous materials add up together 45.8% of the total raw material consumption in the European paper industry. Recovered fibres make up 38.8%. Then come 14.9% non fibrous materials [CEPI statistics 97] out of which about 11% are fillers and pigments, mainly in form of kaolin and calcium carbonate. The remaining 3% include the chemical additives. A large share of this is starch, which is derived from renewable raw materials. The traditional chemical papermakers' alum, i.e. aluminium sulphate, makes also a large contribution to the group of chemical additives. As an average about 1 % of the raw materials used for paper production are synthetic chemical additives [EUCEPA, 1997]. The total amount of chemical additives used for paper production reaches 8.1 million tonnes worldwide. 2.8 million tonnes of synthetic chemicals are used (related to dry substance) This amount of chemicals justifies a closer look to better understand any environmental potential impact this may have. The general target is to

find the right balance between water and chemicals consumption, paper quality and protection of the environment.

This great variety of chemicals is faced with a limited number of groups of synthetic chemical additives. There are no statistic data available on the quantities of specific types of additives in the European paper production. But, it can be assumed that the amounts are similar to those reported on a global reckoning. Referring to the Figure 6.8 about 50% of the synthetic chemical additives consist of coating binders, 25% of sizing agents and 8% of wet strength agents.

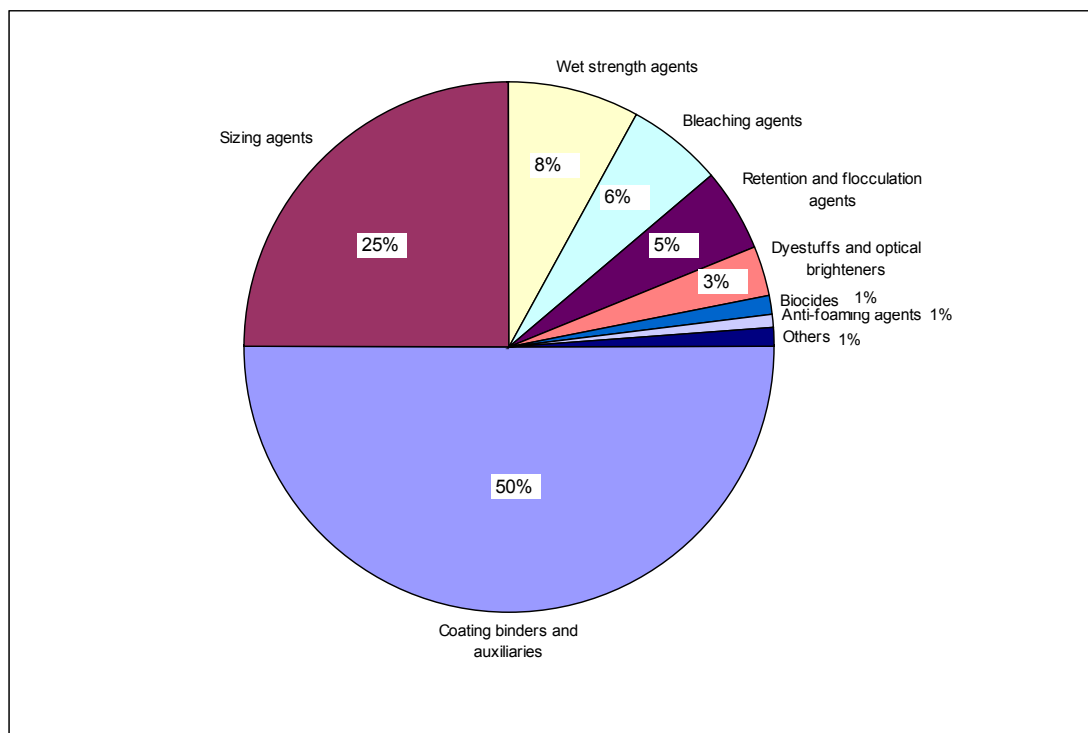


Figure 6.8: Share of different synthetic chemical additives related to the global consumption [EUCEPA, 1997]. It can be assumed that the relative amounts of additives are similar to those used in Europe. Sizing agents include dry strength agents (e.g. cationic starch) used for wet end sizing

Figure 6.8 shows that 5 groups of substances are representing about 95% of the total amount of synthetic additives used.

General issues related to chemical additives

Chemical additives are usually formulations of different chemical substances rather than uniform compounds - they only develop the desired capabilities when mixed. Besides, they can contain by-products originating from product manufacture (e.g. monomers, rests of by-products).

Safety data sheets and goods information sheets of the chemical additives often do not contain information on the actual quantities of dispersants, solvents and auxiliary agents but quote sometimes only the category of the active substance. Furthermore, environmental hazard assessments are often difficult because the names of the ingredients are given as cryptic, non-chemical designations, e.g. tensides or emulsifiers. To prevent risks to environment it is important that all users of chemicals find out what is meant by designations such as "emulsifier" or "tenside". Currently, the operator and the inspector as well often do not know the exact composition of the additives used and this is true in particular of the information on potential

environmental impacts of the formulations. Hazard assessment should therefore preferably involve the chemical additive supplier and an agreed risk management procedure.

There is a need to improve the availability of environmental data on chemical additives and the knowledge of suitable alternatives to better understand environmental fate and effects during use and after discharge.

In some Member States (e.g. Netherlands, Sweden, Germany) extensive survey projects have been carried out aiming at identifying and minimising the possible health and environmental risks, associated with the use of various chemical additives. Some of the projects are still running. It shall be pointed out that the potential problems associated with chemical usage in the paper industry have not been finally "solved" through these projects. An extensive knowledge of the risks of various types of chemicals has been gained, but there is still much work to be done before the environmental effects of each chemical is known.

After use the individual components of added chemicals are distributed in different proportions between the paper product, wastewater, solid wastes and exhaust air, depending on the chemistry and physics of the additive components, the paper raw material and on the conditions of chemical addition as well. Figure 6.9 shows by use of one example (here: biocides) how the fate of additives in the paper manufacturing process may look like.

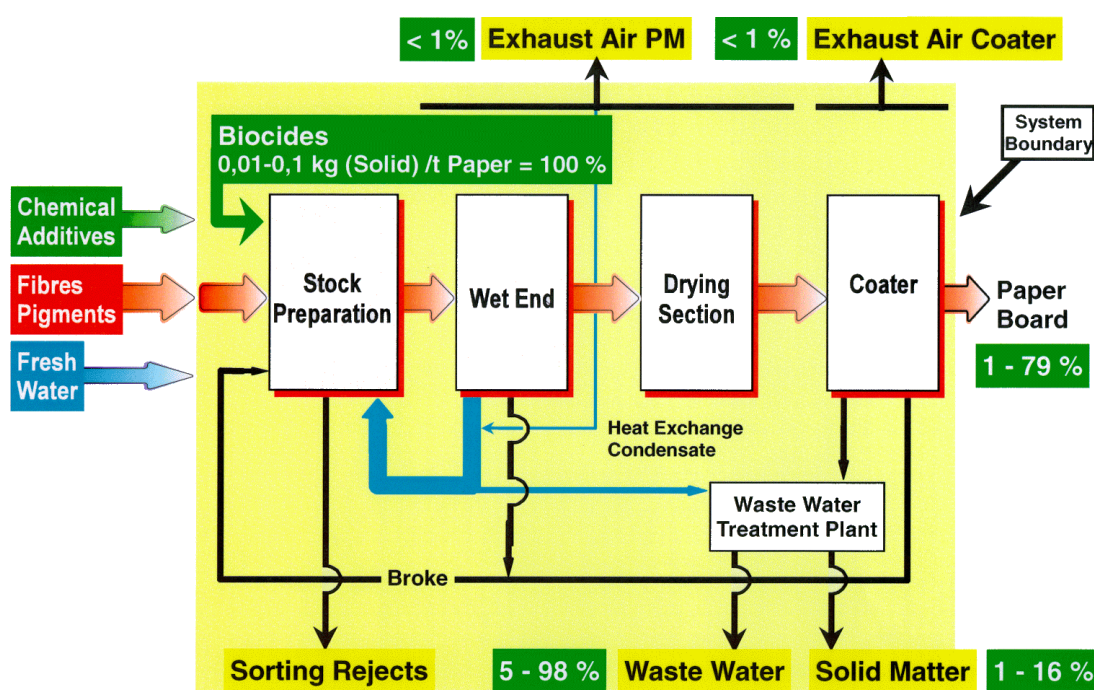


Figure 6.9: Fate of chemical additives in the paper manufacturing process; the example biocides [EUCEPA, 1997]

The example shows that besides the application of biocides in the papermaking process itself (between 10 - 100 g/t of paper) the input of biocides to the system together with other wet-end chemicals (e.g. starch, polyacryl amide), fillers (slurry of calcium carbonate) or utilised fibres (some recovered papers) has to be taken into account for the assessment of the mass flows of biocides presented in Figure 6.9. Because of the big variety of the group of biocides and the fact that a lot of assumptions have been made to assess the possible dispersion of biocides to various parts of the environment the investigation has found relatively large ranges.

In general, the potential releases of chemical additives are screen rejects, wastewater (after treatment), sludge from primary and secondary wastewater treatment and exhaust air from the drying section of the paper machine and the coating machine respectively. A certain amount is usually retained in the paper sheet.¹³

The expected discharge of additives to water is directly related to the retention of the chemicals to the paper product (retention in the process) and the retention in the waste water treatment plant.

The retention factor describes the share of applied chemicals which is retained in the paper product and which is thus not passed to the environment (water, air, and land). The higher the retention the lower the discharge to the effluent and the lower the potential environmental effect of the applied additives. In case of product aids a maximum degree of retention is desirable from an economic (loss of additives) and ecological point-of-view. Since product aids are designed to give paper a particular characteristic, for reasons of costs and efficiency they generally have a relatively high level of retention to the cellulose fibres. Process aids are usually less retained because they produce their effect in the water circuits of the paper mills. A large proportion is discharged with wastewater. Knowledge about the retention of chemical additives and auxiliaries is therefore important.

The degradability of a substance is the crucial point to assess the amount of substances that will end up in the aqueous environment. Supposed that most effluents from paper mills are treated in biological wastewater treatment plants the retention factor together with the biodegradability makes it possible to carry out a rough estimation of the amount of substances released to the recipient.

Finally, if substances are neither retained in the paper web nor eliminated in the wastewater treatment plant data on aquatic toxicity and potential of bioaccumulation are of special importance.

For more specific information on main groups of substances or single substances it is referred to Section 5.2.2.3 and especially to Table 5.6. This table gives an overview about the main process and product aids. For further information it is referred to annex 1 ("chemicals and additives in paper manufacturing"). There the main groups of applied additives are discussed one by one divided into functional chemicals (product aids) and chemical aids (process aids) and subdivided into the most important groups of substances in terms of use and environmental effect.

Where available information on retention factors, biodegradability, toxicity and bioaccumulation are also given.

6.2.2.4 Energy demand

Paper industry could be generally described as energy intensive. Energy is the third highest cost in the papermaking process, accounting for approximately 8% of turnover [DG XVII, 1992]. This is inconsistent with the fact that less is published on specific energy requirement on process level than on water management for instance. Therefore, it is rather difficult to find qualified information on energy consumption related to different paper grades and product qualities, energy efficient technologies, and energy practices and usage within the European Paper Industry.

¹³ This systematic and integrated assessment of chemical additives for which the use and fate of biocides is only one example has been worked out by the German ZELLCHEMING Technical Committee "Paper Production" and for some of the most common substances results have already been published in 1997 [EUCEPA, 1997]. The project is still running. However, there is still a lack of information about the extent to which the different substances are found in receiving environment.

The papermaking processes can be divided into the main areas: stock preparation, wet end, dry end and coating (optional). These can be further sub-divided into main process units. Table 6.6 shows the role of energy in each process and the potential for energy savings in these stages.

Main processes	Main process units	Type and role of energy in each process	Potential for energy saving
Stock preparation	Slushing	Up to 60 kWh power /t to break up dry pulp	Moderate
	Cleaning/screening	The amount of pumping energy and stock heating depend on the number of stages required and the type of fibre (recycled fibre needs more than virgin); About 5 kWh/t is used for virgin stock	Low for virgin fib.
	Refining	Very energy intensive. Electrical energy is mostly used to drive the rotor in the refiner. Depends strongly on the paper properties to be achieved; 100 - 3000 kWh/t	High
Wet end	Forming and draining	It uses large amounts of electricity for machine drive and vacuum processes. Energy efficient design of the headbox and twin wire machine leads to power savings; About 70 kWh/t is used for vacuum systems (varies with grade and porosity)	Moderate
Dry end	Pressing	It is not energy intensive in itself but efficient dewatering can give very large energy savings in the dryers	Moderate
	Drying	Apart from refining it is the most energy intensive process in papermaking. Mostly heat energy	Very high
	Size press and 2 nd dryer section	Heat energy for after size press drying	low
	Calendering	Electrical energy for machine drives and pressing	low
Coating	Coating and dryer	Electrical and heat energy for re-drying	low

Table 6.6: Role of energy in the main papermaking stages and potentials for improvement [According to DG XVII, 1992; changed by EIPPCB]

The total demand for energy (consumption) in the form of heat (steam) and electric power for a non-integrated fine paper mill has been reported [SEPA-report 4712-4, 1997] to consume

- Process heat: 8 GJ/t (\cong 2222 kWh/t)
- Electric power: 674 kWh/t.¹⁴

This means that about 3 MWh electricity and steam/tonne product is consumed. When considering the primary energy demand for converting fossil fuels into power a total amount of 4 MWh/t of paper is needed.

The figures represent a modernised mill, like a mill built in the 1970s and since then modernised. The values include all the stages from disintegration of fibre raw materials to the final paper product and include also necessary service departments. Energy consumption for the coating process is included in the case of the production of coated paper (the mill is considered to have a capacity of 125000 t/a of coated fine paper from market pulp. The paper has a pigment content of 39% and a moisture content of 4.5%).

Table 6.7 shows the energy consumption in the form of heat and electric power for this non-integrated fine paper mill in a little more detail.

¹⁴ This figure does not yet take into account the losses when transferring the energy of fossil fuels into electricity. When converting purchased electricity into primary energy consumption an energy yield of the electricity generating companies of 36.75%, can be assumed. In this case an electricity consumption of 674 kWh/t corresponds to 1852 kWh/t primary energy (e.g. coal).

Department	Process heat [MJ/t]	Electric power [kWh/t]
Stock preparation	0	202
Paper machine	8000	350
Coating kitchen	0	118
Total paper mill	8000	670
Effluent treatment	0	4
Total consumption per tonne of paper	8000	674
Turbine generator		0
Total external supply	8000	674

Table 6.7: Energy consumption in a non-integrated coated paper mill with a production capacity of 125000t/a [SEPA-Report 4712-4, 1997]

The external supply figure shows the amount of the total demand that is purchased from external sources as fuel oil, coal and gas and electricity

The electricity consumption depends to a certain extent on the paper grade produced. The lowest values correspond to packaging paper or corrugated base paper that consumes about 500 kWh/t, whereas printing and writing paper account for about 700 - 800 kWh/t. The highest power demand, up to 5600 kWh/ADt, is needed for some special paper grades. The power is mainly consumed by more intensive refining. More detailed information on electricity consumption is given further below.

Process heat in paper industry is mainly used for four purposes:

- Heating of water and liquors, wood or pulp, air and chemicals to the process demanded temperatures.
Pulp and white water systems can often be kept warm enough without addition of steam. It is essential to minimise the use of fresh water and increase the use of white water from an energy point of view. In non-integrated paper mills except addition of warm fresh water, circulation of the white water through heat recovery is often necessary to keep the temperature at a sufficient level in the white water system.
- Evaporating water.
In papermaking paper drying is the most energy demanding stage during which the major amount of heat is consumed to evaporate water in the paper sheet. It is important to minimise the amount of water to be evaporated by mechanical measures (pressing). Development of the press section (use of twin-wire and extended nip press) has resulted in somewhat lower moisture levels of the paper entering the drying section (this does not apply to tissue paper). In the case of surface sizing or coating the dried paper has to be dried again after adding surface glue or coatings to the paper web. Higher concentration and temperature of these chemicals result in reduced heat consumption.
- Covering the heat loss to the surroundings.
The major part of heat losses with the humid exhaust air from the drying section is compensated by inlet dry air that has to be heated again. The heat requirements can be reduced by reducing the airflow through the drying section. This gives also a higher humidity of the outlet air, which increases the value of air as a source of secondary heat. Heat recovery through heat exchanger between the outlet humid air and the inlet dry air reduces also the heat consumption.
- Conversion into electric power.
An increasing number of mills have installed co-generation of heat and power plants.

Electric power in paper industry is mainly consumed for the operation of various motor drives and refining in stock preparation.

The motors are used for running fans, pumps, compressors, stirrers, paper machines, presses, vacuum systems, various conveyors, etc.

For refining the electrical energy is primarily used to drive the rotor in the refiner. The energy usage varies by product with filter and blotting papers requiring least energy and tracing papers requiring the highest input. Typical power consumption is shown in Table 6.8.

Type of paper	Net energy ¹⁾ for refining [kWh/t]	Gross energy ²⁾ [kWh/t]
Tissue	no data	up to 100
Printing and writings	60 - 100	90 - 300
Carbonless papers	150 - 200	250 - 500
Glassine/Greaseproof papers	450 - 600	600 - 1000
Tracing papers	800 - 1200	1600 - 3000
Notes: 1) Net energy is derived from the gross power minus the no load ³⁾ or free running power 2) Gross energy is the total electrical energy consumed including the losses 3) The no load of a motor is the power that is taken up by mechanical drag and turbulent forces and this therefore not available to treat the fibres.		

Table 6.8: Typical power usage in refining by product [DG XVII, 1992]

The potential for energy savings will be high in many cases. For example, many refiners are incorrectly sized or not well maintained and this results in a high no load power, which reduces refiner efficiency. Incorrect refiner fillings will cause an increased use of energy to achieve a given property. New refiners with enhanced efficiency can also save energy because of the very low no load power associated with this type of refiner.

In the following the consumption of electricity in paper mills is discussed more detailed to illuminate the technical background that build the basis for improvements and the application of energy efficient technologies.

The total electrical energy consumption at paper mills is summarised in Table 6.9. All energy usage inside the paper mill starting from pulp storage towers (in integrated mills) ending at finishing operations is included in these figures. Non-integrated paper mills must have pulpers that increase specific power consumption a little (up to 60 kWh/t). Wastewater treatment is not included. It should be noted that the mill efficiency changes the figures. The lower the efficiency the higher the deviation from the dimensioning figures that refer to 100% efficiency. The correction of the figures by the efficiency rate achieved plays a bigger role at old machines or multi-grade machines with a lot of grade changes.

Paper grade	Power consumption [kWh/t]
Newsprint	500 - 650
LWC paper	550 - 800
SC paper	550 - 700
Fine paper (uncoated)	500 - 650
Fine paper (coated)	650 - 900
Multiply board	≈ 680
Sack paper	≈ 850
Linerboard	≈ 550
Tissue	500 - 3000 *
Notes: * Data range refers to real world examples i.e. no assumption of 100% efficiency. In general, for tissue production new equipment require higher energy consumption, allowing, on the other hand, a reduction of raw material needs. The different drying systems used in tissue mills, conventional Yankee, through air-drying or processes such as recreping, have a much greater effect on the energy consumption than other factors in the mill [according to ETS].	

Table 6.9: Typical electrical energy consumption at modern paper mills based on dimensioning capacity of the paper machine [data from a supplier]

All electric power inside the PM building is included and can be calculated from total electrical energy consumption divided by the dimensioning production of the machine

The total figures for power consumption of paper mills is composed of a number of energy consuming subsystems that are explained in the following. The sum of the subsystems of Table 6.10 and Table 6.15 [all data from a supplier of paper mill equipment] correlates with the total power consumption figures of Table 6.9:

Type of machine	Power consumption	Remarks
Fast machines (> 1300 m/min.)	80 - 120 kWh/t	Head box feed pump energy increases in the third power when PM speed is increased
Slow machines	60 - 100 kWh/t	Slow machine may not have deaeration

Table 6.10: Typical specific energy consumption at the approach flow system of paper mills

Type of machine	Power consumption	Remarks
Fast machines (> 1300 m/min.)	70 - 110 kWh/t	Fast machines have bigger production; therefore specific power consumption is lower
Slow machines	80 - 120 kWh/t	

Table 6.11: Typical specific energy consumption at the vacuum system of the PM wet end at paper mills

Position	Power consumption new machines	Power consumpt. old machines	Remarks
Couch pit	3 -5 kWh/t	3 - 7 kWh/t	Older PMs (before the 90's) typically had concrete vats or the tank shape was not optimised for slushing; technical development resulted in decrease of power cons.
Press pulper	5 -8 kWh/t	7 - 12 kWh/t	
Dry end pulper	7 - 12 kWh/t	10 - 20 kWh/t	
Note: Under machine pulpers are tanks under the PM where paper web is slushed with water. This pulper operates only during the web break			

Table 6.12: Typical specific energy consumption at the under machine pulpers of the PM

Pulp grade	Power consumption	Remarks
De-inked pulp	30 -70 kWh/t	Manufacturing of pulp is not included in these figures; the higher end of the range refers to lower CSF levels. The actual power consumed per tonne of end-product depends on the amount of refined pulp used per tonne of end-product (if e.g. only 30% of refined pulp is required the values have to be multiplied by 0.3)
Long fibre (bleached)	100 - 200 kWh/t	
Short fibre (bleached)	50 - 100 kWh/t	
Long fibre (unbleached)	150 - 300 kWh/t	
Short fibre (unbleached)	100 - 150 kWh/t	

Table 6.13: Typical specific energy consumption for new machines at the refiners per tonne of refined pulp

Type of process	Power consumption	Remarks
White water system	20 -30 kWh/t	Water storage towers, save all, chests, pumps
Broke system	40 -60 kWh/t	Broke tower, broke screens, tanks and pumps
Mixing	10 -15 kWh/t	Mixing chest, machine chest, pumps and agitators
Bale pulping (only for non-integr. mills)	25 -40 kWh/t	Bale pulpers and conveyors, tanks and pumps
Pulp dosing (integr.)	5 - 10 kWh/t	Pulp line from storage to mixing chest; tanks, pumps
PM showers	5 - 10 kWh/t	PM shower water system consisting of pumps, filters, screens
Total electricity	70 - 120 kWh/t	per tonne of product

Table 6.14: Typical specific energy consumption at the stock preparation and white water systems per tonne of paper (excluding refining, pulpers and approach flow system)

Type of process	Power consumption	Remarks
Paper machine	80 - 140 kWh/t	PM drives, former, press, dryer, sizer, reel
Ventilation, PM	40 -60 kWh/t	Hood air supply, hood air exhaust, air to runnability components, wet end ventilation, machine room ventilation, fans and pumps
Ventilation (finish.)	50 - 80 kWh/t	All equipment after the reel (e.g. coating, calendering, winding area, etc.)
Steam and condenser	5 - 10 kWh/t	Condensate and vacuum pumps
Lubrication & hydraulic pumps	15 - 40 kWh/t	Lubrication units and hydraulic pumps
Coaters	15 - 25 kWh/t	
Calanders	100 - 120 kWh/t	
Winders	5 - 10 kWh/t	
Finishing	10 - 15 kWh/t	
Chemicals	5 - 50 kWh/t	Chemical mixers, feed pumps, screens

Table 6.15: Typical specific energy consumption of PM drives

Nearly all electric power that is consumed is transferred to energy in form of mechanical work, and is finally transferred into heat. This heat may be useful in many cases, since the heat contributes in keeping the systems at required temperature levels.

Electric power consumption in many systems in a mill is quite constant and fairly independent of production levels, especially in mills where regulators are not extensively used. A low specific energy consumption may then be achieved by keeping an even and high production level. Amongst others, a minimum idle run of machines implies a minimised electric power consumption.

6.2.2.5 Wastewater emissions

There are different sources of wastewater discharges from paper mills (see Figure 6.3):

Rejects from stock cleaning

Pulp is cleaned ahead of the paper machine for the removal of impurities. The rejects from the cleaners contain the impurities (e.g. shives and sand) and also some valuable fibres, suspended in water. These rejects are usually discharged to the effluent treatment, but may also be discharged directly to the sludge dewatering.

Excess white water

The process water together with the chemical additives applied is drained off in the wire section of the paper machine, to the main part, and is then finally removed from the paper in the press section and the drying section. The white water also contains the spent shower water from the cleaning of wires and felts. The main part of the white water is recycled within the paper machine as dilution water and shower water. The excess of white water - a certain amount of fresh water is added continuously to the paper machine which displaces white water - is discharged to the effluent or being used in stock preparation in integrated mills. This water usually passes through a fibre recovery unit before being discharged.

The amount of discharged white water depends on the degree of closure of the water circuits. It contains the major part of the continuous discharges of suspended solids and dissolved organic substances normally expressed as COD and BOD.

Temporary and accidental discharges

These discharges are not directly connected to the process and occur intermittently. Examples of such discharges are overflows of white water or even pulp from tanks or other equipment with poor level control, spent wash water from cleaning of equipment and flushing water from flushing of floors etc.

Emissions to water or soil from storage and handling of potentially hazardous chemical additives should be prevented by appropriate design and operation of the facilities in such a way that potential pollutants cannot escape (see Section 2.2.2.8)

Cooling and sealing waters

The spent cooling waters and sealing waters from the vacuum system and pumps do usually not contain suspended solids. These waters are often recycled to some extent. Clean cooling waters should be separated from the other effluents in order to minimise the load on treatment plants and to maintain their efficiency.

The most common quality parameters used for final effluent discharges from paper mills include Suspended Solids (SS); BOD_(5 or 7); COD; Total N and total P; AOX; and sometimes individual metals. More recently whole sample toxicity has been used for single mills (e.g. in Germany) or as parameters in an ordinance for paper mill wastewater (e.g. Austria) because of the complexity of effluents containing a wide range of substances.

The data in Table 6.16 below represent typical ranges for key wastewater parameters in discharges of French paper mills manufacturing different grades. These data should essentially be valid for mills within EU. However, the table can only give an indication about typical emissions because no further specifications or assumptions were presented and there are variations within each category. Data on discharges of European paper mills published at other places were less qualified so that it was even more difficult to understand what they represent. Qualified data on common emissions to water are still rare in Europe i.e. those data that include specifications for the different paper grades and also information whether or not and to which extent pulp production is included.

Paper type	TSS [kg/t]		COD [kg/t]		BOD ₅ [kg/t]	
	before treatment	after treatment	before treatment	after treatment	before treatment	after treatment
Woodfree printing & writing	12 -25	0.3 - 2	7 -15	1.5 - 4	4 -8	0.4 - 0.8
Paper board	2 - 8	0.3 - 1	5 -15	1.2 - 3	3 -7	0.3 - 0.6
Tissue	2- 30	0.3 – 3 ²⁾	8 -15	1.2 - 6 ²⁾	5 - 7	0.3 - 2 ²⁾
Speciality paper ¹⁾	20 - 100	0.1 - 6 ¹⁾	no data	1.5 -8 ¹⁾	no data	0.3 - 6 ¹⁾

Notes:
1) The figure for speciality paper is derived from [SEPA-Report 4713-2, 1997] and should represent the common emission levels to water from this mills in the EU. After treatment means in this report means after primary treatment only
2) The upper end of the emission range for tissue mills is derived from information of the German Paper Association.

Table 6.16: Typical wastewater discharges paper mills before any treatment and after biological wastewater treatment [ADEME, 1996]

For speciality papers after treatment means after primary treatment only. The values seem to represent yearly averages (but it is not indicated)

The ranges reflect the differences in system closure, conditions of mills (size, age of equipment), applied internal measures to optimise water use as well as the different efficiencies and process control of external wastewater treatment plants. In integrated mills (e.g. recycled fibre processing mills) the white water of the paper machine is integrated with the process water of the stock preparation. Therefore, it is sometimes hardly possible to distinguish emissions from stock preparation and paper machine in recovered fibre processing mills (see Chapter 2 to 5).

The discharge of organic matter originate mainly from:

- Organic matter carried over or included in the pulp. This amount is normally more important in the case of an integrated mill
- Organic matter dissolved from the pulp in the refining stages ahead of the paper machine. This amount of released organics generated in the paper mill is generally higher for mechanical pulps than for chemical pulps. This amount - generally referred to as "generated in the paper mill" - corresponds to about 2 - 10 kg COD/t paper. This organic matter is mostly the dominating COD (and BOD) discharge from non-integrated paper mills.
- Organic chemicals applied as additives or auxiliaries in papermaking, which are not retained in the paper web. Usually, starch and their degradation products contribute significantly to the organic load. However, these substances are readily biodegradable. The significance of the contribution of chemical additives to the organic load of the paper mill depends on the amount and type of chemicals used. At least for some paper grades the share of additives to the total organic load discharged to the recipient is significant as nowadays the water emissions of paper mills have become generally lower after efficient biological treatment. Generally, there is a lack of knowledge about the contribution of chemical additives to the total wastewater load. In an investigation of a few mills in Germany the share of additives of the total COD load after biological treatment has been assessed. In the investigated example mills they amount to about 26% for coated printing and writing paper, 20% for newsprint from recovered fibre, 43% for hand towels from recovered fibres and 35% for coated carton board from recovered fibres [IFP, 1997]. However, these results may have great uncertainties (e.g. limited number of mills investigated; retention factors obtained in laboratory tests). The values therefore give only an indication about the possible amount of chemical additives that may be released via wastewater. They should not be generalised.

AOX emissions from paper mills have decreased over the last years as chlorine bleaching is practically abandoned today and are in general orders of magnitudes lower than those from ECF pulp mills. Nowadays, sources of absorbable organic halogen compounds are therefore mainly

some additives (e.g. wet strength agents and impurities as e.g. epichlorohydrin)) and to less extent process water treated with chlorine containing desinfectants (if applied).

Nitrogen and phosphorus compounds originate mainly from the necessary addition of these nutrients for effective operation of biological treatment plant. Some chemical additives may also contain organic bounded nitrogen compounds. For example, optical brighteners may contain up to 30% organic bound nitrogen (urea).

6.2.2.6 Solid waste generation

Various types of waste are generated at paper mills according to the following different sources:

Rejects from stock preparation

Rejects are generated by cleaning of the pulp furnish before the paper machine headbox. The rejects contain various impurities like shives, sand etc. and also some fibres. The dry solids content is usually around 1 - 25%. These rejects are normally led to the effluent treatment but may also be led directly to the sludge dewatering. Most of the solids will end up in the primary sludge from primary clarification. This is why the rejects are often not separately accounted for in the waste data.

Sludge from water treatment

Sludge from raw water and wastewater treatment represents at many paper mills one of the main groups of potential waste. Different types of sludge can be distinguished:

- Sludge from chemical pre-treatment of surface water to generate process water by means of chemical precipitation/flocculation. It is only generated in mills using surface water that needs this special treatment. In that cases the amount of sludge can be significant.
- Sludge from primary clarification. It is generated at most mills. It consists primarily of fibre and fines and of inorganic material at mills using fillers.
- Excess sludge from biological treatment. It contains a high proportion of organic material. The generation of sludge in anaerobic treatment is moderate (about 1/7 compared to aerobic treatment).
- Sludge from chemical flocculation is generated at mills carrying out tertiary effluent treatment. This treatment produces a considerable amount of sludge. The amount of organic/inorganic material in the sludge varies from mill to mill depending on the dosage and type of flocculants used. Many mills that manufacture coated papers operate a separate treatment of the wastewater from coating operations. For this concentrated effluents flocculation is a common practice resulting in sludge that has to be de-watered and further treated.

Table 6.17 gives some examples of the amount and types of rejects, sludge and other waste fractions generated per tonne of produced paper. The quantities of solid waste generated in paper mills depend on the type of paper manufactured, the raw materials used and to the techniques applied. It is difficult to find representative figures for the typical amount of solid waste for different types of paper mills that are sufficiently qualified, and that differentiate between different raw materials and paper grades. In different countries different waste fractions are reported. The main options of valorisation and major disposal routes respectively are described subsequently.

	Woodfree paper and board	Tissue from purchased chemical pulp	Speciality papers
Production per year (1994)	904509	24540	965962
Number of mills	6	1	20
Solid waste, total	29761	211	161945
Bark	0	0	407
Rejects from screening/cleaning	0	0	639
Sludges, total	27972	50	76506
- Chemi-mechanical sludge	8852	0	46259
- Biological sludge	120	0	159
- Mixed sludge from wastewater treatment	19000	50	30088
Residues from incineration, total	1	0	26842
- ashes/slugs	1	0	26671
- residues from abatement of air emissions	0	0	171
Others, total	1788	161	57551
- paper waste	1709	90	46817
- others	79	71	10734
Specific waste [kg waste/t product]	33	9	168

Table 6.17: Amount of solid waste in [t/a] for some paper grades (The figures refer to moist waste with a dry solid content needed for further utilisation of disposal), they show the total waste regardless if they are utilised or not [Solid Waste Handbook, 1996]

Biological and chemical sludges have poor dewatering properties. The sludge is usually thickened before being dewatered in a belt press, filter press, screw press or on a vacuum filter. Normally they are mixed with primary sludge (or bark if available) before dewatering.

Inorganic and/or organic chemicals are used to improve the dewatering of sludge by forming larger flocs. Mixed sludge can be dewatered to a 25-35% dryness with belt presses, 35-40% with filter presses and to 40-60% with a screw press using steam in the pre-treatment stage. The achievable degree of water removal depends to a certain extent on the quantity of biological sludge mixed with primary sludge, the ash content and the fibre content. In some paper mills the sludge is also dried after de-watering.

In many Member States the dumping of waste with high organic content is discouraged by governments and will probably be prohibited in the near future. The EU Directive on landfill of waste will support this tendency in setting targets to cut the amount of biodegradable (municipal) waste sent to landfills. Consequently alternative disposal routes and pre-treatment options need to be developed for larger quantities of sludge (see Section 6.3.14). Many organic substances are burnt for energy recovery. Burning reduces the volume of waste and the inorganic content remains as ash, which is normally transported to a landfill site. Ash is also used as raw materials for cement industry.

Besides production related rejects and sludge, ash and dust from power boilers form a group of waste which is generated in some mills (depending on the fuels used and the applied abatement technique for air emissions).

Other waste fractions

In addition, there are other types of waste generated in smaller amounts, but which still may create problems as regards disposal. The following types can be distinguished but they are difficult to quantify as specific amount per tonne of product:

- scrap iron and other metals
- plastics
- chemicals including coating residues
- spill oil
- glass
- packaging (e.g. container for chemicals, palettes, etc.)
- building waste as wood, concrete, bricks etc.
- waste from laboratories
- domestic waste
- paper waste that can not be utilised in the mill
- wires and felts

Most of this material can be utilised when the single waste fractions are collected and stored separately.

6.2.2.7 Atmospheric emissions

Air emission from energy generation

Air emissions from paper and board mills are mainly related to energy generation i.e. to various types of power plants and not to the papermaking process itself. Because atmospheric emission levels of paper mills are directly linked to energy consumption saving energy will lead to a reduction in air emissions. For instance, co-generation of heat and power consumes less energy than conventional separated generation of electricity and heat because the conversion efficiency of fuel use of CHP plants is significantly higher. For the amount of total primary energy used and the associated emissions it is very significant whether the mill uses purchased electricity from the public grid or power generated on site in a CHP.

Furthermore, the emission levels depend on the type of fuels used (coal, oils, gas) and the implementation of emission control technologies for reduction of SO₂ and NO_x, particulates and non-incinerated organic gaseous substances. Abatement techniques for air emissions are generally applicable to combustion processes of fossil fuels for generating power and steam. Because air emission control technologies are not specific related to the paper industry but the industry in general, this issue will not be broadly elaborated in this BREF. Only some generally acknowledged opportunities for improvement of the environmental performance of energy supply in paper mills are discussed as techniques to consider in the determination of BAT (see Section 6.3.15 and 6.3.16).

Air emissions from the paper mill

Releases to air that are not related to energy generation are mainly volatile organic compounds (VOC). This emission is usually of minor importance and within generally acceptable limits (i.e. below national limit values for these substances).

Situations where emissions of volatile organic compounds need to be controlled are related to a limited number of paper mills of different types. In the exhaust air of paper mills that utilise volatile organic additives in the production process those substances are measured in low concentrations. Most volatile components of virgin pulps have been lost to atmosphere by the time that the pulp reaches the paper machine. However, in the dryer section of the paper machine or after coating the paper web is heated up to 100°C to evaporate the residual water. Apart from the water vapour also volatile components from the fibre material and from chemical additives are released. Usually no special abatement techniques for these emissions are applied in paper mills because the released loads are rather small.

The results of a recent investigation of the exhaust air in 7 paper mills in Germany are summarised in Table 6.18.

Investigated installations	Total mass flow as orgC, total	Mass concentration as mg orgC/Nm ³	Remarks
PM, woodfree paper, unsized	0.7 kg/h	2 - 17 mg/Nm ³	98% from the dryer section
PM+CM woodfree paper, coated	No data	10 - 30 mg/Nm ³	Fluctuations; maybe partly caused by residual methane
PM+CM, woodcontaining, coated	No data	48 mg/Nm ³ at pre-dryer 24 mg/Nm ³ at post-dryer	90% from pre-dryer; 10% post-dryer;
CM, woodfree paper, double-coated	4.9 kg/h	30 - 67 mg/Nm ³	Emissions partly caused by residual methane
PM, woodfree, size pres	1.6 kg/h	2 - 77 mg/Nm ³	Main emissions (56%) from suction of wire and press section
PM, RCF paper and board	0.8 kg/h	6 - 26 mg/Nm ³	70% from pre-dryer
PM, RCF paper	2.4 kg/h	3 - 8 mg/Nm ³	
Notes: PM = Paper machine; CM = Off-line coating machine; PM+CM = Paper machine with in-line coating machine			

Table 6.18: Organic substances measured in the exhaust air of paper mills before heat exchanger [PTS-FB 09/97]

It can be concluded that the concentrations of organic substances in the exhaust air of paper mills can usually be considered as low so that no abatement technique for air emissions is required. The measured concentration of total organic carbon varies significantly. Values between 2 and 135 mg/Nm³ have been measured. A specific load between 0.05 - 0.5 kg orgC_{total}/t of paper was determined in the exhaust of the seven investigated mills [PTS-FB 09/97]. The emission of some single substances of concern in the exhaust air of coating machines as e.g. acrylonitrile (occur only when acrylonitrile butadiene binder systems are used) can be avoided or reduced by careful choice of coating colour recipes. Coating colour recipes that contain carcinogenic compounds should be avoided. Formaldehyde - concentrations between 0.1 - 4.8 mg/Nm³ have been measured - is normally more difficult to prevent because it has different sources as wet strength agents, preservatives, biocides etc.

Examples of operations where higher concentrations of VOCs are released are the following:

- Coating of paper with coating colours that contain organic solvents, although the basis of coating colours is exclusively aqueous (lower concentrations of various volatile substances (as e.g. formaldehyde, alkyl substituted aromatics, lower alcohols) can be measured in the exhaust of every coating machine).
- Preparation of papers with resins and production of speciality papers by using volatile additives.

Examples of volatile organic compounds (VOCs) which are released to the atmosphere are the following:

- Alcohols
- Formaldehyde contained in urea or melamine formaldehyde (UF/MF) resins used as wet strength agents
- Acetone and other ketones
- Phenols (only in special cases)
- Solvents used for cleaning machine fabrics (usually a minor application)
- Organic acids and residual monomers of polymers

In a few special cases particulates from some finishing operations may raise concern.

Emissions from sludge and residue incineration (optional) may also occur. However, on-site incineration of sludge and other residues is usually only carried out in integrated mills (see Chapter 2 -5). In integrated mills sludge may be incinerated together with bark in bark boilers or in recovered paper mills in dedicated incinerators together with other rejects.

Odours from vapours and from wastewater treatment plants (local)

In paper mills odours may be found. They may be caused by too long retention times of process water in the water system (pipes, chests, etc.) or deposits of sludge causing the built up of volatile organic acids (volatile fatty acids (VFA) primarily acetic and propionic acids). These compounds may be formed by microbial action on organic substances (notably starches) under anaerobic conditions, which may be released at the wet end, during paper drying and during effluent treatment. To a small extent, hydrogen sulphide could also be generated under anaerobic conditions. If so, they can be avoided by suitable process engineering measures. The wastewater treatment plant may also emit significant quantities of odour. If the wastewater treatment is well designed and controlled annoying odours can be avoided.

6.2.2.8 Noise from paper machines (local)

Noise from paper mills has only a local impact but for the working environment and the neighbourhood it may be the most serious of all environmental problems caused by a paper mill.

Paper machines are known as noisy installations. The major noise sources of paper and board machines as wire section, press section, dryer section, coater, winder and ventilation are compiled in Table 6.19.

Wire section	Press section	Dryer section	Coater	Winder	Ventilation
Suction rolls	Built-in gears	Steam and condensate system	Air dryers	Dust control system	Process ventilation fans
Vacuum system	Suction rolls	Basement enclosure	IR dryers (cooling air)	Drives	Machine room ventilation fans
Showers	Hydraulic systems	Process ventilation	Structure born noise from machine frame	Trim handling	Air dryers
Drive system	Showers	Electric motors	Blade coating	The paper web	Nozzles
Ventilation	Steam boxes	Gears	Drives	Gears	Fan drives and motors
Electric motors	Structure borne noise from machine frame (gears & guide rolls)	Broke conveyor	The paper web	Hydraulic system	Air intake opening
Centrifugal cleaners	Drives	The paper web	Fan room for air dryers	Knives	
High pressure pumps	Vacuum system	Dry end pulper		Nips	
Wet end pulper	Press pulper			Winder pulper	

Table 6.19: Major noise sources of paper and board machines

Besides the paper machine, there are other sources of noise that may contribute to the noise level. Examples are the refiners and vacuum pumps. By use of an example, ranges of noise levels for a paperboard mill are shown in Figure 6.10. The absolute values of this example are not considered to be representative for the sector but rather to be low because the board machine is running at a low speed (600-800 m/min) and has applied a lot of measures to reduce the noise level. In the wet end of a fast running paper machine (e.g. 1700 m/min.) the noise level is 95 - 105 dB(A).

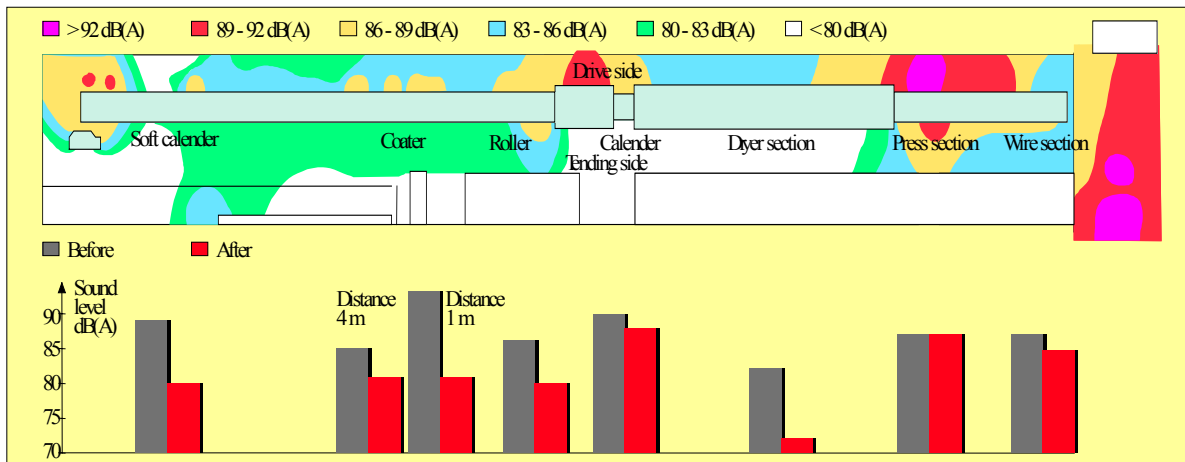


Figure 6.10: Machine room noise levels before and after the rebuild in different sections of a paperboard mill.

Noise zones on machine floor level. Board machine and adjacent operational buildings [Paper News]

It can be seen that for internal noise levels there is a difference between drive side and tending side of the machine.

The figure shows that it is possible to decrease the noise level step by step by a bundle of measures at the main noise source. A possible measure for internal noise control is for example the installation of a new closed hoods with higher sound insulation. As an example the results for a board machine is presented in Figure 6.10. There, the sound level on the floor in the central part of the hoods of the dryer section is 82 dB(A) and at the press Section 85-88 dB(A).

For external noise control examples of measures are the installation of absorptive silencers and/or pipe resonators to reduce noise levels from exhaust air fans and vacuum pumps, or silencers and sound insulation hoods for the fans on the building roof etc. (see Section 6.3.19). The measures applied will depend to a large extent to the specific noise problem of a mill and the targets set. Usually they will be much stricter when the mill is located adjacent to a residential area.

To a certain extent the suppliers of machinery have replied to this problem of noise and vibration in developing more silent equipment and efficient silencers. The activities are focused on the measures necessary to attenuate noise at the source. Those measures aim at the prevention of noise already at the machine design stage and noise attenuation for existing equipment. The target noise levels applied depend on the country and the mill location and the object to create a better working environment for the papermakers themselves.

6.3 Techniques to consider in the determination of BAT

In this paragraph all **relevant** techniques currently commercially available for prevention or reduction of emissions/waste and reducing consumption of energy and raw materials, both for new and existing paper mills are given. In this document these main technical options for environmental protection and energy saving are called "techniques to consider in determination of BAT" what means relevant technical alternatives or possibilities for improvement with the best environmental and economical performance. They cover in-process measures and end-of-pipe technology as well. Advantages and drawbacks of the implementation of certain techniques are outlined. This list of available techniques is not exhaustive and may be continued when reviewing this document.

The presentation of the available techniques includes for each technique a description, main achieved emission levels, applicability, cross-media effects, economics, operational data, example plants and literature.

Some measures described in this paragraph are only valid for specific paper grades whereas others are applicable independently from the paper grade produced. The former will be noted. Otherwise the measures are considered to refer to papermaking in general.

Many paper mills are integrated with a pulp mill others are partly integrated i.e. part of the pulp used is purchased pulp and part is manufactured on-site. Therefore, there is a certain overlapping between chemical or mechanical pulping and recovered paper processing respectively on the one hand and papermaking and related processes on the other. In that cases cross references to the respective chapters will be given to avoid unnecessary repetition and to show similarities and differences between the given processes.

Because in numbers most paper mills in Europe are non-integrated paper mills it seems worth to dedicate a separate chapter to papermaking as a stand-alone activity. But we have to bear in mind that often the mill might operate - at least to a certain extent - a pulping unit. In that cases the corresponding chapters on pulping have to be considered as well.

In an overview the techniques for reduction of emissions from papermaking and related activities are given. It was tried to give potential cross-media effects of every technique to consider in the determination of BAT in the same table. It can be concluded that it is not an easy task to describe cross-media effects in a way that would not cause any dispute. There are a lot of "grey-zones" in the assessment of cross-media effects. Furthermore, they may depend on other techniques, which may be linked to a given measure, on the reference to which a technique is compared with and on the system boundary taken into account as well. Therefore, the qualitative assessment of cross-media effects should only be taken as help for operators or inspectors. They can show which side effects a measure may possibly have. However, it is not much more than a starting-point when considering possible shifts of pollution from one environmental media to the other. The results of the assessment should not be considered as imperative. Furthermore, prevention and control measures can avoid some of them.

The table also indicates at which environmental media (water, air, waste, and energy) a measure is aiming at. The corresponding paragraphs under the detailed discussion of every technique give further explanations.

In the rows, the single available techniques are compiled. In the columns the tendency of effects caused by different techniques as raw material consumption and emissions are indicated qualitatively by using arrows up "↑" and down "↓". The arrows down "↓" indicate savings of raw materials or energy and a reduction of emissions into the different media water, air and soil. Arrows up "↑" indicate an increase of emissions and consumption levels. Some of the measures for pollution prevention and control presented in this section concern more than one

environmental medium (as water, air or soil) at a time. Some techniques may have a positive and/or negative impact on other environmental media or on raw material and energy consumption (cross-media-effects). The given effects will be noted by using the arrows. An arrow in brackets "(↑)" means only a slight - often negligible - increase of energy consumption, raw material use or emission to environment when implementing a certain measure.

The economic aspects (investments, operational costs) are not included in the table but are explained in the text. In principal, data on economics can only give a rough picture and indicate the levels of costs. They will vary with the design of the whole plant and depend among others on the size of the mill and how a measure fits together with other mill equipment.

Each technique is provided with a reference mark, which helps to identify the according section in the text where each single technique is discussed in detail.

Techniques to consider in the determination of BAT	Effects on the consumption and emission levels (cross-media effects)					
	Chemical consumption	Energy (E) & water (W) consumption	Emission to water	Emission to air	Solid waste	Applicability
6.3.1 Water management and minimising water usage for different paper grades	(O)	(↓) E, (↓) W	↓	O	O	All grades
6.3.2 Control of potential disadvantage of closing up the water systems	↑	O	(↓)	O	O	All grades
6.3.3 In-line treatment of white water by use of membrane filtration	O	(↑) E, (↓) W	(↓)	O	O	All grades
6.3.4 Reduction of fibre and filler losses	↑	↓	↓	O	(↓)	All grades
6.3.5 Recovery and recycling of coating-colour containing effluent	(↓)	O	↓	O	↓	All coated grades
6.3.6 Separate pre-treatment of coating waste water	(↑)	O	↓	O	(↑)	All coated grades
6.3.7 Measure to reduce frequency and effects of accidental discharges	O	O	(↓)	O	O	All grades
6.3.8 Measurement and automation	(↓)	↓	↓	O	O	All grades
6.3.9 Equalisation basin and primary waste water treatment	O	O	↓	O	O	All grades
6.3.10 Aerobic biological treatment	(↑)	↑ E	↓	O	↑	Most grades
6.3.11 Chemical precipitation	↑	(↑) E	↓	O	↑	All grades
6.3.12 Substitution of potentially harmful substances	O	O	↓	O	(↓) harmfulness	All grades
6.3.13 Pre-treatment of sludge	(↑)	(↑) E	O	O	↓ volume	All grades
6.3.14 Options for waste treatment	not applicable	not applicable	not applicable	not applicable	not applicable	All grades
6.3.15 Installation of low NO _x technology in auxiliary boilers	O	O	O	↓	O	All grades
6.3.16 Use of combined heat and power generation	O	↓ E	O	↓	O	All grades
6.3.17 Optimisation of de-watering in the press section of the paper machine	O	↓ E	O	O	O	All grades
6.3.18 Energy savings through energy efficient technologies	O	↓ E	O	O	O	All grades
6.3.19 Measures for external noise control	O	O	O	↓	O	All grades
Notes: The positive and negative side effects are also given. ↑ = increase; ↓ = decrease; O = no (or negligible) effect; (↑) or (↓) = low influence depending on the conditions;						

Table 6.20: Overview of available techniques to consider in determination of BAT for paper mills.

6.3.1 Water management and minimising water usage for different paper grades

This measure should be read together with Section 6.3.2 that is about control of potential problems of closing up water circuits.

Description of the technique: Water reduction measures in paper and board machines are a complex issue and depend greatly on the aimed degree of closure. Although there are a lot of technical alternatives that might differ somewhat from mill to mill there are some basic water reduction solutions that comprise:

- Efficient separation of cooling waters from process water and their recooling with cooling towers for reuse. 10-15 % fresh make-up water is required for reuse stream. For protection a micro-screen or other strainer is recommended to remove solids. Where cooling water fractions are sewered they are not led to contaminated process water sewers.
- In integrated mills the water circulation in the paper machine is kept separate from pulping sections and excess white water from the paper machine is fed in counter-current mode to the pulping department.
- The shower water system is usually the biggest consumer of fresh water in the paper machine system. Shower water consumption is usually in the range of 4 - 15 m³/t assuming a total water consumption of about 20-30 m³/t of paper. To reduce the fresh water consumption to reasonable levels, most of the fresh water must be replaced by clarified white water. Efficient fibre recovery with associated clear (or super-clear) white water production to replace fresh water in paper machine showers is applied for this purpose (see 6.3.3 and 6.3.4). Thus, shower water system with significantly reduced fresh water demand can be achieved. However, normally it is not recommendable to use save all filtrates for the press section showers (e.g. high-pressure felt showers) because otherwise precipitation of colloidal material from the clarified white water on the felt may occur. This may lead to clogging of the felt. Up to now, high-pressure felt showers require fresh water. In case that an operator still wants to use filtrate, it has to be carefully investigated how to treat the water, that at least the colloidal material is getting away (see Section 6.3.3 or 5.3.8).
- Recycling loop for part of the vacuum pump sealing water with cooling and solids removal.
- Management of all raw material flows through the paper mill in considering them as a unit of fibres, chemicals and water that interfere with each other. All input of chemicals for instance is controlled and investigated how they influence water quality and wet end chemistry (controlled system input).
- Design and maintenance of piping and storage chests in such a way that excess water volumes can be stored and the water quality is not deteriorated.
- Training and motivation of the staff is crucial to achieve and maintain low water consumption

Depending on the starting point, the characteristics of the mill and the product quality, with these arrangements the fresh water consumption of an uncoated paper or board machine could reach 5-12 m³/ADt and a coated printing paper machine 7-15 m³/ADt.

Reducing water consumption aiming towards the further reduction of effluents requires additional implementation of a physico-chemical (see 5.3.8), biological (see 5.3.4) or mechanical means (see 6.3.3) or their combination to treat the water for recycle.

The amount of many accumulated inorganic and organic substances is an important restriction to achieve this goal because these impurities have to be kept at low levels to prevent problems in machine operation and fulfil paper or board quality requirements.

Applicability and characterisation of the measure: Process integrated techniques. Water reduction measures can be carried out both in existing and new mills. However, the separation of pulp and paper water loops in integrated mills or a high degree of water system closure is

more expensive in older mills because the major rebuild of piping and major modifications to the machine wet end are likely when aiming to further closure. In existing machines these modifications are beyond a point difficult to reach without major rebuild or expansion of the process. With new machines the reduced water consumption can be applied somewhat more easily. Another problem to be addressed in existing mills is the suitability of materials to withstand accumulation of corrosive substances, such as chlorides, and elevated or increased water temperature. In general, water loops are the most difficult to close the more differentiated the products are and the more often the type of paper produced is changed. Smaller mills with only one paper machine face usually more production changes during the year (or day) than bigger mills manufacturing bulk grades. The individual configuration of plants has to be considered.

Main achieved environmental performance: The achievements depend mainly on the preceding situation of the mill. In existing mills fresh water use reduction of 10-15 m³/ADt of cooling waters, and a reduction of 5-8 m³/ADt of process water can often be obtained without the implementation of any special in-mill treatment, but the degree of closure depends very much on the product. With low-brightness boards lower effluent volumes can be more easily achieved than with liquid-packaging boards or printing and writing papers.

Depending on the initial state of the mill, achievable values for total fresh water consumption for some different paper grades are in the range of:

- Newsprint: 8 - 13 m³/t
- Uncoated fine paper: 5 - 12 m³/t
- Coated fine paper: 5 - 15 m³/t
- LWC paper: 10 - 15 m³/t
- SC paper: 10 - 15 m³/t
- Multiply folding boxboard: 8 - 15 m³/t (virgin fibres)
- Fluting: 4 - 10 m³/t (virgin fibres)
- Tissue: 10 - 15 m³/t (virgin fibres; heavy weight products or lower quality grades)
15 - 25 m³/t (virgin fibres; light weight products or high quality grades)

Consumption of fresh water depends mainly on paper grade, amount of showers and the amount of fibre containing waters used for the paper machine showers, mill conditions and gathering of water usage information. Lightweight paper products generally require somewhat more water per tonne of end product.

Monitoring of emissions: Typical monitoring devices include flow meters for paper machine fresh water feed, shower water feed and major white water streams. Suspended solids or turbidity measurements for clear white water is emphasised especially, if it is used for paper machine showers.

Cross-media effects: In paper mills with low water consumption contaminants are more concentrated in the effluent which contributes often to higher removal efficiencies. To a certain extent losses of raw material and energy might be reduced. Lower water volumes mean usually also lower heat load to the recipient.

Operational experiences: The measures described are implemented in many paper mills in Europe. The experiences are good also in existing mills and current paper machine design supports well their application.

Clear or superclear white water from the save-all is increasingly used in paper machine showers. If the white water solids content or the particle size rises beyond the shower nozzle capacity, the nozzles would plug. The water distribution to such showers should go through a protective in-line strainer and equipped with an automatic purge, to protect against the effects of save-all upsets and in addition in avoidance of white water replacement with fresh water. Also shower

cleaning equipment, with internal brush or other purging equipment, can help avoiding problems.

However, in existing mills low water consumption as the result of a combination of different measures needs usually many years of development and improvements in the process.

Economics: No general information on cost structures for water loop closure is available because each single plant is an individual case in this respect. The expenses depend mainly on the technical characteristics of the mill and the local conditions. The costs of these measures depend on the number and nature of water circuit re-arrangements necessary and the type of additional installation needed.

Driving force for implementing this technique: A bundle of possible measures to reduce fresh water consumption is called for in mills where fresh water availability is restricted or it is a paid commodity. The improvements have often a net positive effect because of possible savings achieved by lower costs for raw water, lower losses of fibres and fillers, sometimes lower energy consumption and lower volumes of wastewater to be treated. Both increases of production capacity or limited hydraulic capacity of the existing effluent treatment plant are also reasons to apply these measures.

Example plants: Numerous mills in Europe.

Literature: [CEPI, 1998 b]

6.3.2 Control of potential disadvantage of closing up the water systems

Description of the technique: The enhanced recycle of process water in paper and board machines causes a rise in the concentration of colloidal and dissolved organic and inorganic constituents in these streams. Depending on the characteristics of the pulp infeed and the used chemicals in papermaking the closed-up water systems can have an adverse effect on the runnability of the machine, the quality of end product and even the production costs due to increased use of chemicals. These potential negative effects need to be controlled. The possible advantages and disadvantages of reducing water consumption are given in Table 6.21. Possible drawbacks of closing up the water circuits are calling for control measures that are discussed below.

Possible advantages	Possible drawbacks
Improved retention of soluble material in the paper web	Higher concentrations of dissolved and colloidal materials in water circuits
Reduced energy requirement for heating and pumping	Risk of slime production leading to deposits and web breaks
Better de-watering properties on the wire that leads to energy savings in the dryer section	Risk of lower product quality e.g. concerning brightness, strength, softness, porosity
Less investment costs for reduced equipment	Increased consumption of process aids
Saving raw materials due to lower losses	Risk of corrosion (higher concentration of chlorides)
Higher reduction efficiencies of wastewater treatment	Higher risk of blocking of pipes, shower nozzles, wire and felts
Reducing total releases to water bodies	Problems of hygiene control for tissue, food contact and medical applications

Table 6.21: Possible advantages and drawbacks of increased closure of water circuits in paper mills

The pulp and the water carrying it contain dissolved and colloidal organic compounds called “anionic trash”. At higher concentrations these organic substances affect the retention and

formation of the paper web and increase plugging of machine press felts and cause sticking of the paper web on machine rolls. When producing papers from mechanical pulp the problems are more pronounced because most of the compounds of the wood are still present in the pulp and are partly dissolved in the process water. In the production of food packaging materials the product must be free of harmful soluble matter. The temperature rise at the paper or board machine needs also to be controlled so that limits of operating temperature, 45-55 °C at the wet end, are not exceeded. On the other hand, on the paper machine wire section a hot pulp suspension is advantageous because the viscosity of water is decreased with increasing temperature, resulting in improved dewatering.

The requirements in controlling the effects of closed-up water circuits are:

- The paper or board machine white water system does not receive water from integrated pulping departments or from parallel machines. The separation of water loops is usually carried out with thickeners. The optimum design of water loops is crucial as well.
- The recycled cooling or sealing water and clean white water feed to machine showers are treated with an appropriate strainer to protect against plugging or wear of machine equipment.
- Sealing water recycles are cooled sufficiently by heat exchanging equipment or clean make-up water. Especially vacuum pump performance limits allowable sealing water temperature.
- The composition (e.g. presence of colloidal substances), hardness, pH and temperature of recycled waters fed to a specific use are compatible with the equipment or the process streams there. It is beneficial to determine the water quality that is really needed.
- The pulps should be efficiently washed prior to feed to the paper mill to reduce the content of dissolved or colloidal substances. In integrated mills beneficial would also be the pulp feed to the paper mill at over 30 % instead of typical 2-4 % to reduce the carryover of dissolved matter. This can help to decrease the consumption of paper chemicals, such as alum, polymer or starch and machine aids like washing chemicals, slimicides and biocides.
- The selection of the paper chemicals and the machine aids has to be reassessed when closed-loop principles are applied, because some chemicals behave very differently in the changed chemical environment.
- Monitoring of recycled water streams by on-line meters and lab analysis is beneficial to avoid that target quality limits are exceeded.

Applicability and characterisation of the measure: Process integrated techniques. The measures can be applied both at new mills and at existing mills. However, existing mills need usually many years to implement most of these improvements. The required level of measures varies for individual cases: the machine type, the product(s) and the degree of closure are the key parameters. The requirements are the lowest in production of unbleached packaging grades and get strict for high-quality grades, such as fine papers.

Elevated dissolved or colloidal matter concentrations due to increased process water recycle tend to retain more of these substances in the end product. Limits to this are set by the product quality and the acceptable consumption of papermaking chemicals.

Also in sealing and cooling water applications the stream temperature and dissolved and particulate solids concentrations set limits and must be attacked by cleaning equipment and/or sufficient bleedout.

For sealing the current technology offers also mechanical seals that do not need water.

Main achieved environmental performance: The measures are considered to be an integral part of the measure described in Section 6.3.1. They support these measures to achieve and maintain low fresh water consumption without significant adverse effects.

Monitoring of emissions: At the points where the effluent is discharged out from the paper machine monitoring with flow meter is practical. On-line suspended solids or turbidity

measurements are important peak indicators. At least in the external treatment plant the temperature shall be monitored.

Cross-media effects: Control of paper machine water and recycle quality calls for improved control and monitoring of the pulping process as well. In some cases the need of paper chemicals and paper machine aid chemicals will increase. The type of the used chemicals must be reassessed to maximise the suitability for a certain paper grade.

Operational experiences: The risk of scaling caused by calcium compounds, slime and pitch problems is pronounced and must be counter-attacked with appropriate mix of water fractions, pH control, increased dosage of machine aids or appropriate purge of calcium out of the system (see 5.3.4).

If the machine can be operated at over 50°C temperature the growth of microorganisms and their activity in the water system is lower. But anaerobic activity may still occur above 50°C (thermophilic bacteria) generating odour in sulphur- and carbohydrate-rich environment that needs to be controlled.

The optimisation required by the implementation of these control measures is usually carried out in steps over a long period of time in existing mills. The success in applying this technology depends on the wet end chemistry case by case. Some mills have been attacking the control problem just by using more chemicals. The selection for proper chemicals and additives and their combination is fairly sophisticated procedure and often poorly understood, but necessary to obtain maximum runnability and low cost and environmental impact.

Economical paper production in numerous partially closed-cycle mills has been successfully implemented even for high-speed paper machines. Through the use of enhanced recycle water purification (see sections 6.3.3 and 5.3.4 and 5.3.8) certain problems can be solved and machine control with chemicals relieved, but other problems have sometimes evolved.

Economics: The expenses depend mainly on the condition of the mill. The costs of the measures depend on the number and nature of re-arrangements necessary and the type of additional installation needed. No data on single costs are available.

Driving force for implementing this technique: The enhanced recycling of process water in paper mills can have adverse effects on the runnability of the machine, the quality of end product. These potential negative effects need to be controlled when paper mills are aiming at low water consumption.

Example plants: Numerous mills in Europe.

Literature:

[CEPI, 1998 b], [Italian Comments]

6.3.3 Internal treatment of white water by use of membrane filtration and recycling of treated process water

This technique may also be applicable in RCF based mills. However, there are no full-scale applications for recovered fibre processing mills until now. Biological in-line treatment of process water is an option for "brown papers" manufactured from recycled fibre (see Section 5.3.4).

Although the technique described in this section is the same as the one in Section 6.3.5 the application is very different.

Description of the technique: Conventional filtration cannot well remove solids and colloidal material below 1 μm effective size. Thus small bacteria and colloids escape the filter media. However, this is only true for unflocculated solids and colloids. They can also be transformed into 100 - 1000 μm flocs by flocculation and easily filtered off. But the addition of flocculants may have the drawback that undesirable salts are introduced in the water system (modern organic/synthetic flocculants do not introduce a significant salt burden).

Membrane technologies, depending on the applicable membrane cut-off size (corresponding to the approximate “molecular weight” of organic compounds removed) and filtering pressure, can theoretically remove almost 100 % of the organic material (see Figure 6.11) without introducing undesirable compounds in the water circuits

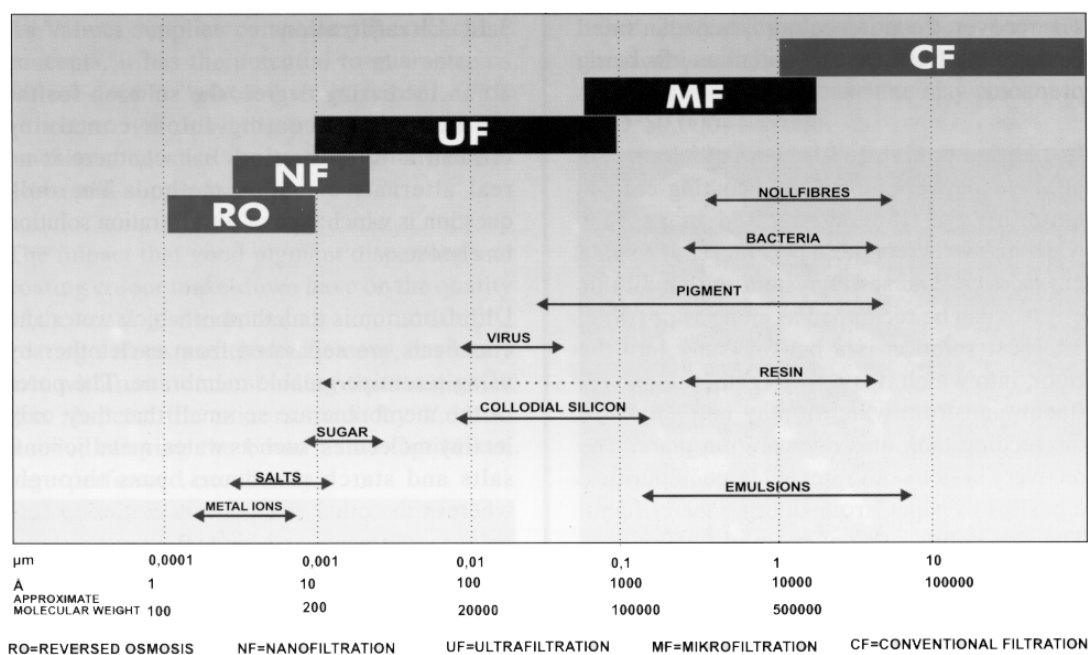


Figure 6.11: Filtration ranges of different filtration technologies

According to the differences in pore size different membrane processes can be distinguished:

- Micro-filtration, which operates at below 1 bar pressure and uses membranes with 0.1–0.2 μm pore size, could be used were 1-5 mg/l of very fine solids is acceptable after treatment. Currently, there is one full-scale application for paper mills in Europe.
- Ultra-filtration operates at 1-2 bar pressure difference and it is regarded a possible solution for 100% removal of residual solids and colloids and high molecular weight organics from pulp and paper mills water or effluent streams. In Europe, there exist a few full-scale applications for white water treatment with UF technology.
- Nano-filtration (NF) or reverse osmosis (RO) use pressures reaching 15-25 bars, but so far these methods have not been seriously considered for full-scale use in pulp and paper industry in Europe (there is one full-scale application in the high desert of north-western New Mexico).

Any type of membrane filtration cannot handle sudden peaks of suspended solids. If the suspended solids are homogenous (even) only police filter is needed to avoid sudden peaks.

Key issues affecting the selection of a membrane technology, if considered for paper mills, are as follows:

- Input stream, its composition and hydraulic load, including peak operating conditions.
- Clean water quantity and quality required and the applicability of treatment output in varying operating conditions for intended end uses and effect on pulp or paper quality.
- High-pressure filtration methods produce cleaner water, but consume more electricity and must be sized larger or equipped with more efficient pre-treatment or countermeasures to protect against plugging.
- Maintenance requirements (symmetric or asymmetric membrane structure, washing with acids or alkaline, spare capacity, automated or continuous cleaning). Symmetric membranes have higher tendency to plug. Plugging can be avoided by maintaining highly turbulent conditions close to the membrane wall, but this requires somewhat more energy.
- Final treatment and disposal of the concentrate or sludge, which in most cases is waste. Liquid waste may be concentrated enough to cause toxic effects at an external effluent treatment or it may require further concentration or absorption into a solid fuel for disposal by incineration. Some inorganic salts in the concentrate are corrosive, which must be taken into account in selection of equipment and piping materials.

When considering this aspects, UF can be used as a kidney to handle disturbing matter in the white water and close the water system further.

For in-line white water treatment, the kidneys might consist of a disc filter, bow screens and the UF system. The pre-filtered white water is piped to the UF's system feed tank and pumped the UF unit. The number of filters in operation regulate the clean UF permeate capacity. The pressure difference is kept as low as possible as for instance to 0.7 - 0.8 bars. The quality of the UF filtrate is sufficient for use as, for example, shower waters, sealing water and for dilution of paper machine chemicals. The concentrate from the filters can be piped to the main effluent treatment. A possible lay out for a paper mill using ultrafiltration for white water purification is shown in Figure 6.12.

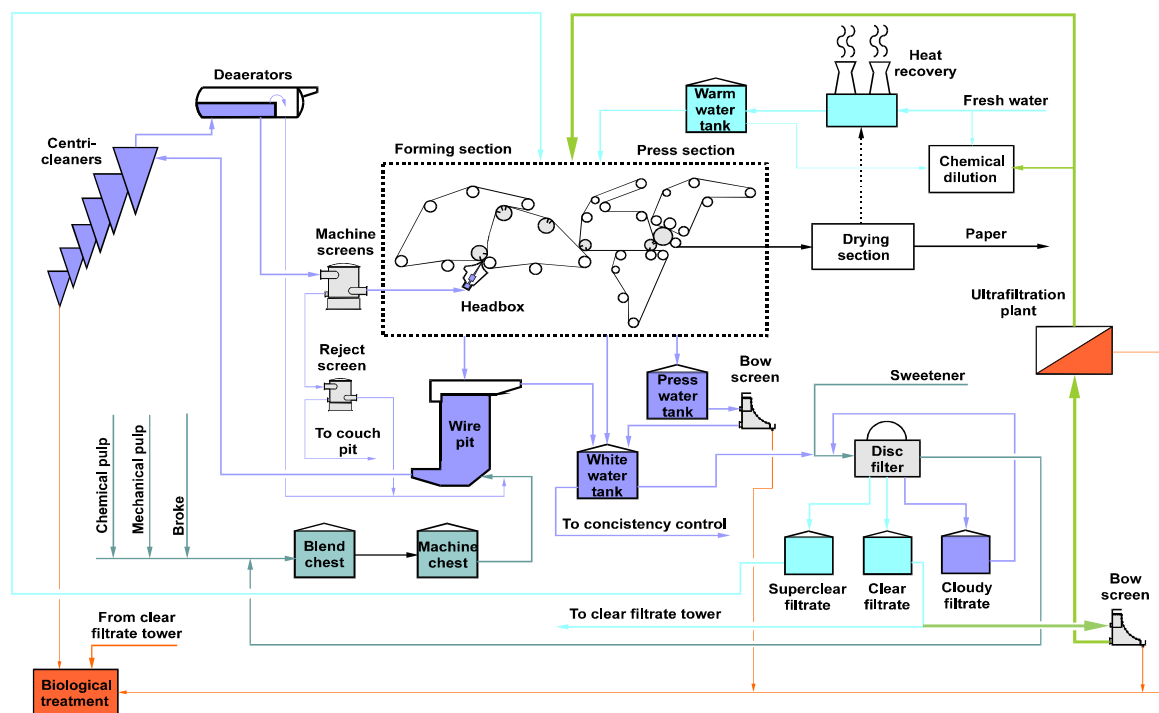


Figure 6.12: Possible simplified layout for a paper mill using ultrafiltration for white water purification.

Applicability and characterisation of the measure: Process integrated technique. Membrane filtration has been applied in a few mills in the world to remove suspended solids, bacteria, colloids, anionic trash and high molecular organic compounds from partial water streams of paper or board mills. The treatment of excess white water for reuse with UF-membrane filtration is usually only applied in special cases.

For higher concentrated process water in paper mills as those from production of "brown paper" from recycled fibre, the application of biological in-line treatment of process water followed by sand-filtration is a feasible option that is described in Section 5.3.4. There are also combined systems under development so-called membrane bio-reactors (MBR) as described in 5.5.2. In special applications, such as coating chemical recovery from paper machine coating effluents, UF-membrane technology is already a tested technology and several applications exist (see Section 6.3.5).

In general terms, paper machine water loop closure with self-contained removal of dissolved organic or inorganic constituents is a technique that undergoes still some development work. It is not as well established as e.g. biological treatment.

Main achieved environmental performance: The removal efficiency of UF-membranes for organic compounds is case specific, the target levels being set by the allowable contaminant levels in the paper machine system and specific uses of recycle water.

Besides partly removal of organic compounds, other membrane filters with smaller pore sizes (as NF or RO) can also reduce inorganic material, but the system size and the pressure/energy required increase exponentially when the removal rate for low molecular organic compounds or salts is increased.

Ultra-filtration (UF) in white water application means usually the treatment of clear filtrate and/or parts of the cloudy filtrate from the disk filter. The UF-membranes remove in practice 100 % of TSS, 99% of bacteria, 100% of turbidity (all colloidal material is removed), 45 -70% of anionicity. Dissolved COD is lowered by about 10 - 20%. That means, UF still allows parts of the organic substances (e.g. all low molecular weight organics) and soluble inorganic matter to pass through. First of all, UF of white water gives better quality of re-circulated water that can be used for low- and high-pressure shower water in the wire section, dilution water for chemicals, press section lubrication water or other washing and cleaning purposes. There are not yet experiences whether the permeate could also be used for felt cleaning.

A possible reduction of water consumption can indirectly lead to a decrease of the discharged nutrients load (N and P) because the total N and P releases are governed by the minimum concentration that is required for the growth of biomass in wastewater treatment plants.

The concentrate from membrane filtration (3 - 5% of feed) is led to biological treatment or is to be disposed of by incineration. The latter would require a concentration step before combustion, which calls for the control of volatile organics, when it is performed with evaporation. The incineration of the concentrate in an auxiliary boiler mixed with normal fuels may be possible depending on the type, capacity and fuel feeding system of the boiler.

In a full-scale UF-application in Europe (Finland), the concentrate is further treated in the biological treatment plant. In that case no reduction of the total pollutant load to the recipient is achieved. However, investigations how to use permeate for other purposes (e.g. high-pressure showers) to replace fresh water and whether to treat the concentrate separately (maybe by combining UF with other techniques) are still carried on.

Monitoring of emissions: Monitoring is discussed in a separate chapter.

Cross-media effects: Ultra-filtration requires electricity in the range of 2.6 kWh/m³ treated white water for pumps to overcome the pressure difference. There are no data available to compare environmental performance of common activated sludge systems with the system using UF + biological treatment of the concentrates in an integrated manner. For membrane filtration the solution how to treat the liquid or solid wastes is crucial.

Operational experiences: Membrane treatment processes used specifically for paper or board machines white water have been tested only few in full-scale. In Europe, the full-scale applications so far are:

- Metsä -Serla Kirkniemi mill, Finland, white water treatment, feed from save-all, the permeate is used as low pressure shower water in the wire section (instead of clear filtrate).
- Stora Uetersen, Germany, paper machine white water treatment
- Rottneros board mill, Sweden, suspended solids separation before evaporation of the concentrate

The practical limitations of membrane filters are usually set by the membrane material itself, which is sensitive to plugging unless the units are equipped with pre-treatment for solids removal or in-built systems that provide cleaning or maintain strong turbulence close to the membrane surface. Regular washing of filters with acids or alkaline solutions (NaOH, detergents, and tensides) is required, generating small amounts of liquid waste. When the flux of permeate goes down the membranes must also be changed from time to time (the lifetime of a membrane is about 15 months).

Economics: For membrane filtration of white water the capital costs would be about 0.3 Euro/m³. (Corresponding to 5000 m³/d treated white water). Service and maintenance costs (membrane change and working hours) are in the range of 0.05 Euro/m³, energy costs about 0.07 Euro/m³, washing chemicals 0.02 Euro/m³. The total operational costs are in the range of 0.14 Euro/m³.

Driving force for implementing this technique: This technique may be applied first in mills which face strict requirement for discharge either because they are situated on a sensitive recipient or they intend a significant increase of capacity. In the latter case, some authorities in Europe require that the effluent load should not increase with capacity. Usually the pioneers that achieve much lower emission by use of new technologies use the "green mill concept" as part of their marketing philosophy. These techniques may also be applied in cases where availability of water is scarce.

UF of white water may also reduce downtime of the paper machine caused by required washing off substances concentrated in the recycled clear filtrate.

Example plants:

Metsä-Serla, Kirkniemi mill (magazine and fine paper production), Finland, Stora Uetersen, Germany, Rottneros board mill, Sweden, McKinley Paper Co. (linerboard), New Mexico

Literature:

[Teppler, 1996], [Bentley, 1999]

6.3.4 Reduction of fibre and filler losses

Applies to all grades except tissue. For tissue the recovery of filler or fines has no relevance because they can not be used in tissue paper and are thus removed in the stock preparation.

The Section 6.3.5 also contributes significantly to the reduction of valuable materials for coated paper grades.

Description of the technique: Waste management in terms of efficient fibre recovery within the paper or board production is important because in virgin fibre processing typically over 98 % of the pulp fed through the paper or board machine stock preparation is acceptable for the end product. The chemical or mechanical pulp fractions used should already prior to the machine stock preparation warrant this high pulp quality. In the paper and board machines the waste management involves mostly with

- screening in stock preparation
- wet end save-alls and
- wet and dry end broke handling.

Partly related to fibre management are also the measures taken to reach reduced water usage and closure of water loops. By improvement of water loops closure in most cases also reduced discharge of organics out from the mill is obtained.

Rejects from the screening of paper or board machine stock preparation should be returned in integrated mills to the pulping department, where reprocessing is done and the good stock will finally end up back in the machine and in the end product. An efficient screening prior to the machine consists of cascading pressurised screens and several cyclone stages.

Fibre and filler recovery in paper and board machines has significance in terms of reduction of suspended solids.

When the pulp discharges from the machine headbox to the wire and starts forming the paper web a fair amount of fibres and fillers is not retained the first time but are discharged to collection pits, under the machine (see Figure 6.1). The short circuit water is recycled untreated. The rest of these waters are passed through a save-all unit, typically a drum or disc filter or a dissolved air flotation unit, to separate solids from the water stream. These solids are then collected into a chest and recycled back to the paper machine feed. The clarified water, called white water, is typically collected as clean and cloudy fractions and recycled the appropriate uses in the paper machine: pulp dilution in the machine stock preparation, broke dilution, paper machine showers. In integrated mills the excess white water is best used in the pulping process or if acceptable, in the parallel paper or board machines, but in non-integrated mills it is sewerred.

For paper machine fibre and filler recovery with a save-all unit, the disk filter is for most cases an efficient solution to attain high recovery. Especially a pre-coat type unit, which utilises a small amount of paper machine pulp feed on the filter surface to improve filtering efficiency and solids recovery is often used at modern mills. The filter works in batch mode, but the solids removal and the regeneration by applying the precoat take only a short period of time.

The disk filter allows efficient fractionation of white water to clean and cloudy parts, in closed-cycle mills even a super-clean fraction may be separated for specific uses. The super clear filtrate from a disk filter could have 10-20 mg/l suspended solids and clear filtrate 20-50 mg/l solids, in comparison to well over 50 mg/l of conventional filters. Clear filtrate can be used in many machine wet-end shower applications and cut fresh water usage. The cloudy filtrate and the rest of clean portion can be used in pulp dilution preceding the paper machine, in so-called short circuit, or in machine broke dilution and in integrated mills in the pulping process. Thus, depending on the situation before implementing improvement measures even 10-20 kg/ADt more pulp and (additionally fillers, when applicable) is returned to the machine feed instead of being sewerred in excess white water.

In the paper machine and even preceding it also other methods to cut fibre and filler losses are available:

- Tuning of the pulp refining and screening just ahead of the feed to the paper machine to maintain proper balance of different types of fibres in pulp. Heavy refining increases the amount of short fibre that in turn may be removed as reject in screening. In integrated mills, certain fraction of rejects from the screening may be recycled to the pulping department.
- Efficient control of paper machine headbox to produce an even paper web across the machine width.

- Sufficient use of paper chemicals and machine aid chemicals together with modern control system to reach improved fibre retention on the wire and good paper web formation. However, overdosing should be avoided.

The broke and white water storage capacity has also an effect in solids management and water conservation. The chest sizes should allow at least 2-3 hour machine flow to be stored in broke chests to recover these fractions that are high in fibre content. This reduces the frequency and length of sudden peak fibre or hydraulic discharges to the mill sewer. In paper machines producing coated grades the broke collected after the coater should be mixed with fresh pulp and wet-end broke in such proportion that the amount of fine solid matter in the paper machine wet end keeps in control.

Applicability and characterisation of the measure: Process integrated techniques. The listed improvements can be applied in both existing and new mills. However, in older mills the paper machine areas are more limited for rebuilds due to space or lay out problems.

Main achieved environmental performance: The total solids losses from a paper machine, from rejects from paper machine stock preparation, excess sewer white water, paper machine press sections and pulp tank overflows are found in the range of 10-100 kg dry solids/ADt. Better performing mills reach 10-20 kg/ADT (i.e. 1-2 % loss) for many paper grades. Some existing liner and fluting or speciality paper lines exceed 50 kg dry solids/ADt. When carried out in an existing mill producing 1000 ADt/d of printing grades a recovery of 10-20 kg/ADt of solids means that this solids load is not passed to the primary effluent treatment and to effluent sludge disposal.

The reduction in solids discharge reduces only slightly the organic load measured as COD or BOD₅. However, higher COD and BOD₅ capture is obtained for effluents from production of paper grades containing high-yield pulps.

Monitoring of emissions: White water and broke chest level monitoring is important. Paper mill effluent sewer equipped with flow indication and turgidity meters help to register surges in solids discharge.

Cross-media effects: Due to lower suspended solids discharge, the external effluent treatment operation is improved. Less sludge from primary treatment is produced. Fibres and fillers are used for the product and must not be handled as waste. When fibres and fillers are recovered to a higher extent it has also to be considered that raw material and energy which were necessary to produce this materials are saved.

Operational experiences: These measures are implemented in many paper mills without any problems. Generally, there are two means to be considered: good unit processes and more accurate process control and monitoring of unit operations by means of automation.

Economics: No data available

Driving force for implementing this technique: Improved stock recovery is usually economically beneficial because of better raw material efficiency and less waste to be disposed off. Reduced solids load to the external treatment and minimisation of discharges of suspended solids to the recipient might also be a motivation to implement the described measures for fibre recovery or spill prevention.

Example plants: Numerous mills in Europe.

Literature:
[CEPI, 1998b]

6.3.5 Recovery and recycling of coating-colour-containing effluent

This measure can be applied alternatively to the BAT under 6.3.6. Membrane technology should be preferably applied because it offers the option for reuse of coating chemicals.

Description of the technique: Paper mills producing coated paper grades generate a hydraulically low flow wastewater (about 2 - 5% of the total flow) which, however, is rich in pigments and adhesives (see 6.3.6). The heavy solids load and by nature sticky compounds in these wastewaters cause operating problems in the external effluent treatment, if sewerred there without an appropriate pre-treatment. On the other hand the pigments are expensive, so the recovery of a part of the coating colour for reapplication and minimisation of coating kitchen is cost-effective.

Environmentally sound coating waste stream management comprises of:

- Minimum discharge of coating kitchen colours to sewer by efficient production and optimum inventory of prepared coating colours, especially, when paper grade changes need a change in coating colour composition. Significant factors are efficient work routines and good "housekeeping".
- Optimum design of coating colour kitchen and supply systems
- Coating chemical recovery by ultra-filtration of coating wastewater.

Ultrafiltration is a method in which water and chemicals are separated from each other by using a semi-permeable membrane. The pores of the membrane are so small that they only let tiny molecules such as water, metallic ions, salts and starch monomers pass through, whereas the other components of the coating colour - pigments and binders - are too large to get through (see Figure 6.11). The effluent fed into the process is typically 2 - 4 % and that of the concentrate 30 - 35 %. Added to fresh coating colour it will not dilute too much. As shown in Figure 6.13 a complete ultrafiltration system comprises the filter, necessary tanks, piping, field instruments and control system.

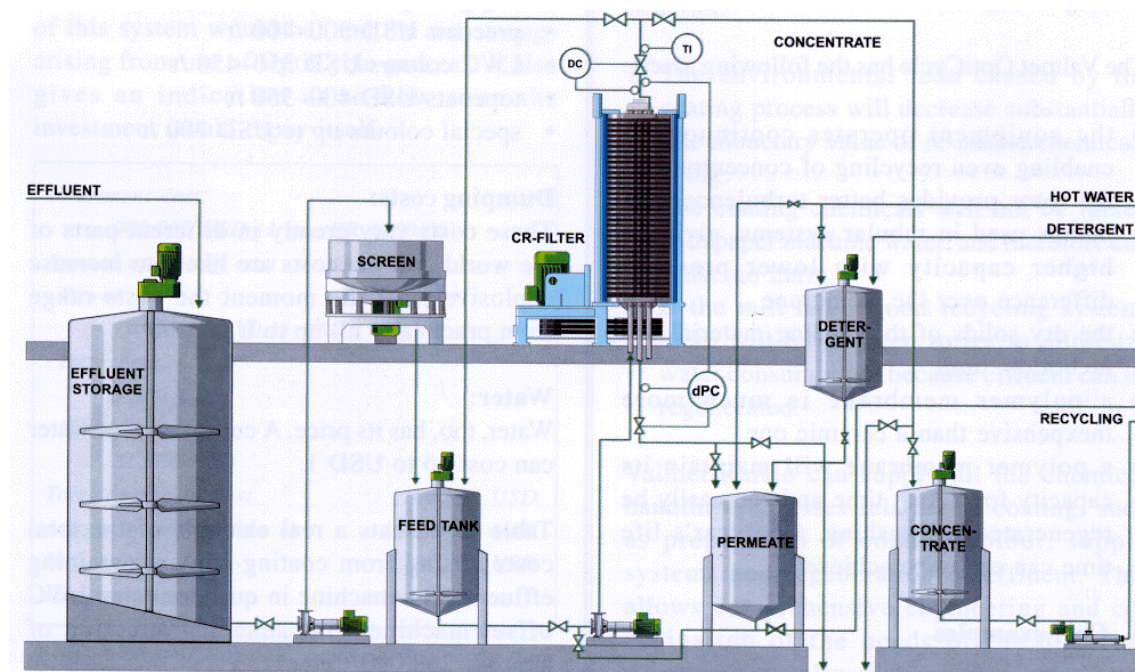


Figure 6.13: Example for an ultrafiltration recovery system for coating colours [Roitto, 1997]

Applicability and characterisation of the measure: Minimum discharge management of coating colours and separate collection of coating effluents for their separate treatment by means of ultra-filtration can be applied at both existing and new mills. Ultrafiltration is technically suitable for most coating mills manufacturing magazine paper, fine paper or board grades. It can be unsuitable for some speciality grades. If effluents are very small and produced in various places, a good recovery system for the effluent can be difficult to create. In greenfield mills there is no such problem. If the grades of coating chemicals are totally unsuitable for mixing (e.g. big number of different grade at one site) the reuse may be limited. The achievable concentration of the solids is limited to about 35 - 45%. If there is no excess water in the formulation of the coating colour it can be difficult to reuse all the concentrate. Limitation can also occur when the amount of effluents is too high.

Main achieved environmental performance: Emissions to water and the amount of waste is reduced markedly. Coating chemicals can be not only recovered but also recycled back to the production. There is also a little reduction of water consumption because the permeate can be re-used.

Monitoring of emissions: On-line metering of coating wastewater flows at critical locations is beneficial. In addition coating chemicals quality follow-up by lab analysis of solids, BOD₅ and COD content is called for.

Cross-media effects: Reduction of coating wastewater discharge with separate treatment of these wastewaters improves the performance of an external effluent treatment. Depending on the ratio coating/paper produced the amount of solid waste can be lowered by 70%. This means significant savings depending on the cost for landfilling.

Operational experiences: The application of ultrafiltration has proven successful in many mills. No negative effects on fine and art paper quality have been reported when using concentrate precoat. In magazine paper mills small amounts of UF concentrate can be used without drawbacks in quality. In a board mill the recovered coating colour is re-used for back coating. The amount of concentrate must be constant. Also bacterial and hygiene are important aspects to be considered. The lifetime of the membrane can exceed one year. Typical washing sequence is once a week creating a liquid waste of about 2 - 5 m³. Good results has been achieved for instance with polymer membranes using the cross-flow principle (CR-filter).

Economics: A small UF unit can handle 2000 l/h effluent in 2% of solids. This kind of system is feasible for a mill using 10 - 50 tonnes per day coating colour. Investments amount to about 0.2 - 0.3 MEuros for this size. Remarkable savings (costs for landfill, saving of expensive coating colour) can be achieved by recycling coating chemicals. In some cases, the value of recovered chemicals and reduced costs for dumping can give a payback time from about 1 - 2 years. Another example was reported as follows: The investment cost for a process that is capable to handle 200-400 m³/d coating effluent costs about 0.5-1.5 MEuro. Typical running costs are 0.1 MEuro/a.

Driving force for implementing this technique: These techniques are required to cut the mill suspended solids discharges and improve the operability of the external effluent treatment. It is considered to be the preferred option compare to Section 6.3.6. The key factor for implementation of UF is reducing the costs for dumping and savings in raw materials of costly coating colours. Therefore, it is crucial for the applicability of this technique that the recovered coating colours can be re-used.

Example plants: Blendecques board mill, France; Assi Frövifors board mill, Sweden; Cascades Djupafors board mill, Sweden; Hansol Taejon board mill, South Korea; Yuen Foong Yu Fine Paper mill, Taiwan; Metsä-Serla Kirkiniemi, LWC/MWC/fine paper mill, Finland; Metsä-Serla Äänekoski, Art paper mill, Finland; Enso Fine papers, Oulu, Finland; APP Pindo Deli, Fine

paper mill, Indonesia; MD Papier Plattling, LWC paper mill, Germany; SCA Fine Paper Stockstadt, Germany; Zhuhai S.E.Z Hongta Renheng board mill, China.

Literature:

[Roitto, 1997], [Nygard, 1997]

6.3.6 Separate Pre-treatment of Coating Wastewaters

This measure can be applied alternatively to the BAT under 6.3.5. Membrane technology should be the first choice because it offers the option for reuse of coating chemicals.

Description of the technique: Coating chemicals include several groups and types, where the pigments and binders are the two main elements.

Coating colour discharges can be divided into two main types of wastewaters:

- Undiluted surplus coating colour (about 50 -70 % dry solids) from coating kitchen and coater station. In case of product changes and during breaks the system has to be washed (disperger, chests, pumps, piping, and coater station). Furthermore, sometimes not all of the coating colours can be completely used and the rest is washed as well. The concentrated discharge can be collected in tanks or mobile containers for solid waste disposal.
- Diluted coating components from washing water from tanks etc.
The dry solids content of dilute effluent is typically 2 -4 %. If they are discharged to the treatment plant sudden high organic loads have to be handled in the treatment plant (COD values > 10000 mg/l up to 100000 mg/l). The diluted spills are collected in tanks and pretreated before discharge to the external wastewater treatment plant.

If wastewaters are not treated before biological treatment they can have adverse effects on the wastewater treatment plant, causing difficulties in primary clarification and in biological phases.

A typical pre-treatment arrangement is as follows:

The wastewaters are collected into an equalisation basin. The wastewaters are screened with a step screen and pumped to a chemical precipitation. The chemicals are added in a rapid mixing unit. Aluminium sulphate and polyaluminium chlorides are used as precipitation chemicals. Polyelectrolyte is used as a flocculation aid chemical and it is dosed into the flocculation tanks. The flocculated wastewater flows into a lamella clarifier where the suspended solids settle on the bottom of the clarifier and the clear overflow is discharged to the wastewater channel for further treatment. Sludge from the bottom of the clarifier is collected to a sludge tank and from there it is pumped to a centrifuge for dewatering. The dewatered sludge at the concentration of about 30 - 40 % is transported to a landfill.

At one mill however, the precipitated coating colours are dewatered by centrifugation and reused as coating colour for precoat. This option needs a lot of development work.

Applicability and characterisation of the measure: The pre-treatment of coating wastewaters can be applied at both new and existing mills. However, in existing mills the arrangements for wastewater collection and rerouting may be more complicated and more expensive. New installation will probably prefer ultrafiltration of coating wastewater because usually they offer a relatively short payback time.

Main achieved environmental performance: The main achievements are operational benefits especially in the wastewater treatment plant. Total suspended solids (TSS) loads to the WWTP are reduced and also accidental spills (sudden SS loads) to the treatment plant can be

minimised. The upsets of the primary clarifier can be reduced because there are less sudden disturbances in settling of TSS or increase in the torque of the clarifier drive mechanism. The risk of clarifier overloading is also reduced. The upsets of biological system are reduced because the inert matter (e.g. pigment particles) in coating effluent is not carried over and accumulated to the active biomass of the biological treatment process. Thus, the environmental load is reduced. The clear filtrate from the coating colour effluent treatment can be reused elsewhere in the paper mill, for instance for dilution of coated or uncoated broke. However, wastewater streams are only controlled and concentrated but waste remains. Therefore the technique of Section 6.3.5 is considered as the option to be favoured.

Monitoring of emissions: Monitoring is discussed in a separate chapter.

Cross media effects: The separation of coating chemicals from the biological wastewater treatment may have a positive effect of the further treatment of the biological sludge. It is easier to burn the sludge of the mill's main wastewater treatment plant because a pre-treatment for coating wastewaters reduces the ash content of the main sludge streams. However, compared with ultrafiltration of coating colours (see 6.3.5) waste is still produced because the experience to recycle the precipitated coating colours are still very limited. Flocculation results in a certain increase of salts in the effluent.

Operational experiences: The process has been used many years in paper mills across the Europe. However, some difficulties have been detected from the dewatering of the sludge produced. If the dewatering device is not chosen properly there may be wear problems.

Economics: The investment for the separate coating wastewater treatment by means of flocculation is about 1.2 - 1.4 MEuros for a production of about 1000 ADt/d. The annual operating costs are 75000 - 150000 Euros/a, excluding landfill costs. Because the value of the chemicals is lost when they are landfilled there is no possibility for payback.

Driving force for implementing this technique: The driving force to adopt this measure is the difficulties in the external wastewater treatment plant if this pre-treatment is not applied. The high TSS of coating wastewater can upset the operation of primary clarifier and biological process and result in sludge incineration problems.

Example plants: Numerous plants in Western Europe (Germany, Austria, France, Sweden and Finland).

Literature:
[CEPI, 1998 b]

6.3.7 Measures to reduce the frequency and effects of accidental discharges

Description of the technique: In a paper and board machine the aim is to maintain long uninterrupted runs of the paper web through the machine to obtain the end product. Variations in the machine performance or pulp quality during operation are likely and up to a limit are kept under control but at worst lead to paper breaks and lost production. In addition the machines need maintenance, much of which cannot be done when the machine is in operation, thus calling for more short stops and start-ups. If the machine produces a variety of paper grades the thing is still further complicated with stops required to change from one grade to another.

The accidental discharges typically occur due to:

- Paper machine operational upsets
- Scheduled maintenance shutdowns and start-ups
- Poor management of white water tanks or machine broke chests in the wet-end or dry-end broke chests or off-machine coating

By improved paper machine automation the on-line monitoring of the paper sheet and machine parameters become fast and more accurate. The pulp discharge from the headbox, the speed of machine rolls, by variable speed drives, and the amount of steam used for drying can be better balanced and optimised according to the needs. As result, paper quality is improved, and when the controls are properly built and connected to affect each other also the number of machine breaks decreases. On the other hand, in production of high quality grades the refining and screening operations must meet higher standards, because less quality variations is allowed in the paper web.

The most important item keeping the accident discharges to a minimum is the proper sizing of the white water and broke chests. As a rule of thumb, the broke chests should have enough volume to store at least 3 hours worth of pulp at the rated production. Otherwise, there is an increased probability that significant water and solids discharge to the sewer occur. The white water storage capacity must match this broke storage so that no fresh water is required during sheet breaks or when the broke is returned to the machine. In paper machines producing coated grades the return of the broke collected from on- or off-machine coaters must be controlled carefully. This is because the proportion of coated broke must be below a case-specific limit to make a proper mix of fresh pulp and different brokes and thus to avoid problems in the paper machine wet-end. The coated broke storage volume must meet this demand.

The control of white water tank level according to broke inventory, pulp inventory and production plan must be exercised to prevent spillage.

In mills that change paper grades frequently the tank control is more difficult, because the inventories are often kept low in order to minimise losses from clean-ups at grade changes. For this reason also the machine feed characteristics must be controlled more carefully so that the amount of broke stays low. In mills with many paper machines such losses may be reduced, if another machine can use this material.

In order to protect the wastewater treatment plant (WTP), and simultaneously the environment, the implementation of an equalisation basin (retention basin) could be considered. In case of accidental spills, the wastewater can be conveyed to this basin. From there it can be discharged to the WWTP in a controlled manner.

Measures to avoid accidental discharges from handling and storage of chemicals are the following:

- Design and operation of facilities in such a way that dangerous substances cannot escape
- Quick and reliable detection of leakage from all parts of the facility that come into contact with dangerous substances. Escape prevention of leaks and appropriate disposal. When not double-walled and provided with a leak indicator, the facilities should be equipped with a collection system/device of a tight and durable design. Collection chambers may not have any discharge openings.
- Operating instructions including monitoring, maintenance and alarm plans are drawn up and observed
- The wastewater treatment is the most crucial point for accidental discharges. A well performing treatment plant and a good communication between employees of the production units and of the wastewater treatment unit is a prerequisite. In case of an accidental spill, the latter can take adequate measures to protect the treatment plant.

Applicability and characterisation of the measure: Control of accidental discharges is of primary importance in the paper machine and can be applied in existing and new mills. However, problems may arise in existing old mills if they do not have enough space to expand water or pulp storage.

Main achieved environmental performance: These measures reduce the frequency of hydraulic or solids peak discharges from the paper machine.

Monitoring of emissions: On-line monitoring of sewerage effluent flow rate and lab monitoring of suspended and dissolved solids, pH, temperature and organic content as BOD₅ or COD of the sewerage and occasionally some recycle streams is recommended. Also on-line suspended solids or turbidity meter can be used.

Cross-media effects: The development of an efficient white water and pulp chest management resulted in improvements of production economy and reducing the number of accident discharges. No other significant effects.

Operational experiences: Increased level of automation has been proven effective in increasing the control of accidental discharges although the main reason for its implementation is usually improved machine runnability and, in most cases, increased capacity. Static and currently dynamic modelling have brought improved understanding at many mills for advance control of machine operations.

Economics: Investment costs for one additional white water tower of 3000 m³ and one uncoated broke tower of 2000 m³ would be about 1.0 - 1.2 MEuros. If a second broke tower for coated broke would be required, it would cost with necessary auxiliary equipment, piping and electrification about 0.4 - 0.5 MEuros. These investments correspond to a paper production of 1000 ADt/d.

Driving force for implementing this technique: First, these measures are to prevent upsetting discharges from the paper machine entering the mill sewer and keeping the load to the external effluent treatment more stable. Second, the process automation coupled with sophisticated white water, pulp and broke inventory improves the machine runnability.

Example plants: Numerous mills in Europe.

6.3.8 Measurement and automation

Description of the technique: For high effectiveness of a papermaking, it is important that the process is stable and the quality uniform. These characteristics are essential for environmentally sound production. Unstability in stock preparation and wet-end area causes web breaks and thus disturbances in water systems. On-line measurements and accurate process control are therefore essential for effective papermaking. The major areas where measurement and automation increases both quality and productivity and environmental performance are mentioned below.

- *Save all operation:* Suspended solids or turbidity measurements are important peak indicators when target is to use filtrate as much as possible for shower waters. Unnecessary fibre losses are thus avoided and the load on wastewater treatment is diminished. Feed consistency measurement and control facilitate the optimisation of filter operation.
- *Blending:* In thick stock proportioning and blending, variations in consistency and pulp quality (e.g. freeness, fibre length, ash content) are stabilised in order to avoid quality variations at the paper machine.

- *Refining*: The refining control strategy requires accurate flow and consistency measurements at minimum. For optimum refining control result, pulp quality measurements such as freeness/drainage and fibre length measurements are needed.
- *Wet end management*: The information on headbox and white water total solids and filler consistency levels provides an early indication of potential problems in wet-end chemistry. Automatic retention aid control where the target is to retain uniform amount of fines and fillers in the paper web is based on on-line fibre and filler consistency measurement in short circulation. The use of white water consistency control has drastically increased the stability of wet end operations and reduced the number of wet end breaks. In addition to the consistency variation in short circulation variations in the incoming dissolved and colloidal material are a major source of problems in paper machine runnability and optimisation. Cationic demand is measured from the white water and is used to control the detrimental substances. While retention control acts by controlling flocculation, charge control stabilises by controlling coagulation.

Applicability: The above mentioned measurements and controls can be applied at both small and large mills. Biggest benefits are obtained when high quality end products are produced.

Main achieved environmental performance: It is difficult to quantify the environmental benefits achieved because they depend on the characteristic of the installation, the degree of productivity before improvement, the paper grade (s) manufactured etc. Water management is facilitated, the pollution load to the wastewater treatment as well as the loss of material (waste) is reduced.

Cross-media effects: No negative cross-media-effects known. The increase of productivity and decrease of breaks or losses by use of better process control and automisation have only positive effects on the environment. Less disturbances in water systems, less energy consumption and less waste is the result of these measures.

Operational experiences: Measurement and automation have been applied in many existing mills to increase efficiency without problems and is natural part and further developed at new mills.

Economics: From economic point of view the goal is to enhance papermaking profitability. Eliminating one 7 minute break a week means results in 0.5 % more uptime which in a 300 tones per day mill yields in 1.5 tonne per day more production. If the net cost of lost production is USD 500 per ton, the savings due to better stability would be over USD 260000 per year. In addition energy which is wasted during the break for e.g. in drying cylinders and pumping is saved.

High and uniform retention also means savings in wastewater treatment plant. The wastewater treatment plant need not be over-dimensioned for peaks, when a more uniform wastewater load is reached with a more uniform retention control.

Against this savings the investment and operating costs of the equipment has to be taken into account. The payback time for measurements and control when implemented is typically less than one year. After appropriate training the mill operators can operate the unit. The mill electrical & instrumentation people can do the necessary maintenance work when needed.

Driving force for implementing this technique: Measurement and automisation is primarily applied for economic reasons and to achieve higher paper quality. It results in time savings in paper production (e.g. allows faster grade changes, faster start-ups, faster recovery after sheet break), lower production costs (e.g. by furnish component optimisation, effective usage of additives, decreased energy consumption) and maximised paper quality (e.g. through less cross direction (CD)/machine direction (MD) variation, optimised dewatering, formation etc.). Optimised dewatering for a given machine is obtained by a proper stock preparation and wet

end management (e.g. refiner control and control of chemicals). It is furthermore easier to manufacture a wider range of paper grades.

Example plants: Numerous mills in Europe

Literature:

[Nokelainen, 1995], [Nokelainen, 1997]

6.3.9 Installation of an equalisation basin and primary treatment of wastewater

Description of the technique: For most paper mills, this measure is not considered as a stand-alone technique but as a pre-treatment. Pre-treatment is usually carried out ahead of biological treatment in order to facilitate and improve the treatment process. In some special cases where the organic load is too low for efficient biological treatment it may be the only wastewater treatment.

The following methods are the most important ones:

- Coarse screening is carried out in order to remove larger objects and sand, which may cause damage to the subsequent equipment.
- Equalisation and spill collection may be required for effluents with large variations as regards flow and content of pollutants. Such variations may disturb the function of the subsequent treatment processes, particularly biological processes. A value of 4 hours retention time in the equalisation basin can be taken as an indication for appropriate design. However, the appropriate retention time of the equalisation tank depends on fluctuation of water quality.
- Primary or mechanical treatment by means of gravity forces is carried out for the removal of suspended solids (SS), such as fibres, bark particles and inorganic particles (fillers, lime particles, etc.). A certain minimum size of the particles is required. The finer particles will settle too slowly for practical use or not settle at all. Sedimentation is the first type of treatment to be applied at a pulp and paper mill, and or a pre-treatment ahead of, for instance, a biological process. Flotation can also be used for primary clarification. Some smaller mills use primary treatment by means of filtration as the only wastewater treatment.

The particles, settling to the bottom of the primary clarifier form a sludge, which has to be removed. This is achieved by pumping, in circular clarifiers in combination with bottom scraping. The sludge is normally low in dry solids (DS) content, approximately 1-2 %, and has to be dewatered before final disposal. In some mills the sludge from the primary clarifier is reused in the production process, which provides the sludge properties to be suitable.

Applicability and characterisation of the measure: End-of-pipe technique. The process can be applied at both existing and new paper mills. Some kind of water consumption reduction measures should preferably be carried out to reduce the hydraulic load and thus investment costs for the clarifiers.

Main achieved environmental performance: The result of the primary treatment depends on the effluent properties, but also on the degree of internal fibre recovery in the pulp or paper mill. For suspended solids (TSS) the removal rate may be within 60-90 %. For settleable solids the removal will normally be higher, approximately 90- 95%.

TSS values after the primary sedimentation may be in the range of 30-200 mg/m³.

Monitoring of emissions: Monitoring is discussed in a separate chapter.

Cross media effects: The effluent treatment plant produces sludge which after dewatering has to be further treated. There are many different options for further treatment of this sludge which are to a certain extent site-specific (see Section 6.3.14). One option is incineration providing in some cases net positive heat value.

Operational experiences: Gravity type primary clarifiers have been used for many years in all types of paper and board mills with good results.

Economics: Investment cost of primary treatment for a new 1000 ADt/d integrated paper mill and comprising of pumping, primary clarifier, sludge dewatering and chemical dosing systems, is 3.5 – 4.5 MEuros. The operating costs depend very much on the required chemical consumption (if so) being 0.4 - 0.6 MEuros/a.

Driving force for implementing this technique: Primary treatment is used to reduced TSS load to the recipient or biological treatment.

Example plants: Numerous paper mills in Europe for all types of effluents.

6.3.10 Secondary or Biological Treatment - Aerobic Methods

Description of the technique: For secondary treatment the basic alternatives are between the use of aerobic and anaerobic/aerobic biological systems. However, anaerobic treatment is restricted to wastewater that contains high loads of biodegradable organic substance (as a rule of thumb $COD \geq 2000$ mg/l) to allow methanisation. It is therefore mainly applied at recycled fibre processing mills (see Section 5.3.5) especially in paper mills manufacturing corrugating medium or board.

There is a wide variety of designs of aerobic treatment of paper mill effluents. Activated sludge systems, aerobic submerged biofilters, trickling filters as one or more step application or in combinations with each other, sequencing batch reactors, rotating biological contactors, are in usage.

The main technologies for external biological treatment of paper mill wastewater and the concentration range of suitable application are shown in Figure 6.14.

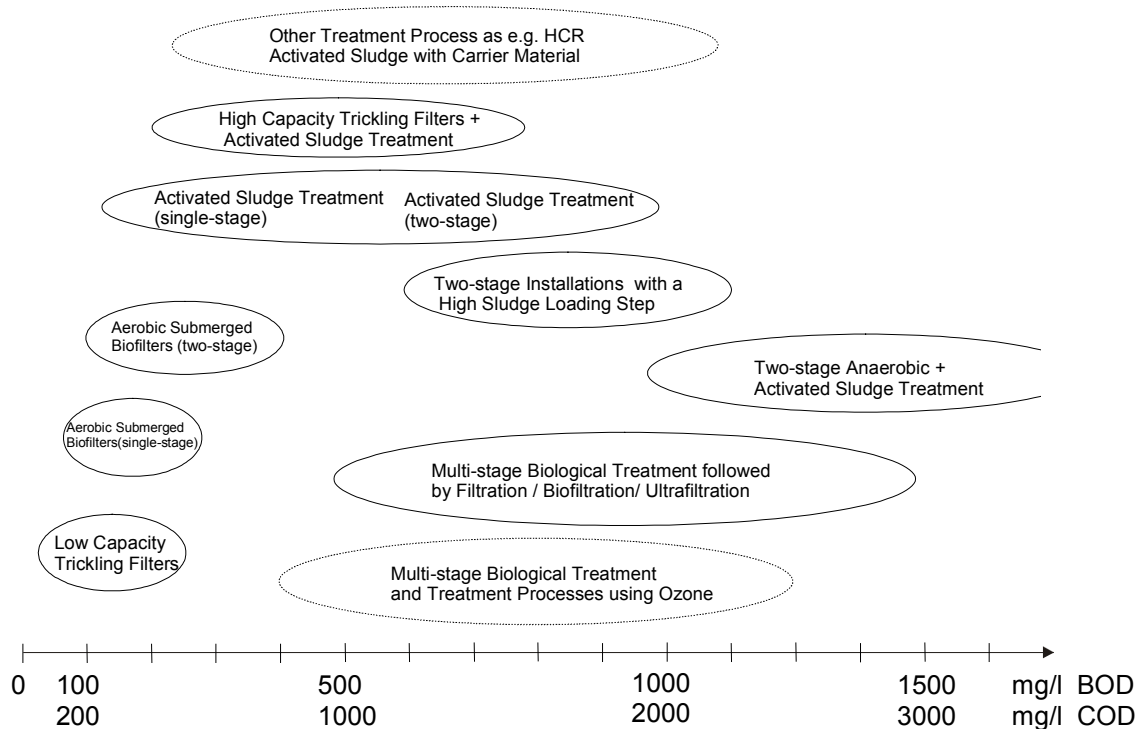


Figure 6.14: Main processes for external treatment of paper mill wastewater and the ranges of suitable application

The concentration values refer to inlet concentrations.[According to Demel in PTS, 1998]; the dotted areas represent more recent treatment techniques with less applications in Europe. Ozone treatment is still regarded as emerging technique (see 5.5.1). A two-stage activated sludge system comprises two separated aeration basins with two separated excess sludge recycling systems

It is a good general principle to provide some hydraulic buffering to protect the treatment plant from large variations (peaks) in flow or organic load that may otherwise cause periods of poor plant performance. Buffering also allows for plant size to be optimised for the average flow rate.

In Table 6.22 an overview is given over the most important biological treatment systems, their suitable range of application, some advantages and drawbacks as well as some additional remarks

Process	Application (BOD inlet concentration)	Advantage	Drawback	Remarks
Aerobic submerged biofilters (1-stage)	20 - 100 mg/l	Safe process; immobilised biomass; low concentration of SS in the effluent	Sensitive to higher concentration of SS	
Aerobic submerged biofilters (2-stage)	100 - 300 mg/l (or more)			
Low capacity trickling filters	< 100 mg/l	Simple construction; low energy consumption; cooling of the wastewater	In some cases risk of clogging; odour caused by stripping	
High capacity trickling filters + activated sludge	200 - 800 mg/l			
Activated sludge (single stage)	100 - 1000 mg/l	Conventional process with a number of variants; a lot of experiences	Energy cons.; Excess sludge; problems with bulking or floating sludge	
Activated sludge (two stage)				Separation of sludge circuits is important
Activated sludge (2-stage with high sludge load step)	600 - 1200 mg/l	Improved properties of activated sludge	Energy cons.; Excess sludge	
Moving bed biofilm reactors (fixed biomass on mobile carrier material)	300 -1500 mg/l	Fixed biomass; smaller reactor volumes; no return sludge; less sensitive to peak loads	Excess sludge;	e.g. Kaldness process; allows high volume load
Rotating biological contactors (RBCs): Fixed biofilm system/biodiscs	Applied as bulk removal step or for advanced treatment	Cost effective for smaller mills; low energy demand (<0.3 kWh/kg BOD removed)	In many European countries there is less experiences with RBCs	Successful application in USA and Italy in paper industry
Activated sludge as Sequencing Batch Reactor (SBR)	100 - 1000 mg/l	More flexible operating of the process	Higher efforts for process control; discontinuous process	

Table 6.22: Biological wastewater treatment of wastewater from paper mills; survey [According to PTS, 1998, changed by EIPPCB]

Biological treatment can also be combined with advanced treatment as ozone treatment or membrane filtration if more stringent requirements have to be achieved. In Germany, in 1999 two systems that combine biological treatment with ozonation and ultra-filtration are going to be put into operation for further reducing the COD load to the recipient (see Section 5.5.1).

For further information on wastewater treatment it is referred to the examples given below and respective handbooks of wastewater engineering [e.g. Metcalf&Eddy, 1991].

Applicability and characterisation of the measure: End-of-pipe technique. The process can be applied at both existing and new paper mills. In some special cases where the organic load is too low for efficient biological treatment virgin fibre mills may only apply primary treatment to meet the required standards (refer to Section 6.3.9).

Main achieved environmental performance: For biological treatment of papermaking effluents the following pollution load reduction efficiencies can usually easily be achieved:

- Activated sludge: 85 - 96 % for BOD₅; 75 - 90 % for COD.
These removal efficiencies are achieved by low load activated sludge systems with a food/mass ratio between 0.1 and 0.2 kg BOD/kg TSS*d. In a few applications also for high load plants good removal efficiencies are reported.
- Trickling filter: 60 - 70 % for BOD₅; 50 - 60% for COD
- Moving bed biofilm reactors/suspended carrier reactors: 85 - 95+ % BOD₅; 80 - 90% COD
- Submerged biofilter: 60 - 80 % for BOD₅; 50 - 60% for COD

It should be noted that the removal efficiencies depend to a certain extent on the incoming concentration of pollutants. Concentrations of organic substances in the wastewater on the other hand are governed by raw materials used, paper grades produced, specific water consumption and applied process-integrated measures.

Wastewater from paper mills after treatment can reach values between 50 - 150 mg COD/l. BOD₅ levels below 25 mg BOD₅/l are normally achievable and can reach values down to 5 mg/l. The COD/BOD ratio of filtered samples of paper mill wastewater after biological treatment is usually between 4 and 7 or 8 (up to 10). The load discharged to the recipient depends mainly on paper grade manufactured, the product properties to be achieved, the water flow per tonne of product, the chemical additives applied and the design and operation of wastewater treatment. Proper design and maintenance of treatment plant are a prerequisite for good performing biological systems.

Monitoring of Emissions: Usually COD, BOD₅, TSS, N and P and AOX are controlled. Additional measurements to control the biological system are also recommended as for instance O₂-content, Sludge volume index (SVI), waterflow and from time to time microscopic examination of the activated sludge. The latter is gaining increasing importance.

Cross media effects: During aerobic wastewater treatment excess sludge is produced which has to be thickened, de-watered and further treated. A typical value for low loaded activated sludge plants is in the range of 0.3 – 0.4 kg excess sludge /kg BOD₅ eliminated (as dry solids) generated during treatment. Sometimes also slightly higher values are observed. The treatment of lower BOD concentration in submerged biofilters generates less excess sludge: about 0.2 kg excess sludge /kg BOD₅ eliminated (as dry solids). High loaded plants have a higher specific excess sludge generation.

For aeration of the active biomass (activated sludge) and for pumps electrical energy is needed. The specific energy consumption for degradation/elimination of 1 kg BOD₅ amounts to 0.3 - 3 kWh. It depends mainly on the specific amount of oxygen needed for degradation of organic substances and the designed load of the activated sludge system. High load activated sludge systems require about 0.3 to 0.5 kg O₂/kg BOD₅ eliminated. Low load systems need 1.5 to 2 kg O₂/kg BOD₅ eliminated. Consequently, high load activated sludge treatment consumes about 0.5 kWh/kg BOD₅ eliminated and low load activated sludge consumes about 1.5 to 2 kWh/kg BOD₅ eliminated. If the low loaded system is well-designed a value of < 1 kWh/kg BOD₅ eliminated can be achieved [Möbius, 1997]. This value can also be used to compare expected operating costs of different wastewater systems.

Mineral nutrients are usually added to the biological treatment plant to keep the balance C : P : N which is of crucial importance for the growth of active biomass. Usually, phosphorus is added as phosphorus acid and nitrogen in form of urea. Part of the added nutrients normally will be released together with the treated effluent. When the system is well optimised nutrients discharge of 1 mg tot-P/l and below 10 mg inorganic-N/l are achievable (as a daily average value).

Especially during the summer period, the wastewater treatment plant of paper mills may emit annoying odours. If the wastewater treatment is well designed and controlled annoying odours can be avoided.

Operational experiences: Aerobic biological treatment for effluents from paper mills has been successfully used for over 20 years.

The tendency of sludge bulking in activated sludge treatment needs to be controlled by appropriate measures. It appears generally when there is a disturbance in the system caused e.g. by variations in pollution load, variations in dissolved oxygen in the activated sludge basin, lack or excess of nitrogen and phosphorus or variation in the amount of recycling sludge fed back to the aeration basin.

Sludge bulking is usually temporary. A stepwise approach may give insight in the origin of sludge bulking. This approach may include for instance control on the design of the treatment plant, microscopic examination of the activated sludge, monitoring of the incoming wastewater. In general, monitoring is necessary to get insight in possible causes for problems. In some cases, it appeared that lower carboxylic acids like acetic acids, were the main cause for prevalent growth of filamentous bacteria that are responsible for sludge bulking. Filamentous bacteria can also appear when sulphur is present in the effluents.

For less critical paper or board grades (e.g. testliner or paperboard) the reuse of (parts of) treated effluent from biological wastewater treatment, usually after additional treatment by flotation or sand filtration, is also an option.

Economics: The following figures on investment costs for biological treatment can only give a rough indication on the magnitude of costs involved. When comparing investment costs based on the polluting load treated (e.g. kg COD) one has to bear in mind that treatment plants are often oversized to take into account a possible future increase of production.

However, some examples of treatment systems in French paper mills are compiled:

- activated sludge for a printing paper mill (200 t/d paper production): 2 MEuros
- activated sludge for a printing paper mill (300 t/d paper production): 3 MEuros
- biofiltration for a speciality paper mill (130 t/d paper production): 1.5 MEuros
- activated sludge for a printing paper mill (260 t/d paper production corresponding to 2.5 t COD/day): 2 MEuros
- activated sludge for a corrugated paper mill (100 t/d paper production): 1.5 MEuros [all data from CTP, Grenoble].

The investment costs can be summarised as follows:

Activated sludge treatment: 300 - 600 Euros/kg COD*day; Biofiltration: 500 Euros/kg COD*day. The range of investment costs depends above all on the quantity of polluting load per day to be treated.

Driving force for implementing this technique: Many Member States have set requirements for effluents from paper mills which consider biological treatment generally as BAT on a sector level. As a consequence, many paper mills in Europe had to build biological wastewater treatment plants or other treatment systems with comparable efficiencies.

Example plants: Numerous aerobic wastewater treatment plants are operated in European paper mills.

Literature/References:

[Möbius, 1997 b], [Cost data from CTP, Grenoble], [PTS, 1998]

6.3.11 Chemical precipitation of wastewater from paper mills

This technique is considered as an alternative or complementary technique to Section 6.3.10 "aerobic biological treatment" of wastewater from paper mills. Chemical precipitation could be a compliment to biological treatment either before or after.

Description of the technique: In some cases, chemical precipitation as complete secondary treatment of untreated wastewater from paper mills can be an option to reduce emission to water. Chemical precipitation involves the addition of chemicals to alter the physical state of dissolved and suspended solids and facilitate their removal by sedimentation or flotation. Different substances have been used as precipitants. The most common ones are aluminium salts [$\text{Al}_2(\text{SO}_4)_3$ and $\text{Al}_n(\text{OH})_m\text{Cl}_{3n-m}$], ferric chloride (FeCl_3), ferric sulphate ($\text{Fe}_2(\text{SO}_4)_3$), ferrous sulphate (FeSO_4) or lime ($\text{Ca}(\text{OH})_2$). To optimise the flocculation, polyelectrolytes are used in the mixing phase.

Suspended and colloidal matters are separated by precipitation and subsequent filtration or clarification including the removal of nitrogen and phosphorus. It is possible by chemical precipitation to obtain a clear effluent, substantially free from matter in suspension or in a colloidal state.

This treatment is applied as stand-alone treatment or in combination with biological treatment. The latter is applied when lower emissions of organic substances (measured as COD and/or BOD) are supposed to achieve. Chemical precipitation has a role to play in particular when nitrogen, phosphorus, and TSS are of concern while biological treatment when oxygen depletion is the problem and not eutrophication.

Applicability and characterisation of the measure: Applicable to both and existing mills. End-of-pipe measure. It is especially applied at smaller mills.

Main achieved environmental performance: Chemical precipitation as complete secondary treatment of untreated wastewater from paper mills is mainly applied to reduce nutrients especially phosphorus, TSS and part of the organic matter (particulate and colloidal compounds). Results from Swedish plants where chemical precipitation is used as stand-alone treatment of wastewater from non-integrated paper mills are given in Table 6.23. Sometimes chemical precipitation is also applied in combination with biological treatment.

Mills	COD before any treatment [kg/t]	COD after treatm.		TSS		Tot-P		Tot-N	
		kg/t	mg/l	kg/t	mg/l	g/t	mg/l	g/t	mg/l
Klippans mill, fine paper	n/a.	6.4	120	0.7	13	2	0.04	200	3.7
Hafreström, fine paper	n/a.	4.3	270	0.75	47	5	0.31	70	4.4
Silverdalen, coated fine paper ²⁾	n/a.	0.7	100	0.11	16	1	0.14	50	7.1
Grycksbo, coated fine paper ¹⁾	n/a.	1.0	100	0.27	27	1	0.10	40	4.0
Skapafors, tissue	n/a.	3.7	110	0.48	15	1	0.30	430	1.3
Nättraby, tissue ⁴⁾	8 ³⁾	2.5	170	0.16	11	2	0.13	30	2.0
Langasjönas, tissue	12 ³⁾	3.7	190	0.18	9	2	0.10	120	6.0
Pauliström, tissue	5 ³⁾	1.4	140	0.07	7	1	0.10	10	1.0

Notes
 1) Grycksbo operates chemical precipitation + biological treatment in a moving bed system
 2) The Silverdalen mill has an aerated lagoon before chemical precipitation
 3) The COD before any treatment includes COD from total suspended solids
 4) The Nättraby mill has only flocculation and not true chemical precipitation

Table 6.23: Performance of chemical precipitation as secondary treatment of paper mill wastewater
All mills have applied chemical precipitation, some have additional treatment. [SEPA report 4924 and personnel communication]; yearly average values

Reduction rates of about 97-99 % for TSS and 70 % for COD referred to the raw effluent (before any treatment i.e. before the primary clarifier) are achieved. The COD reduction is mainly due to reduction of TSS. The soluble part of COD (and BOD) is only slightly reduced (about 10%). The reduction of the soluble compounds of COD and BOD can be achieved by biological treatment (see Section 6.3.10).

The COD/BOD-ratio in the range of 3 after chemical precipitation shows that a substantial parts of the removed COD is consisting of less biodegradable, and therefore potentially more harmful matter. It also shows that these effluents are appropriate for further biological treatment.

Cross media effects: The precipitation of TSS, nutrients and to less extent organic material with inorganic chemicals results in a great quantity of sludge that is difficult to dewater and often dumped to landfill. The amount of generated sludge is in the range of 3-6 kg/m³ including 60 to 80 % water (after presses or centrifuges the dry substance is about 20 - 40%).

The chemical cost is substantial and the purification is selective; neutral substances cannot be captured as efficiently as dissociated ions or colloidal and particulate matter. The use of precipitants result in an increase of salts (chlorides or sulphates) in the effluent. The use of metal-salts is normally between 200 and 400 g/m³.

The treatment consumes some energy for pumps and drives.

Operational experiences: No specific problems are known which are linked to the application to this technique.

Economics: The investment costs for physico-chemical treatment amount to 1 MEuros for a printing paper mill with a capacity of 100 t/d. The investment costs for chemical precipitation includes equalisation tank, chemical dissolving equipment, chemical dosing equipment, precipitation and flocculation unit and clarifier. On operating costs no data were available.

Driving force for implementing this technique: Usually chemical precipitation of wastewater from non-integrated paper mills is applied when the nutrients, TSS and non-soluble parts of the organic matter in the effluent have to be removed.

Reference plants: Some smaller mills in Portugal and some non-integrated paper mills in Sweden

6.3.12 Substitution of potentially harmful substances by use of less harmful alternatives

Description of the technique: In paper industry water is the medium where most of the released substances may end up because usually the additives are added to the aqueous fibre-filler-suspension and are then either retained in the paper or come to the white water. Air is of less importance and soil may be affected via waste disposal (composting, use of paper sludge in agriculture, landfilling).

The expected discharge of additives to the water is directly related to the retention of the chemicals to the paper product, the degradability of the substances and the retention in the waste water treatment plant. The higher the retention, the lower the discharge to the effluent and the lower the potential environmental effect of the applied additives. In case of product aids a maximum degree of retention is desirable from an economic (loss of additives) and ecological point-of-view. Since product aids are designed to give paper a particular characteristic, for reasons of costs and efficiency they generally have a relatively high level of retention to the cellulose fibres. Process aids are usually less retained because they produce their effect in the water circuits of the paper mills. A large proportion is discharged with wastewater. Furthermore, it should be noted that broke is normally re-pulped so that some of the additives are returned to the water circuit. Knowledge about the retention of additives is therefore

important. The degradability of a substance on the other hand, is the crucial point to avoid the risk of accumulation of a given substance in environment and organisms respectively.

Some water authorities use both, the retention factors and the biodegradability of substances to assess and minimise the contribution of additives to the COD load after treatment. In Germany for example, the application of the method shown in Figure 6.15 resulted in a reduced application and/or substitution of some additives that caused a significant share of the COD load after treatment (substitution principle). Furthermore, the mill had to report how and why various chemicals have been used.

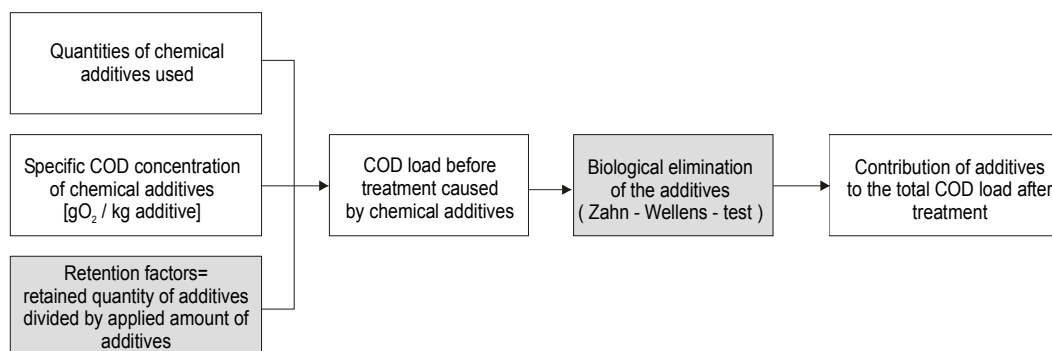


Figure 6.15: Pragmatic approach for assessment of the amount of heavily biodegradable additives to be expected in effluents from paper mills after treatment [IFP, 1997]

Besides a general approach for reduction of releases of chemical additives to water there might exist some candidates for substitution/replacement from an environmental point-of-view. This might be especially the case when chemicals are considered as hazardous and there are less hazardous substitutes achieving the same purpose available. Biodegradable, non-toxic and non-bio-accumulating chemicals should be favoured whenever possible. Chemicals suspected to pose a risk to humans or environment should be avoided e.g. those with ozone depleting effects, suspected endocrine disruptors, CMR substances (carcinogenic, mutagenic, reprotoxic). Organically hydrocarbons as benzene (carcinogenic), tuloene (toxic), and xylene (toxic) originating from solvents and detergents that might be used for cleaning of wires, felts and machines should be replaced by solvents that show less toxic effects. Alternatives (e.g. esters) that are also to some extent biodegradable are available.

Main achieved environmental performance: A possible result of such an approach for monitoring of additives might be similar to the one that is shown in Figure 6.16. Some substances - mainly process aids - are neither retained nor biologically degraded (substance A). In this case the applied additives end up completely in the recipient. Others are partially retained and partially eliminated in the wastewater treatment plant (substance B), others again are retained to nearly 100 percent and do not even reach the treatment plant. It can be assumed that most of the product aid additives are both partially retained and to a certain extent eliminated in the wastewater treatment plant. Process aids have a low retention to cellulose fibres and can therefore be expected to end up in the wastewater.

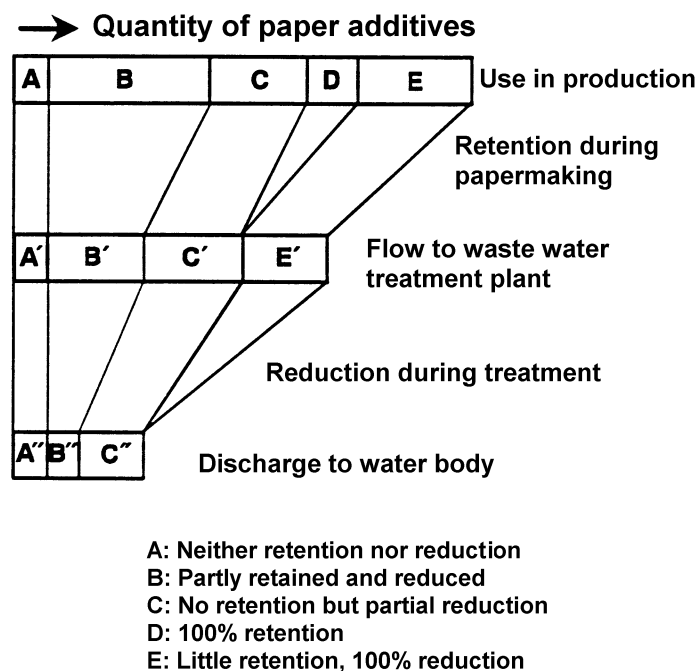


Figure 6.16: Schematic presentation of the fate of chemical additives in paper manufacturing including external treatment [IFP, 1997]

Monitoring: The required data should usually be provided by the supplier of the substances.

Cross Media Effects: Reduction of harmful additives in paper processing will result in less impact on water and waste compartments. It can also be beneficial from the perspective of life cycle management. By using environmentally sound product aids, harmful substances can be prevented from ending up in the product, which in turn might be used as raw material in recovered fibre processing.

Operational Data: For chemical additives and auxiliaries a "transparent" information system is still missing in which manufacturers, importers and users of chemicals would carry out "self-assessments" of chemicals for the stage of their life-cycle that they are responsible. Relevant data would then be passed from one company to the next to avoid duplication of work. Some governments provide guidance and audit companies' assessments on chemicals, others also wants companies to do more to improve the "Eco-efficiency" of chemicals manufacture - using fewer resources and emitting less per unit of product. An overview of the development and current state of selected environmental risk assessment schemes of substances, with emphasis on the aquatic environment, is given in [EurEco, 1997].

Economics: No data available

Driving Forces for implementing this Technique: Some water authorities set requirements to minimise the contribution of additives to the COD load after treatment. Requirements on reduction of releases of biocides can also be found. Biodegradable, non-toxic and non-bio-accumulating chemicals should generally be favoured whenever possible. Chemicals suspected to pose a risk to humans or environment should be avoided especially those with ozone depleting effects, suspected endocrine disruptors, CMR substances (carcinogenic, mutagenic, reprotoxic).

Example Plants: A limited number of plants in Europe.

Literature

[IFP, 1997], [Braunsprenger, 1996], [EurEco, 1997]

6.3.13 Pre-treatment of sludge (de-watering) before final disposal or incineration

Description of the technique: In effluent treatment plants large amounts of sludge are generated in the primary treatment, biological activated sludge plants and chemical flocculation plants, including coating colour treatment. Aerated lagoons, as well as anaerobic plants, typically generate sludge in lesser amounts.

The sludge handling includes the following main stages:

- reuse of fibre sludge from primary treatment. This is practised in many cases.
- thickening and dewatering of fibre/biological/(chemical) sludge
- final disposal of dewatered sludge.

Reuse of fibre sludge is practised in cases where this is suitable with regard to product requirements etc. Internal fibre recovery, however, often leads to low fibre discharges and poor sludge properties, in which cases reuse of the sludge is not feasible.

Biological and chemical sludges have very poor dewatering properties, and normally they have to be mixed with fibre sludge for acceptable dewatering conditions. So in the presence of biological/chemical sludges, at least a part of the fibre sludge should be dewatered, rather than reused. Also, a far-reaching internal fibre recovery will mean increased difficulties in dewatering biological/chemical sludges

The dewatering aims at removing water from the sludge as far as possible, in order to facilitate the final disposal. Different types of mechanical equipment are available for this operation.

Biological and chemical sludges normally should be thickened prior to the dewatering. This means an increase of dry solids (DS) content from about 1-2 % to 3-4 % or higher. The thickening is usually performed in a gravity thickener, which is basically a settling basin with low load.

Prior to dewatering, the sludge normally must be conditioned with chemicals. Usually a polyelectrolyte is enough. This refers particularly to sludge mixtures with biological and/or chemical sludge.

Dewatering equipment includes the following types:

- belt presses (twin wire presses)
- screw presses
- decanter centrifuges
- chamber filter presses

Most new installations during the last 10-15 years have been belt presses, which have a reliable function and produce fairly high DS values, 40-50 % with fibre sludge and 25-40 % with mixed fibre/biological/(chemical) sludge. However, recent trend is to use screw presses.

Screw presses can be used in two ways:

- to increase the DS content after belt press dewatering; approximately 10 % DS increase can be obtained.

- direct dewatering; higher DS content can be obtained compared to belt-press dewatering.

An increasing application of screw presses has been observed for some years, due to an increasing interest in sludge incineration, requiring high DS values.

Decanter centrifuges are at present mostly used for sludges with very poor dewatering properties, such as pure chemical sludge or biological sludge (if it is dewatered separately). They produce lower DS contents than the belt and screw presses. Rotary precoat filters can also be used for this application achieving higher dry solid contents. The resulting filtrate has very low content of suspended solids normally below 10 mg/l (super-clear filtrate).

In summary, dewatering methods for all sludges are available. They are capable of dewatering to such DS contents that are necessary for final disposal.

Applicability and characterisation of the measure: The measure can be adopted in existing and new mills. Nowadays it is impossible to run a mill without dewatering because the disposal of large amounts of thin sludge faces problems.

Main achieved environmental performance: The sludge dewatering can reduce the sludge volumes up to 20 times.

The environmental achievements are seen at the disposal place. The reduced pollution of ground water is one of the effects.

Monitoring of emissions: Monitoring is discussed in a separate chapter.

Cross media effects: The sludge produced at the effluent treatment plant after de-watering can be burned, providing in some cases net positive heat value.

Operational experiences: Many types of dewatering equipment, ranging from low-efficiency drum filters to high efficiency screw presses have been used in all types of paper and board mills. The current heavy-duty belt filter press and screw press designs used for high sludge dryness target have proven efficient in most cases. Continuous rotary precoat drum filters are also operated in paper industry resulting in 40-50% DS together with high quality filtrate (10 mg SS/l). This is achieved by more rotational speed for thinner-shaved cake.

However, the higher the proportion of biosludge in the mixture to be dewatered and the higher the dryness target the more sensitive the overall system has become to qualitative and quantitative variations in the system feed or to other operation set-up parameters.

Economics: Investment costs for sludge dewatering in a 1500 ADt/d newsprint mill are as follows:

Wire press	1.5 - 1.8 MEuros
Screw press	1.7 - 2.0 MEuros
Centrifuge	0.7 - 0.9 MEuros

The operating costs, assuming dewatering of both primary and biological sludge, are 0.3 - 0.6 MEuros/a. The cost is very dependent on the sludge composition and demand of flocculation chemicals.

Driving force for implementing this technique: More suitable dry solids content for transportation and final disposal are the driving forces to implement this technique

Example plants: Numerous plants all over the world for all types of effluents.

Literature:

[J. Pöyry, 1997 b], [Finnish BAT Report, 1997], [SEPA-Report 4713-2, 1997]

6.3.14 Options for waste treatment

Introduction

The production of paper and board is related to the generation of residues and wastes. The European Waste Catalogue (94/3/EEC) intends to establish a common terminology for the Union Member States. However, in Europe there is still different terminology in use for the different waste fractions generated in paper mills. The European waste catalogue mentions for paper mills the following waste fractions:

- fibre and paper sludge
- for mills using recovered fibres: rejects from paper and cardboard recycling and de-inking sludges from paper recycling; see Chapter 5. There is a certain overlapping with this section
- for integrated mills with virgin pulp production: bark, dregs and green liquor sludge (from black liquor treatment); see Chapter 2, 3 and 4. It is not dealt with here
- waste from the preparation of water for industrial use
- sludges from wastewater treatment plants
- waste not otherwise specified

The waste fractions are separated and merged in different ways, depending on the options for reuse/recycling and further treatment and disposal. Figures for single waste fractions are scarcely available. Often, only data on sludge and rejects or sometimes only sludge are reported. Therefore, in the following the paper mill residues are discussed as one material flow.

The most important specific residues are rejects from stock preparation, fibre and paper sludge and sludge from water treatment. They are generated at both virgin and recycled fibre mills. However, at virgin fibre mills the quantities produced are smaller, usually less than 50 kg/t, whereas in mills using recycled fibre (e.g. tissue mills) the quantities are very much larger, for instance up to 1000 kg DS/tonne of tissue. The composition and amount of the solid waste depends on the paper grade produced, the raw materials used, the process techniques applied and the paper properties to be achieved.

Waste management consists of waste prevention, reuse, material recycling, composting, energy recovery and final disposal. The decision making tree below gives a rough overview over the major options for waste management and highlights some important aspects. There is no standard solution for the waste handling in paper mills.

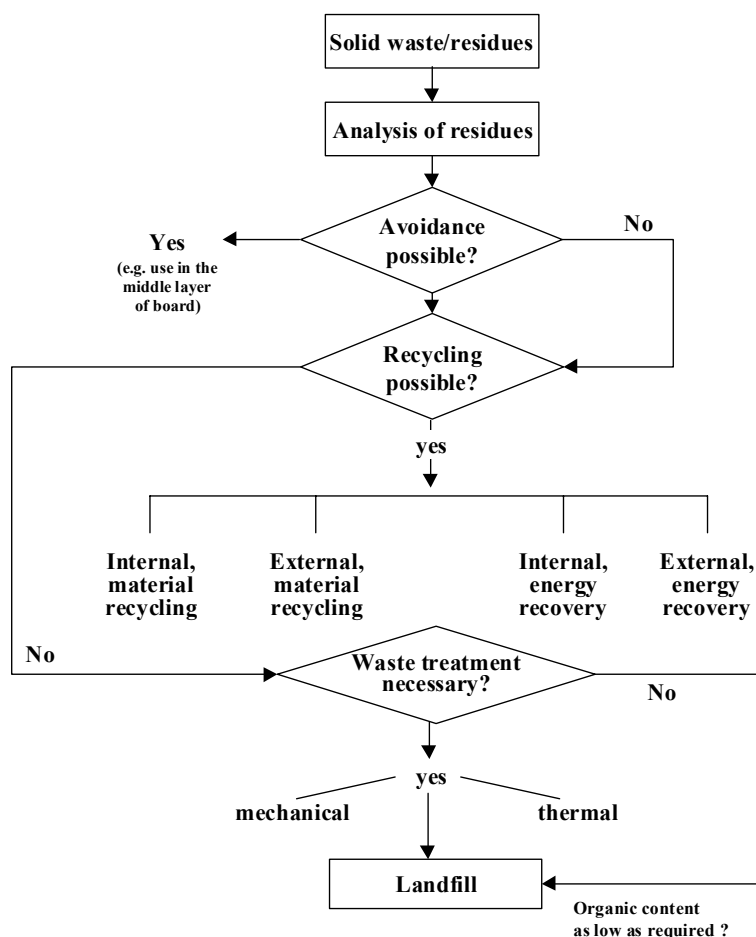


Figure 6.17: Possible decision making tree for waste management of paper mill waste [According to Hamm, 1996]

The residues of paper mills - except the ashes from power plants or boiler houses and from on-site incinerators - are characterised by a relatively high amount of organic material. Nevertheless, landfill is still widely used for waste disposal in many European countries (e.g. UK, Spain). At the same time, in many Member States the dumping of waste with high organic content is discouraged by governments and will probably be prohibited in the near future. The EU Directive on landfill of waste will support this tendency in setting targets to cut the amount of biodegradable (municipal) waste sent to landfills. Consequently alternative recovery operations as material recycling and incineration with energy recovery will play an important role in the future. This treatment options are discussed in the following as techniques to consider in determination of BAT. Recovery operations - were the residues are put to some further use whereby some or all of the constituents (including energy) are re-used or recovered - are considered as preferred waste treatment options, where feasible. BAT is to identify these possibilities and to ensure that they happen. Some important technical aspects are highlighted and the benefits, concerns or limitations of different treatment options are discussed.

Material recycling

An overview about the main treatment options for material recycling and the factors governing the treatment options choice are shown in Figure 6.18.

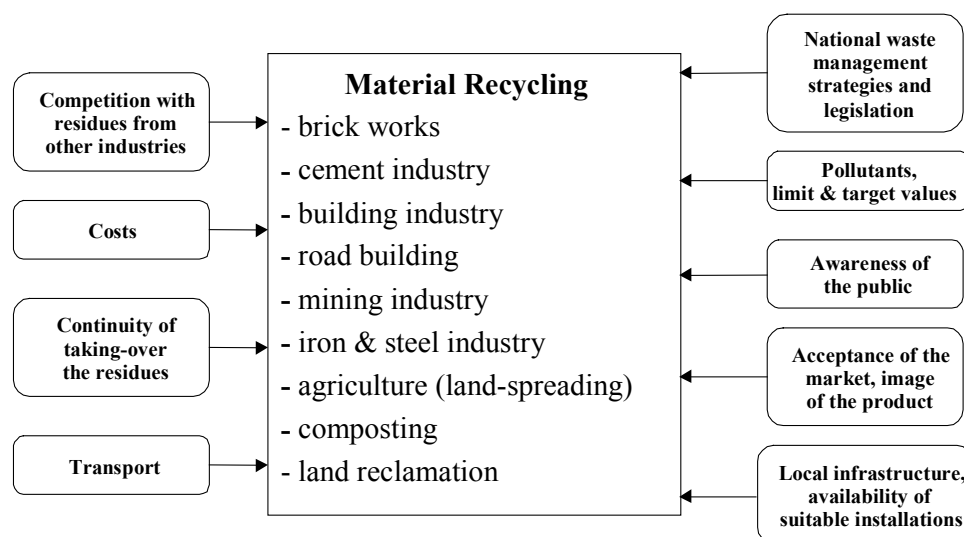


Figure 6.18: Options for material recycling of paper mill residues and factors governing treatment options choice
[Hamm, 1996; changed by EIPPCB]

Figure 6.18 shows that a bundle of factors govern the option chosen by a given mill. The main factors might be local infrastructure, costs and competition with residues from other industries. The latter is especially relevant for the utilisation of paper sludge in cement and brick industry. Concerning transport the principle of proximity reduces environmental impact and costs. The use of paper residues as raw material in different options mentioned in Figure 6.18 is beside others dependent on the local availability of suitable processes.

In some countries, composting of paper sludge or land spreading in agriculture is practised. For this alternative the control of the potential pollutants is of crucial importance. However, sludge from paper mills usually do not contain more pollutants than sludge from municipal treatment works and restricted application can have some positive effects on the soil (CaCO₃ as neutralising agent of acidic soils, moisture retention by fibres and fines on dry soils, low nitrogen content). The possible benefits vary according to the soil type. The periods of land spreading are restricted to some months of the year. It is therefore necessary to build ensure sufficient storage capacity for the sludge.

The feasibility of land spreading is strongly dependent on the acceptance in Member States to apply sludge to agricultural land. In some Member States this practice is encouraged as an economically beneficial disposal route, other Member States are concerned about land spreading of paper sludge. The major concerns are possible contamination of soils with low concentrations of heavy metals and organic micro-pollutants, local opposition because of nuisance problems or image problems for agricultural products from land-spreading areas.

For composting, the quality demands of the compost is most important to get a marketable product. Composts made from organic waste mixed with different quantities of recovered paper and residues of the paper industry fulfil these requirements such as degree of maturity or suitability for plant growth. Furthermore, parameters as salt and organic substance content and the process specific leachate emission is positively influenced. The concentration of harmful substances, especially those of heavy metals must be considered as a limiting factor.

Another option for treatment of sludge from paper mills are the utilisation in the cement and brick industry (to improve porosity) or other building material. In the cement industry both the material and energy content of the paper residues can be recovered. For the use in cement industry sludge from primary clarifiers (or mixed with excess sludge from biological treatment) that contain fibres and fines and inorganic compounds (e.g. fillers, coating pigments) is especially suitable. The sludge (about 50% moisture content) is dried with waste heat from the

pre-dryer of the cement kiln so that no additional thermal energy is needed to reduce the moisture of the sludge down to 10 - 15%. Thus, when burning the dried sludge in the cement rotary kiln the calorific value of the organic substances is used and the ash from incineration of the sludge (mainly) remains in the product (cement). The inorganic substance of the ash of the incinerated sludge is also a compound of the cement clinker. If cement (or brick) manufacturing industries are local to the mill (short transport distance) and are able to use the sludge it is a viable option.

Energy recovery

Residues and sludges contain organic substances that can be burned on- or off-site in dedicated incinerators with energy recovery (for on-site incineration in non-integrated mills the amount of sludge to be burnt is usually not sufficient). Incinerators with energy recovery can be divided in mono-incineration and co-incineration.

In mono-incinerators - usually fluidised beds, multiple hearth furnace or kilns at a temperature range of 850°C to 950°C - exclusively waste from paper industry is burnt. These installations achieve the legal requirements for waste incineration when air emission abatement is applied and are considered as BAT. For further information it is referred to Section 5.3.11 of this document. The ashes can be landfilled or further used in building industry.

Co-incineration of paper industry residues is practised in cement kilns, coal power plants (see Section 5.3.11, example 2), municipal waste incinerators, blast furnaces (iron & steel industry) and cubola furnaces (foundries). For this option residues with a high calorific value are especially suitable to replace fossil fuel (e.g. coal, fuel oil). The paper mill residues are usually mixed with other fuels burned in these installations. Before incineration, they have to be de-watered and sometimes also dried (e.g. for cement and iron & steel industry). As a rule of thumb it can be said the more similar the characteristics of the residues to be burnt to the normal fuel the easier the co-incineration. Homogeneity of secondary fuel and uniform and constant composition of the residues are also important. The control of these parameters makes paper industry waste more interesting for combustion installations.

The combustion behaviour of paper mill residues as de-inking sludge, rejects from cleaning and screening, or sludge from wastewater treatment is shown in Figure 6.19. It illustrates the connection between combustible/organic content, ash content and water content. The area of self-supporting combustion where no additional fuels are necessary is especially marked.

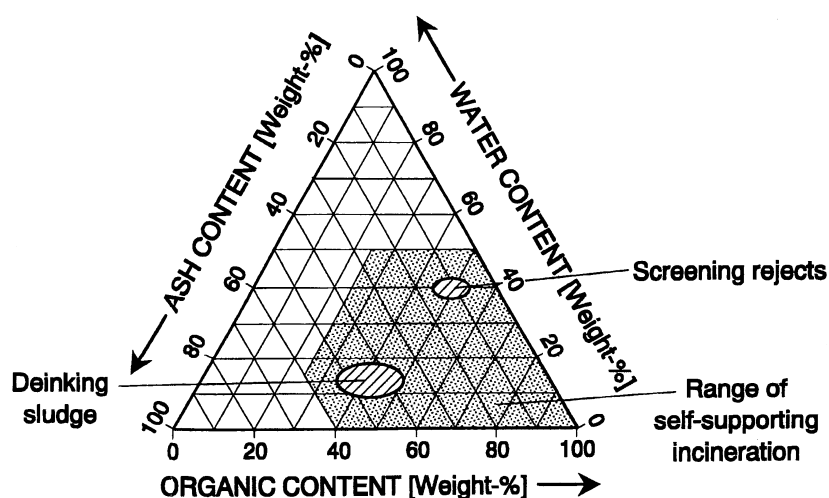


Figure 6.19: Fuel triangle for residues from paper industry (provided by IFP)

The area where de-watered de-inking sludge and de-watered rejects from mechanical cleaning and screening is located is plotted hatched. It can be seen that a self-supporting combustion is achieved for both rejects having relatively high calorific values as well as de-inking sludge with relatively high ash content. In sludge burning the net energy production is about zero or negative if the dry-solids content in the sludge is below 40% and if the sludge contains a very high amount of inorganic material. In those cases, to maintain good burning conditions the use of auxiliary fuel is necessary unless the sludge is mixed with bark and other wood waste material. Burning reduces the volume of waste and the inorganic content remains as ash (up to half of the weight can remain as inorganic ash), which is normally transported to a landfill site or used as a resource for building materials.

The effect of co-incineration of paper mill residues and sludge on air emissions depend on the composition of the burnt material. Co-incineration of fibre and paper sludge - especially those with high alkali content - in coal or lignite fire power plants have either no effect on air emissions or lead to a slight reduction of pollutants. Emissions of SO₂, HCl and HF are reduced by co-incineration of sludge with high alkali content (de-inking sludge, fibre sludge containing coating pigments and filler). The content of heavy metals in fibre and paper sludge is also low compared to coal and lignite. Rejects from stock preparation of recovered paper mills manufacturing corrugating material have higher chlorine content (1-3 mass %). First experiences in a full-scale plant in Germany showed however that co-incineration of rejects in lignite fired power plants is feasible. No increase of dioxins has been measured.

The availability of e.g. incineration varies considerably within Member States and also within the single countries. Incinerators sometimes face the considerable obstacle of local objections.

In integrated pulp and paper mills, a major portion of the sludge is usually incinerated together with bark in bark boilers (see Chapter 2, 3 and 4).

Integrated recovered paper mills may have installed an on-site incinerator (see Chapter 5). In those mills ashes and residues from air emission control as e.g. dust from ESP or gypsum from SO₂ removal (if applied) have also to be handled as a waste fraction.

Literature

[Hamm, 1996], [Wünschmann et al., 1995a], [Wünschmann et al., 1995b], [Wünschmann et al., 1995c], [IPTS, 1997], [Guillet, 1997]

6.3.15 Installation of low NO_x technology in auxiliary boilers (oil, gas, coal)

Description of the technique: In paper and board mills, a variety of regenerative or fossil fuels - bark, coal, lignite, oil or natural gas - may be used for supplemental steam production. In burning of these fuels environmentally sound incineration techniques are called for to minimise particulate, SO₂ and also NO_x emissions.

Low NO_x technology applied to burning of solid fuels and pulp and paper mill wastes with fluidised bed boilers is discussed in 2.3.20. Coal and lignite suit well to be burned as main or support fuel in fluidised bed systems, which by careful operation control promotes low NO_x formation.

In conventional oil or natural gas fueled boilers, the burners feeding the fuel-air mixture, must apply designs that maintain low NO_x burning conditions. Also coal or peat is often burned as finely ground dust in conventional boilers, fed through burners that with proper designs provide low NO_x burning.

The primary burning air is brought through the burner in the fuel-air mix. Secondary and tertiary air are fed in separately to maintain an appropriate primary:secondary:tertiary air balance in the flame area to maintain low NO_x combustion. Some air may still be fed, if necessary above the main flame area to complete the fuel combustion.

The purpose of the multi-phase air feed is to burn the fuel without excess air and actually even under reducing conditions, meaning that:

- There is not enough oxygen to promote strong NO_x formation. The flame temperature is lower than in conventional burners which further decreases NO_x formation.
- Part of the NO_x formed will reduce back to elementary nitrogen for instance when a residual amount of the fuel is burned in the outer flame area or outside it.

Applicability and characterisation of the measure: Low NO_x burners and multi-phase air feed can be used both in existing and new boilers.

When powdered solid fuels, such as coal or peat, are used it is important that if they have high humidity they are pre-dried to support fast and efficient burning. Additionally they require that the burning air is preheated to assure quick ignition and complete burning.

Main achieved environmental performance: In comparison to conventional burners with 250-500 mg/MJ NO_x emissions the low NO_x burners can reach considerable lower levels in stack emissions. The achieved emission levels as shown in Table 6.24 are distinguished according to the types of fuel used and whether the boilers are existing or new installations. Best achievements mean these values are achieved by several new plants. Generally achievable means it is achievable by most plants. The values refer to 3% oxygen content and 7% for coal

Parameter	Status	Fuel	Generally achievable		Best achievements	
			(mg/Nm ³)	mg/MJ	(mg/Nm ³)	mg/MJ
NO _x	New	Natural gas/biogas	70 - 100	20 - 30	30 -100	9 - 30
		Light oil/gasoil ²⁾	120 - 200	35 - 60	150	45
		Heavy fuel oil	300 - 450	90 - 135	300	90
		Coal	300 ¹⁾ - 500	115 ¹⁾ - 190	250 ¹⁾ - 280	90 ¹⁾ - 100
NO _x	Existing	Natural gas/biogas	70 - 200	20 - 60		
		Light oil/gasoil ²⁾	150 - 250	45 - 75		
		Heavy fuel oil	400 - 450	115 - 135		
		Coal	300 ¹⁾ - 500	115 ¹⁾ - 190		
SO ₂	New	Natural gas/biogas	0 - 35 ³⁾	0 - 10 ³⁾	35 ³⁾	10 ³⁾
		Light oil/gasoil	350 ³⁾	100 ³⁾	250 ³⁾	75 ³⁾
		Heavy fuel oil	850 - 1700 ⁴⁾	250 - 500 ⁴⁾	850 ⁴⁾	250 ⁴⁾
		Coal	400 - 2000 ⁴⁾	150 - 750 ⁴⁾	400 -2000 ⁴⁾	150 - 750 ⁴⁾
SO ₂	Existing	Natural gas/biogas	0 - 35 ³⁾	0 - 10 ³⁾		
		Light oil/gasoil	350 ³⁾	100 ³⁾		
		Heavy fuel oil	1700 ⁴⁾	500 ⁴⁾		
		Coal	400 - 2000 ⁴⁾	150 - 750 ⁴⁾		
Dust (by use of ESP)	New	Natural gas/biogas	0 - 5	0 - 1.5	0 - 5	0 - 1.5
		Light oil/gasoil	no data	no data	no data	no data
		Heavy fuel oil	50 - 80 ⁵⁾	15 - 25 ⁵⁾	10 - 50 ⁵⁾	3 - 15 ⁵⁾
		Coal	< 50	< 20	10 - 50	4 - 20
Dust (by use of ESP)	Existing	Natural gas/biogas	0 - 5	0 - 1.5		
		Light oil/gasoil	no data	no data		
		Heavy fuel oil	50 - 80 ⁶⁾	15 - 25 ⁶⁾		
		Coal	50 - 150 ⁶⁾	20 - 60 ⁶⁾		

Notes:
1 Fluidised bed technology
2 Depending on N-content of fuel
3 Depending on S-.content of fuel
4 Depending on S-content, size and type of installation; the sulphur emissions of coal and oil fired boilers depend on the availability of low-S oil and coal. Certain reduction of sulphur could be achieved with injection of limestone.
5 Depending on S-content and type of installation
6 Depending on size of installation

Table 6.24: Achievable emission levels (daily average) from boilers with low NO_x techniques (only combustion technology is applied) and dust removal by use of electrostatic precipitators [data are based on a big number of plants in Germany]

Monitoring of emissions: Emission monitoring with online NO_x meters can be carried out. Also oxygen meters can help to determine that low NO_x burning conditions are maintained.

For accurate measurements in-field sampling and lab analysis is required.

Cross-media effects: No major effects.

Operational experiences: Low NO_x burners have been applied in the retrofit of existing boilers and construction of new ones.

Economics: Investment costs are typically 0.6 - 0.9 MEuros for 1000 ADt/d paper production. Operating costs increase with 0.1 - 0.2 MEuros/a.

Driving force for implementing this technique: Air emissions from non-integrated paper mills are mainly related to steam boilers and power plants. These plants are generally standard boilers and do not differ from any other power plants. It is assumed that they are regulated like

any other plants of the same capacity. Low NO_x burners are mainly used to reduce NO_x emissions from auxiliary boilers.

Example plants: Numerous mills in Northern and Western Europe.

Literature/References:

[J. Pöyry, 1997 b], [Finnish BAT Report, 1997], [Ministry of Education, 1994], [Data Provided by German EPA, 1999]

6.3.16 Use of combined heat and power generation

Refer to Section 5.3.9.

6.3.17 Optimisation of de-watering in the press section of the paper machine (Wide nip press)

Description of the technique: A paper machine constitutes a huge dewatering process. It comprises in principle of the three major parts:

- the wire section for sheet formation and first dewatering by gravity and vacuum/suction
- the press section for further dewatering of the wet web by mechanical forces
- the dryer section for drying the web to the final dryness by evaporation on steam-heated cylinders.

After the press section (see also Figure 6.1), normally the web dryness is 45-50 %, i.e. about 1 kg water/1 kg furnish is left. To evaporate these last "water drops", a lot of evaporation energy and a long dryer section is needed.

In a paper machine, most of the energy is needed for paper drying (steam 572 kWh/t). Electrical energy is needed for roll and cylinder drives (electrical 100 kWh/t) and to create vacuum (electrical 67 kWh/t). The higher the dryness of the paper web after the press section, the lower is the thermal energy required for the final paper drying. By 1 % increase of the dryness of the paper web entering the dryer section approx. 4 % heat (in terms of low-pressure steam of approx. 2 bar) can be saved. Therefore, measures have to be taken in the paper machine to maximise the dry content by wet pressing.

In a conventional roll press nip, the nip pressure has reached its high limit and cannot be further increased to improve dewatering in the press section. By substituting conventional short nip presses with wide nip press(es), so-called shoe press(es), a higher pressure impulse than in a conventional roll press is achieved resulting in an intensified dewatering of the wet web and higher dryness of the paper web after the press section. The shoe is loaded against a counter roll with hydraulics. The press concept leads to a significant extension of the pressing zone and contact time in the nip compared to conventional roll presses. High after-press dryness gives drying energy savings and a good runnability in the dryer section because of the good wet strength of the web.

Applicability and characterisation: Process integrated technique. The shoe press can be applied both in new and existing paper machines with most paper grades (apart from tissue) provided that sufficient space is available in the press section and that the building construction permits the higher weights of a shoe press. The foundations must be suitable for the greater weight of the machinery associated with the shoe press concept. The maximum load of the hall crane has in some cases to be increased due to the heavier shoe press rolls. Because of the large additional investment costs the economic advantage is doubtful in the case of smaller paper machines, say with a trimmed width of less than 2.5 m.

With bulk sensitive grades, basically woodfree grades, low load (600 kN/m) long shoe (250 mm) is advantageous. With wood-containing grades, higher load (800 kN/m) and shorter shoe (180 mm) can be used.

The shoe press has been developed even for high-speed machines (today up to 2000 m/min).

Main achieved environmental performance: The effects on the environment are related to savings of thermal energy for paper drying. Dryness increases between 5 and 15 %-points are reported after the installation of a shoe press in existing paper machines for packaging paper and board [IFP, 1998]. Of course, this increase depends significantly on the previous performance of the rebuilt press section and the selected new shoe press concept.

In one case, the rebuild of the press section resulted in a dryness increase of 6 % after the installation of one shoe press. The specific steam demand for paper drying was reduced from 2.13 to 1.76 tonne of steam per tonne of paper, which is equivalent to an 18 % thermal energy saving. The reduction in air emissions due to energy production depends strongly on the type of fossil fuel used. In the paper mill concerned, 46000 tonnes of steam (equivalent to 5.1 M m³ natural gas and an avoided CO₂ emission of 8900 ton) have been saved annually.

In a press with shoe nips, the press section length, number of components and fabrics, as well as the service life of the fabrics will stay constant also with increased production. The shoe nip is a soft nip. There are less service needs, less fabric consumption and waste from it, less vibration and noise. This means that the emissions per tonne of paper are lower.

The shoe press is a tool for increasing the machine speed while maintaining good runnability. High efficiency saves raw materials and energy and ensures higher machine uptime with less waste. High after-press dryness means lower energy need and thereby less emissions in energy production.

On paper machines with limited drying capacity, every 1 % reduction in sheet moisture can be translated into a 4-5 % productivity increase. If the drying capacity of the paper machine is not limited, an equivalent steam consumption decrease in the dryer section can be achieved. Dryer section steam savings up to 170 kWh/t can be reached.

However, for a given paper density, the dryness improvement is furnish-dependent. With woodfree paper grades, the after-press dryness is about 3 to 5 percentage points higher when applying the shoe press. With wood-containing paper grades, the corresponding figure is about 4 to 7 percentage points. The difference is even bigger, up to 12 percentage points, at high machine speeds, because with a long nip dwell time of shoe nip, the dryness will stay at a high level when increasing the machine speed. With wood-containing grades, the whole shoe press load capacity can be utilized, because the best paper properties can be achieved with a high-pressure level in the nip.

When replacing a roll press with a shoe press in a paper machine, the typical total saving in dryer energy is 20 to 30 %.

Cross media effects: Replacement of the conventional roll nips with shoe nips will not significantly increase the electricity requirements. The shoe press has a higher specific electricity consumption but fewer nips producing a dryer sheet, which compensate for each other. Reduced thermal energy consumption can be transformed into avoided air emissions by a calculation based on the specific emission figures of steam generation. However, it has to be taken into account that the reduction in the volume of air-borne emissions is affected by the type of fossil fuel used in the power plant.

The increased dryness after shoe pressing results in an increase of the apparent density and internal bond strength of the finally dried sheet. The relationship is almost linear. Higher strength of the paper web generally improves the runnability of the paper machine due to less web breaks. The result is a higher paper machine efficiency. For example, after shoe press rebuilt, if the number of unplanned web breaks will be reduced by two per day (durability of each 20 min), the daily paper machine production capacity will increase by almost 3%.

If the production capacity of a paper machine is limited because of its drying capacity, the reduced steam demand for drying after installation of a shoe press makes it possible to increase the speed of the paper machine. In those cases, production can be increased by up to 20 % for the same amount of steam as was used before the application of a shoe press.

If steam is produced in a co-generation power plant, the lower steam demand for drying results, however, in a reduced production of electricity. Therefore, more power has to be purchased as grid power. If the paper machine is speed limited due to its drives, the installation of a shoe press contributes to thermal energy savings, and increased paper machine production capacity because of less web breaks and increased paper machine time efficiency.

Operational experiences: One example of a press rebuild is Nordland Papier in Germany. In the compact three nip press section of this copy paper machine, the last roll press nip was replaced with a shoe press nip. After the rebuild, dryness after the press section was about 3-4 percentage points higher. At the same time the production speed was increased from 850 m/min to 1200 m/min, the increase in production being 30 %. To reach this dryness improvement, a linear load of 500-600 kN/m was applied on the shoe press. Later production broke down all records and this rebuild machine became the most efficient fine paper line in the world. Savings in the specific steam demand for paper drying was 30 %.

Similar results have been achieved in several equivalent rebuilds around the world during the last years. Meanwhile numerous installations exist all over the world.

Economics: The investment costs of a shoe press in a paper machine of 5 m untrimmed width total about 10 MEuros (incl. the whole installation). The operation costs including felts, roll covers, roll grinding, drive energy for a shoe press is roughly identical with the costs of a conventional press. The savings of steam for paper drying are in a range between 10 to 15 Euros/tonne steam resulting in a specific steam consumption of 2 tonnes of steam per tonne of paper and savings between 20 to 30 Euros/tonne paper.

In press rebuilds, the typical repayment period of the investment is about 2.5 years, if there are no other limits in speed increase.

Driving force for implementing this technique: The driving forces for implementing a shoe press are manifold. Besides improved strength characteristics, cost savings can be obtained due to a reduced steam demand for paper drying at constant paper production or, alternatively the production capacity can be increased at identical operation costs. Better dryness gives energy savings. The press section concept can be simplified. The shoe press has been a key component for further machine speed increase. In a modern high-speed paper machine, the required dryer section length is 35 % less due one shoe press nip in the press section. Better dewatering effects enhance product quality (higher uniformity of the paper).

Example mills: Due to its superior dewatering capacity, the shoe press was first introduced for linerboard grades at the beginning 80th and on paper machines about ten years later. There are several rebuilds and new high-speed machines around the world using the shoe press component. Since 1997 all new high-speed paper machines include shoe presses. For example, at the beginning of 1998, one new LWC machine in Finland and a SC paper machine in Canada started with a shoe press in the 3rd press nip position. Half a year after the start-ups, both of

these were the fastest LWC and SC paper machines in the world with a production speed of over 1600 m/min. A fine paper machine with two shoe nips started in USA in summer 1998.

In the area of testliner and wellenstoff, in Germany the following installations are known (in alphabetical order): Papierfabrik Adolf Jass/Fulda, Papierfabrik Klingele/Weener, Papierfabrik Schoellershammer/Düren, Papier- und Kartonfabrik Varel/Varel, SCA Packaging Industriepapier/Aschaffenburg, Stone Europa Carton Aktiengesellschaft Papier- und Kartonfabrik Hoya/Hoya, Zülpich Papier/Zülpich

Literature:

[IFP, 1998] This reference quotes other literature on this technique (in German only)

6.3.18 Energy savings through energy efficient technologies

Introductory remarks

There are opportunities for energy saving in many stages within the manufacturing process. Usually these measures are linked with investments to replace, rebuild or upgrade process equipment. However, these measures are mostly not just applied for energy saving. They attract special interest because they increase at the same time production efficiency, improve product quality and reduce overall costs. It is therefore essential that energy saving techniques become incorporated into all aspects and levels of papermaking. The connection between energy matters and processes (synergistic effects) has to be kept in mind when discussing energy efficient techniques. Most of them can lead to process advantages and enhanced productivity.

In general, for energy efficient technologies the information required for the description of techniques to be considered in determination of BAT were not sufficiently provided. Additionally it would need too much space for proper description. Therefore, some energy efficient technologies are just highlighted in Table 6.25 without detailed description of advantages and drawbacks, without presenting actually achieved energy savings, cross-media aspects and economics for every single technique. Table 6.25 can give at best a rough indication on available energy efficient technologies and theoretical potential for improvement of heat and electricity consumption.

The extent to which techniques are already in place in each Member State depends on a combination of the advancement of the industry, the size of mills, the understanding of energy matters in companies and the energy policy of the country in question.

The applicability of the energy saving techniques is not addressed and a closer examination of the details might be needed.

Energy efficient technology	Type of energy demand and amount	% of energy saving and amount	Remarks
High consistency slushing	Electricity for pumps and rotors; 60 kWh/t	33%; 20 kWh/t	achieved through optimisation of rotor design
Best practice refining	Electricity to drive motors; 100 -500 kWh/t	20%; 80 kWh/t	depends on the product properties; varies between grades and furnish
High consistency forming	Electrical; 200 kWh/t	20%; 40 kWh/t	already applied to recovered paper
Twin wire forming	Drive	no data	not just applied for energy savings
Optimised vacuum systems	Electricity	25%	
Variable speed drive system	Electricity	no data	
High efficiency electric motors	Electricity	no data	
Well sizing of electric motors	Electricity	no data	
Hot presses or	Heat in dryer section	15 - 20%	mostly recovered fibres
Extended nip (shoe) presses	Heat in dryer section	15 - 20%	
Cross direction moisture profile correction with IR heaters	Heat in dryer section	1 - 2%	Reduces the extent of over drying
Exhaust air humidity control	Heat	10%	Allows adjustment and reduction of air flow
Exhaust air heat recovery	Heat	10%	see description below
Condensate recovery	Heat	10%	Water can be returned and used
Direct gas fired ventilation air	Heat	40%	Mainly used in tissue paper machine hood
Increasing size press solids	Heat for after size press drying section	Drying load can be reduced by 48%	Leads to a reduction in broke level

Table 6.25: Positions where energy savings could be made and their effect [DG XVII, 1992]
The energy saving potential depends on the present level of energy consumed in a given mill

To summarise the possibilities for energy savings: the areas offering most direct opportunity for energy saving are refining, pressing and drying. However, once the "good housekeeping" changes have been made, drying is also the most capital intensive process to modify. Those offering smaller savings but also synergetic advantages are slushing, forming and size pressing.

Besides the selection of technologies the manner of operation (energy efficient practice) and the energy management in the mill is an important issue. Equipment is often not used at its optimum energy efficiency and with better management further savings can be achieved. The pinch method for optimisation of thermal integration of paper mills can be a beneficial tool to move towards energetically optimised processes.

Achieved energy consumption levels: In many European countries, information on energy balances of paper mills is poorly available in public. Different reporting schemes, if any, for energy consumption are used. Energy demand also depends on the product quality (especially in tissue mills) and partly on local conditions. Therefore, it is difficult to present energy consumption values associated with the use of energy efficient technologies. Reported ranges of energy consumption of paper mills are shown in Table 6.26. They should only be taken as an indication about the approximate need of process heat and power at energy efficient paper mills. Further examples of energy efficient paper mills including the specific conditions might be possible to add in a reviewed version of the BREF.

Type of mill	Process heat consumption (net) in GJ/t	Power consumption (net) in MWh/t	Remarks
Non-integrated coated/uncoated fine paper	5.3 [3]	0.62 [3]	Very big German mill; figure includes all energy consumers of the mill
Non-integrated uncoated fine paper	7.0 - 9.0 [1]; 7.0 - 7.5 [2] * 6.5 - 8.0 [3];	0.7 - 0.8 [1]; 0.6 - 0.7 [2] *; 0.55 - 0.6 [3]; 0.5 - 0.65 [4]	[3] = Austrian mill
Non-integrated coated fine paper	10.0 - 11.0 [1] 7.0 - 7.5 [2] *	1.1 - 1.3 [1]; 0.6 - 0.7 [2] *; 0.65 - 0.9 [4]	
Non-integrated tissue mill	6.5 - 7.5 [1] 5.5 - 6.0 [2]	0.9 - 1.1 [1]; 1.0 - 1.1 [2]; 0.5 - 2 [4]	[4] For tissue production some new equipment such as TAD require higher energy consumption
Notes: * [2] gives only one figure for fine paper in general			

Table 6.26: Indication for energy consumption associated with the use of BAT for different types of paper production per tonne of product.

Data from [1] Jaakko Pöyry, 1998, [2] SEPA report 4712, [3] mill case studies and [4] data from a supplier.

The technique described below should be taken as only one example for possible energy savings through energy efficient technologies. Heat exchangers recover the energy in the exhaust air from the dryer section of the paper machine that is - together with refining - the most important stage in any energy consumption consideration. Further examples might be added and developed further in the future review of the BREF.

Example: Energy savings through heat recovery systems

Description of the technique: The purpose of the heat recovery system is to lower the mill's consumption of primary energy by utilising waste energy from the process in an economically profitable way... Nearly all the heat energy consumed in a paper mill is used for paper drying, making the dryer section easily the biggest energy consumer in a paper machine. Roughly 80% of the energy needed in the dryer section is brought as primary steam to the dryer cylinders, the rest coming as drying and leakage air and with the paper web.

Nearly all energy leaving the dryer section is exhausted with the exhaust air. About 50% of this energy i.e. something like 620 kWh per tonne of paper can be recovered by an efficient heat recovery system (at winter conditions).

Typical applications are using either air-to-air heat exchangers or air-to-water heat exchangers both of plate design (some applications use also scrubbers). The former is mainly used for heating hood supply air and machine room ventilation air. The most common application for the latter is the heating of circulation water and process water respectively. These heat exchangers are part of heat recovery towers. In Figure 6.20 an example is given for combined heat recovery where first the hood air supply and secondly the circulation water is heated.

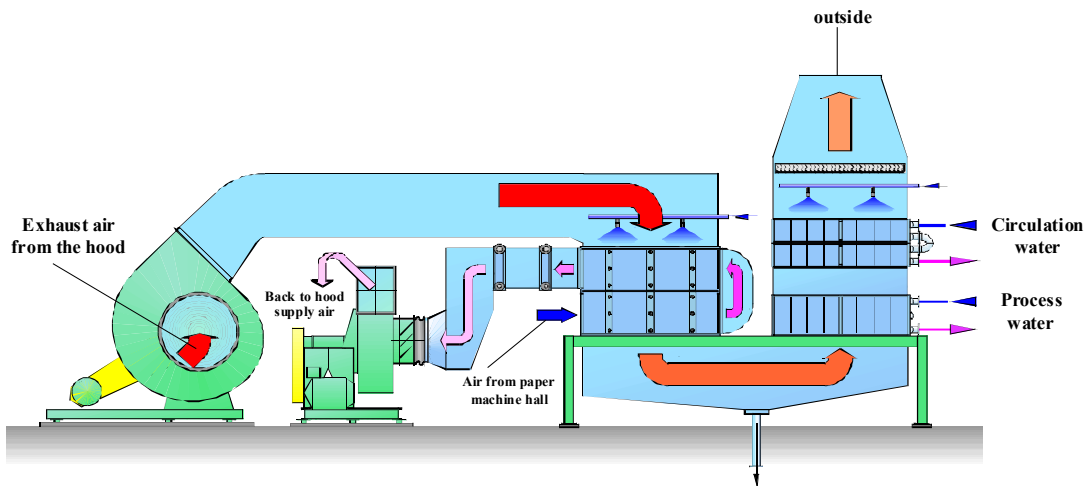


Figure 6.20: Example for a heat recovery tower

Usually only part of the heat recovered is led back to the dryer section with the hood supply air. Most is used outside the dryer section to heat process water, wire pit water and machine room ventilation air.

Applicability and characterisation of the measure: Can be applied both at new and existing plants if processes produce exhaust air flows with high energy content and if there is a need for heating energy for different purposes. Heat exchangers for heating hood supply air are always applicable. Whether heat recovery for heating of circulation water (for heating of the machine hall) or process water can be applied depends on the specific characteristics of production and climatic conditions. Because of the interaction between system units, optimised heat recovery system can only be achieved by analysing the entire heat recovery system.

Main achieved environmental performance: Saving considerable amounts of primary steam, which correspondingly means a lower environmental impact from steam generation. The achievements depend beside others on the climatic conditions.

The main energy flows in the dryer section of a typical newsprint machine equipped with air-to-air and air-to-water heat recovery units is illustrated in Figure 6.21. Most of the heat is recovered in the circulation water, which, in turn, is mainly used to heat the building ventilation air. Another major heat recovery user is the heating of process water (e.g. for showers) and wire pit water. Heating of wire pit water does not apply to TMP mills but for instance to recycled fibre processing mills. Supply air to the dryer section is always heated by the heat recovery system.

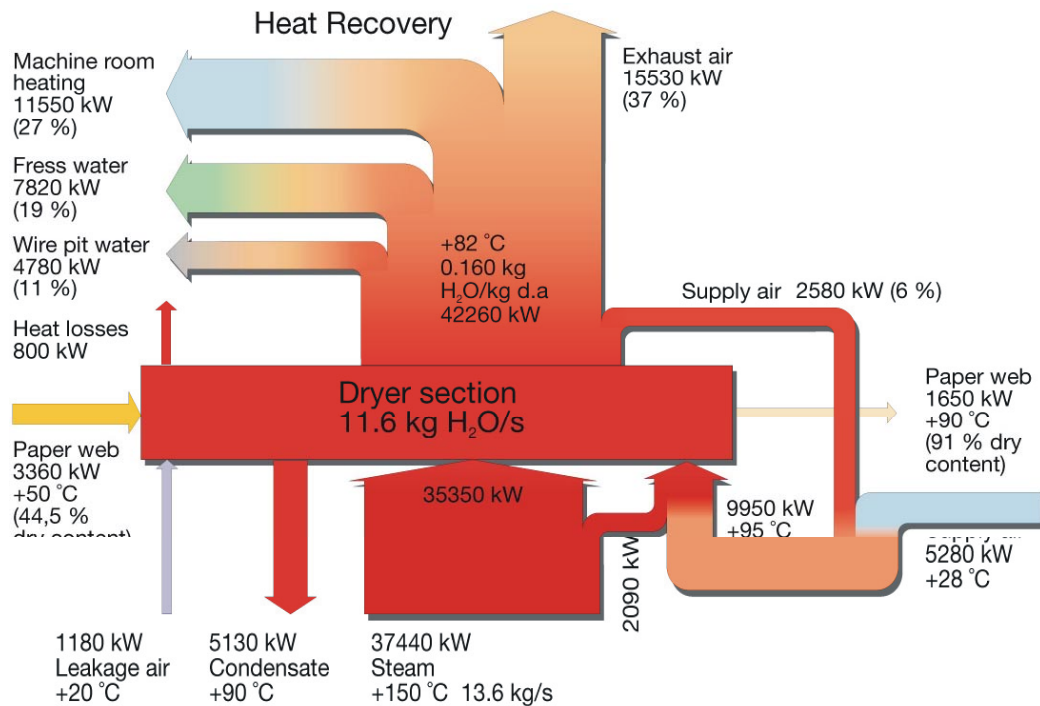


Figure 6.21: Sankey diagram for a newsprint machine (980 t/d).

Monitoring: Preventive maintenance contributes to avoiding unnecessary and expensive shut-downs

Cross media effects: No major cross-media effects are known. Energy saving measures are preferably based on accurate energy balances of the whole mill including energy flow diagrams and alternative process options. There is a strong link between water and energy systems.

Operational experiences: Different types of heat recovery systems are available depending on the supplier of machinery. The optimum heat recovery system for the specific requirements of each paper mill have to be designed individually for each application. Usually the heat exchangers are equipped with washing devices to maintain clear surface and to avoid clogging.

Economics: Heat recovery systems have usually short payback times. It is not always economical to recover as much heat as possible. The specific situation needs to be always analysed. The solution will depend on the relative energy price per kWh for fuel, steam and electricity.

Driving force for implementing this technique: Saving of energy, reducing droplets and mist formation.

Example plants: Numerous plants in Europe

Literature: Pamphlets of suppliers of machinery, [DG XVII, 1992], [Energy Efficiency Office, various publications between 1991 and 1997]

6.3.19 Measures for noise reduction

Description of the technique: Industrial noise sources can roughly be divided into internal and external noise sources. In a papermaking line the number of internal noise sources is big (see Section 6.2.2.8). A possible measure for internal noise control is for example the installations of a new closed hood with higher sound insulation. However, these will not be discussed further because it is considered outside the scope of this document (working environment). For external noise control examples of measures are the installation of absorptive silencers and/or pipe resonators to reduce noise levels from exhaust air fans and vacuum pumps, silencers and sound insulation hoods for the fans on the building roof. Two examples will be discussed in more detail below.

Noise reduction measures should preferably concentrate on the major sources, especially to all openings in the roofs and walls. The major external noise sources of a paper mill are process ventilation (continuous), machine room ventilation (continuous), vacuum pump exhaust (continuous), and steam exhaust (only occasional). Additionally a variety of other noise sources are present especially in old mills, where sound insulation of machinery has not been properly performed.

In the planning and operation of installations, measures necessary for noise prevention must already be taken into account during the planning phase. Usually it is most effective to seek consultation of acoustics experts. When implementing noise reduction measures the following technical aspects should be considered:

- obtaining information at an early stage about noise emissions of machinery, installations and parts thereof;
- use of low-noise machines and processes;
- reducing noise generation and transmission;
- reducing sound emission, e.g. use of sound absorbers;
- maintaining of machinery and soundproofing equipment.

The starting point for noise abatement are the authorities' requirements depending on the mill location (distance to the neighbourhood, recreational or industrial area etc.) and the requirements in the given country. The immission (reference) points can be located at the mill border and/or in several locations in the residential area. The target values in the residential areas must usually be fulfilled always when new machinery is being delivered. However, also existing noise sources must more and more frequently be attenuated, because the requirements are becoming stricter.

Noise cancellation is in most cases relatively expensive. Therefore lay out aspects and the design of noise abatement measures are very important at an early stage of a project. When existing noise sources have to be attenuated the costs for silencers and sound insulation enclosures can become high.

It is important to reduce the noise at the source. This is, however, not always possible. In that cases sound insulation enclosures for noisy equipment or silencers might be needed. When silencers are dimensioned the nature of the noise source must be known.

In the paragraph below on achieved environmental performance, two examples of external noise attenuation by installation of silencers are discussed. The noise attenuation requirements were on different frequency ranges.

Applicability of the measure: External noise attenuation measures can be applied in both existing and new mills. It is mainly the procedure to determine the current and targeted noise levels that makes the difference.

In cases of existing machines the attenuation procedure starts with noise measurements at the immission (reference) points in the residential area. Measurements will continue in the mill in order to find the most critical noise sources. Silencer dimensioning is an interaction of measurements and calculations.

In new installations the sound power levels are based on the machine deliverer's sound power level data. Calculations of predicted noise levels in immission points are made using computer programs for noise propagation, e.g. according to VDI 2714, including the contribution of all relevant noise sources.

Limitations of space might lead to somewhat different lay out solutions for existing mills.

Main achieved environmental performance: The environmental benefit of external noise control measures is shown by use of two examples.

Example 1: Installation of absorptive silencers (in a French Paper mill)

In this case, the equivalent A-weighted sound pressure level targets in the parts of the village bordering the paper mill are 65 dB(A) in the day and 55 dB(A) at night. Measurements of the noise sources showed that the contribution of the closed hood exhaust air fans were among the biggest. Calculations showed that attenuation of these by 15 dB(A) would be enough to reach the target level at night of 55 dB(A) at the reference points.

Fan noise can be characterised as broad band noise and thus absorptive silencers are suitable in this case. Absorptive silencers are efficient at middle and higher frequencies. The fans are located outside and therefore they also need sound insulation. Figure 6.22 shows the noise levels measured before and after the silencer installation at one immission point (sound insulation included).

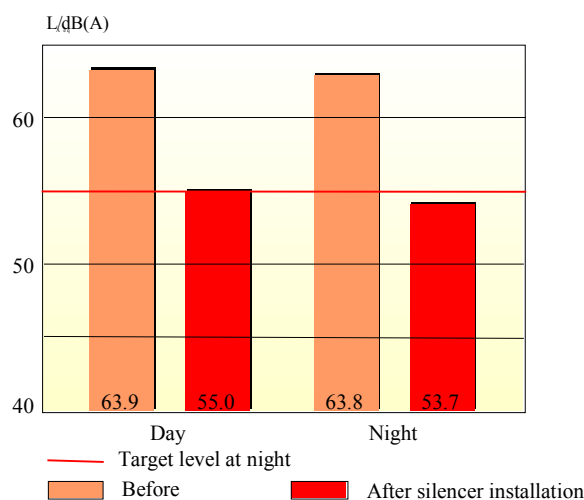


Figure 6.22: Sound levels L_{Aeq} at one reference point.

Example 2: Installation of reactive silencers (in a German paper mill)

In this case, the noise emission from vacuum pumps of a paper machine caused too much noise at the reference point outside the mill area. Measurements of sound pressure levels

at 1m distance from the vacuum pump outlet revealed a noise peak at a frequency of 160 Hz, as shown in Figure 6.23. This peak was over 10 dB(A) higher than any other frequency. Reactive silencers (e.g. pipe resonators) are efficient for lower frequencies (below 500 Hz) and were installed in this case. Measurements after silencer installation showed that the peak noise level has been reduced effectively by about 28 dB(A) and the target value in the immission point 26.9 dB(A) has been reached.

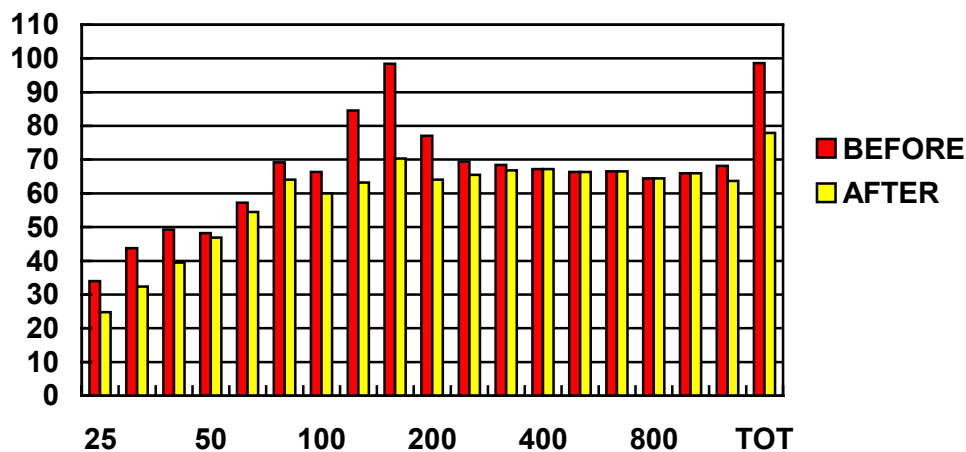


Figure 6.23: Pipe resonator attenuation. Noise levels before and after silencer installation

When the target level at 1m distance from the outlet of fans or vacuum pumps is lower a combination of reactive and absorptive silencers is required. Also special sound insulation enclosures are needed for fans located outside.

Monitoring of emissions: It would be beneficial to measure the noise level from time to time (e.g. once per year) to follow whether silencers needs cleaning. However, normally this is not carried out in paper mills.

Cross-media-effects: Silencers may increase the pressure loss of exhaust air that leads to a slight increase of power consumption (kWh/ADt) from fans. But the additional power consumption is not significant.

Operational experiences: Silencers have been successfully used in many mills in Europe. Maintenance consisting of regularly cleaning and changing of absorption material (when needed) is required where the exhaust air contains moisture and particles.

Economics: It is very difficult to give accurate figures on cost of sound attenuation because the costs depend on the size of the mill, the paper grade produced the speed of the paper machine etc. Total sound attenuation costs (external and internal) of a papermaking line are estimated of being in the range of is 0.5 % of the investment costs of the machinery, or even higher depending on the target noise levels [Valmet].

External sound attenuation costs of a paper machine are in the order 0.2 – 0.4 MEuros depending on the target level and the delivery scope.

Figure 6.24 shows the relative costs of external sound attenuation. When the sound pressure level target is decreased from 85 dB(A) to 75 dB(A) the costs are doubled.

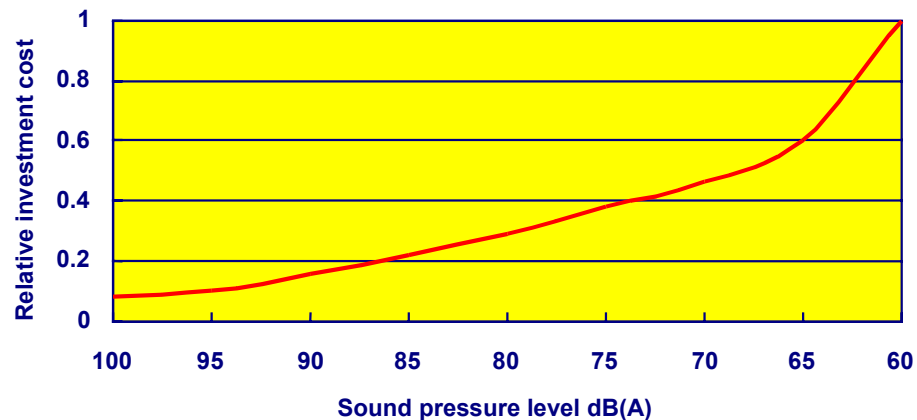


Figure 6.24: Relative costs of external sound attenuation [according to Valmet].

Driving force for implementing these techniques: From the health point of view, noise can stand for one of the most serious of all environmental problems. A big number of people in the EU territory are exposed to injurious noise. Official requirements in different countries, together with EU directives, have led to increased demands for noise prevention at the machine design stage. But they have also set noise standards for existing equipment and external noise control. Depending on the type of area affected by noise impact from paper mills, for example in Germany the following noise levels have to be achieved to avoid harmful noise impact in the neighbourhood:

day-time	night	Type of area next to the paper mill
70 dB(A)	70 dB(A)	industrial area
65 dB(A)	50 dB(A)	trade and business areas
50 dB(A)	35 dB(A)	living area
45 dB(A)	35 dB(A)	areas for special (public) institutions, e.g. hospitals

Table 6.27: Example of noise levels to be achieved in the neighbourhood of paper mills (Requirements in Germany)

However, the variation range of external noise level targets in different EU member countries is big. The explanations for the great variations are the distance of the mill to residential area, differences in population density, traffic density, environmental targets etc.

Example plants: Different types, design and amounts of silencers are used in most European mills. General measures for noise attenuation are implemented in numerous plants in Europe.

6.4 Best Available Techniques

6.4.1 Introduction

In understanding this chapter and its contents, the attention of the reader is drawn back to the preface of this document and in particular the fifth section of the preface: “How to understand and use this document”. The techniques and associated emission and/or consumption levels, or ranges of levels, presented in this chapter have been assessed through an iterative process involving the following steps:

- identification of the key environmental issues for the sector; for the non-integrated paper mills water use, wastewater discharge (COD, BOD, suspended solids, N and P, AOX), energy demand (steam and electricity), solid waste such as rejects, sludge and ash, air emissions from energy generation (SO₂, NO_x, CO₂, dust), noise and waste heat to water are the major concerns; the latter three stand for local impacts;
- examination of the techniques most relevant to address those key issues;
- identification of the best environmental performance levels, on the basis of the available data in the European Union and world-wide;
- examination of the conditions under which these performance levels were achieved; such as costs, cross-media effects, main driving forces involved in implementation of this techniques;
- selection of the best available techniques (BAT) and the associated emission and/or consumption levels for this sector in a general sense all according to Article 2(11) and Annex IV of the Directive.

Expert judgement by the European IPPC Bureau and the relevant Technical Working Group (TWG) has played a key role in each of these steps and in the way in which the information is presented here.

On the basis of this assessment, techniques, and as far as possible emission and consumption levels associated with the use of BAT, are presented in this chapter that are considered to be appropriate to the sector as a whole and in many cases reflect current performance of some installations within the sector. Where emission or consumption levels “associated with best available techniques” are presented, this is to be understood as meaning that those levels represent the environmental performance that could be anticipated as a result of the application, in this sector, of the techniques described, bearing in mind the balance of costs and advantages inherent within the definition of BAT. However, they are neither emission nor consumption limit values and should not be understood as such. In some cases it may be technically possible to achieve better emission or consumption levels but due to the costs involved or cross media considerations, they are not considered to be appropriate as BAT for the sector as a whole. However, such levels may be considered to be justified in more specific cases where there are special driving forces.

The emission and consumption levels associated with the use of BAT have to be seen together with any specified reference conditions (e.g. averaging periods).

The concept of “levels associated with BAT” described above is to be distinguished from the term “achievable level” used elsewhere in this document. Where a level is described as “achievable” using a particular technique or combination of techniques, this should be understood to mean that the level may be expected to be achieved over a substantial period of time in a well maintained and operated installation or process using those techniques.

Where available, data concerning costs have been given together with the description of the techniques presented in the previous chapter. These give a rough indication about the magnitude of costs involved. However, the actual cost of applying a technique will depend

strongly on the specific situation regarding, for example, taxes, fees, and the technical characteristics of the installation concerned. It is not possible to evaluate such site-specific factors fully in this document. In the absence of data concerning costs, conclusions on economic viability of techniques are drawn from observations on existing installations.

It is intended that the general BAT in this chapter are a reference point against which to judge the current performance of an existing installation or to judge a proposal for a new installation. In this way they will assist in the determination of appropriate "BAT-based" conditions for the installation or in the establishment of general binding rules under Article 9(8). It is foreseen that new installations can be designed to perform at or even better than the general BAT levels presented here. It is also considered that existing installations could move towards the general BAT levels or do better, subject to the technical and economic applicability of the techniques in each case.

While the BREFs do not set legally binding standards, they are meant to give information for the guidance of industry, Member States and the public on achievable emission and consumption levels when using specified techniques. The appropriate limit values for any specific case will need to be determined taking into account the objectives of the IPPC Directive and the local considerations.

Manufacture of paper is not a single process but a series of unit processes, often linked and inter-dependent. Therefore it is always a suitable combination of techniques that constitutes BAT for a mill. The order of priority and the selection of the techniques or combinations of techniques depend on the local circumstances.

Best available techniques given below are, if not stated otherwise, applicable to new and existing plants. In paper mills, the applicability of a technique is less driven by the fact whether a mill is new or existing. Paper mills are characterised by the fact that machinery is rebuilt rather than replaced whole-scale. The modular rebuilding and development of plants means that each site is a unique product of its location and history. On the other hand papermaking is a series of unit processes which are common in all countries and for all grades.

Criteria to be considered in the determination of BAT in the specific case are rather that specific costs for smaller mills are relatively higher (economies of scale). Other factors are limitations of space, which some older mills might face, or unsuitable material or lay out of older equipment which does not fit for a higher degree of water closure. More water system closure usually is combined with higher complexity of the system that needs to be monitored, controlled and understood. Smaller mills might sometimes not have the knowledge available which would be necessary to run and control more complex process solutions most efficiently.

6.4.2 BAT for paper mills

For paper mills the following techniques are considered as BAT. The following list of BAT is not considered exhaustive and any other technique or combination of techniques achieving the same (or better) performance can also be considered; such techniques may be under development or an emerging technique or already available but not described in this document. If not stated otherwise, the data refer to yearly average values.

General measures

1. Training, education and motivation of staff and operators. Paper mills are operated by people. Therefore, training of staff can be a very cost-effective way of reducing water consumption and discharges of harmful substances as for instance accidental releases of chemicals.

2. Process control optimisation. To be able to reduce different pollutants simultaneously and to maintain low emissions, improved process control and measurement are required.
3. To maintain the efficiency of the technical units of paper mills and the associated abatement techniques at a high level, sufficient maintenance has to be ensured.
4. Environmental management system which clearly defines the responsibilities for environmentally relevant aspects in a mill. It raises awareness and includes goals and measures, process and job instructions, check lists and other relevant documentation.

Measures for reducing of emissions to water

1. Minimising water usage for different paper grades by increased recycling of process waters and water management.

Exact knowledge on water consumption and quality in different uses forms the basis for good water management. In paper mills that have implemented BAT fresh water is mainly introduced to the process as shower waters and chemical handling. The more efficient fibre and filler recovery technique has made it possible to use the resulting clear water in the less critical showers of the paper machine and thus to increase recycling of water. Dissolved inorganic and organic and colloidal materials (DisCo) have however restricted the use of these waters to the wire section. The amount of fresh water required is determined partly by the concentration of contaminants in the process water.

The recycling rate of clear filtrates can be further increased by adopting ultra-filtration (UF) as technique for internal treatment of white water. Because this technique is still under development and applied in full-scale at only few mills in Europe it is not yet considered as BAT although the industrial experiences are promising. However, due to only partial removal of dissolved materials by use of UF further increase of recycling (e.g. for press section showers) is not yet considered feasible. The accumulation of dissolved materials may impair runnability, paper quality and performance of papermaking chemicals. Closed water circulation of paper machine waters would require more efficient separation techniques like nano-filtration or reverse osmosis or other complementing techniques. Because of high costs, negative cross-media effects (mainly energy) and a lack of industrial experience these techniques are not considered as available.

2. Control of potential disadvantages of closing up the water systems

Closing up the water systems requires awareness, knowledge, and suitable action to control the water system. Microbial control, proper design of the piping and storage systems and material selection helps to keep the surfaces in clean condition and reduce the need of washing. Recycle stream monitoring by measurements and lab analysis can be used to determine the actual performance of separation processes and the quality of shower waters and other process waters.

Data gathering on water flows and the chemical state of the water systems makes it possible to study and control the water behaviour of the whole mill and to determine the best running conditions for quality changes, start-ups and shut downs. For instance, operation procedures with large pH or temperature gradients should be avoided because they would lead to harmful deposit and scaling formations. Automation is also beneficial. On-line measurements and accurate process control are essential for effective and stable papermaking.

3. Construction of a balanced white water, (clear) filtrate and broke storage system and use of constructions, design and machinery with reduced water consumption when practicable. This is normally when machinery or components are replaced or at rebuilds.
4. Measures to reduce frequency and effects of accidental discharge. This includes training of staff for the case of accidental releases of chemicals to the effluent treatment plant and sufficient precautionary measures to prevent accidents.
5. Collection and reuse of clean cooling and sealing waters or separate discharge. Recycling of cooling and sealing waters can be increased by use of heat exchangers or a cooling tower. However, microbial and water quality monitoring and control methods are required to ensure disturbance-free performance of the system.

6. Separate pre-treatment of coating wastewaters.
In cases where recovery and re-use of coating colours from coating wastewaters by membrane technique is not possible flocculation of this concentrated partial wastewater stream is considered as BAT. The UF separation technique is mentioned as a measure to reduce solid waste (see below).
7. Substitution of potentially harmful substances by use of less harmful alternatives.
The removal efficiency after wastewater treatment and the environmental impact as a whole can be improved by using non-toxic and better biodegradable product aids and process chemicals.
8. Effluent treatment of wastewater by installation of an equalisation basin and primary treatment.
These measures are applied at nearly all paper mills and are rather considered as good practice. They are a pre-requisite for well and stable performing biological wastewater treatment plants. They are not considered as BAT as a stand-alone technique except for a few paper grades that release very low specific emission loads to water.
9. Secondary or biological treatment of wastewater, and/or in some cases, secondary chemical precipitation or flocculation of wastewater. When only chemical treatment is applied the discharges of COD will be somewhat higher but mainly made up of easily degradable matter.
There are a lot of different treatment options available that achieve good results in reducing the organic load to the recipients. The choice of the treatment option is mainly governed by the initial concentration, the wastewater characteristics and the removal efficiency to be achieved. Proper design and maintenance of the treatment plant is a prerequisite for good performing biological systems. Dependent on the initial concentration and the treatment system chosen, pollution load removal efficiencies associated with BAT for the pollutants specified below are considered to be:

Initial range of concentration	Treatment	COD removal	BOD removal	AOX removal	TSS after treatment	Nutrients
BOD > 500 mg/l	Trickling filter + activated sludge	80 - 90 %	95+ %	30 - 50%	Concentr. below 30 mg/l	Added to the wwtp
BOD > 500 mg/l	Trickling filter (pre-treatment)	50 - 60 %	60 - 70%	30 - 50%	Concentr. high around 100 mg/l	Added to the wwtp
BOD > 100 mg/l	Activated sludge ¹⁾²⁾	75 - 90 %	90 - 95+ %	30 - 50%	Concentr. below 30 mg/l	Added to the wwtp
BOD < 150 mg/l	Biofiltration	40 - 60%	60 - 80 %	30 - 50%	Concentration: 10 - 30 mg/l	Added to the wwtp

Notes: wwtp = wastewater treatment plant
 1) This removal efficiencies are achieved by low load activated sludge systems with a food/mass ratio between 0.1 and 0.2 kg BOD/kg TSS*d (or about 1 day retention time).
 2) In a few applications also for high load plants good removal efficiencies are reported.

Table 6.28: Examples of removal efficiencies of suitable biological treatment systems for effluents from paper mills

Common treatment of wastewater from a paper mill or a consortium of paper mills in the municipal biological wastewater treatment plant is also considered as BAT when comparable removal efficiencies is achieved by this common treatment.

It is difficult to present figures on the effectiveness of the techniques mentioned in item 1 to 8 that exclude biological treatment because well performing paper mills usually have also biological treatment and do not report the emissions before treatment separately. It is mostly not transparent with which techniques emission levels with primary treatment only are associated. The following examples can therefore not be further qualified on which techniques they are based. The mills are not considered to represent BAT but stand for some real-world examples that might give an indication of releases to water when no biological treatment is applied.

Consequently, the values in Table 6.29 all refer to water discharges with only primary treatment (physical-chemical treatment).

Mills ¹⁾	COD [kg/t]	BOD ₅ [kg/t]	TSS [kg/t]	Flow [m ³ /t]	Production 97 [t/d]	Remarks
Mill 1, uncoated fine paper	8.7	2.2.	1.0	32.6	n/a.	No biological treatment
Mill 2, uncoated fine paper	6.1	1.3	0.7	37.4	n/a.	No biological treatment
Mill 3, uncoated fine paper	5.7	1.3	0.9	42	n/a.	No biological treatment
Mill 4, coated fine paper	3.4	1.1	0.5	13.5	n/a.	Flocculation + clarifier
Mill 5, coated fine paper	5.1	1.5	1.0	48	n/a.	Flocculation + clarifier
Mill 6, coated fine paper	3.6	1.4	1.4	24	n/a.	Flocculation + clarifier
Mill 7, tissue paper, (virgin fibre)	2.2	0.6	0.3	36	n/a.	Flocculation + clarifier
Mill 8, tissue paper, (virgin fibre, DE)	1.1	0.15	0.002	5	29000	Disc filter
Notes: 1)The EIPPCB were asked to treat the provided data confidential						

Table 6.29: Examples of measured yearly average emission levels to water after only primary treatment of some non-integrated paper mills in one Member State (reference year: 1997). The list of mills is a selection of mills where data were available or provided and is therefore not intended to be complete.

Because of a lack of transparency whether or not (and too which extent) the mills without biological treatment have applied BAT no emission levels associated with the use of BAT with only primary treatment are proposed.

Table 6.30 shows achieved emission levels of some non-integrated paper mills in Europe that are considered as well performing. It can be assumed that they have applied a suitable combination of BAT, but not necessarily all, and biological wastewater treatment as well.

Examples of paper mills	Reported achieved emission levels after biological treatment						Type of treatment
	COD [kg/t]	BOD ₅ [kg/t]	AOX [kg/t]	TSS [kg/t]	Flow ³⁾ [m ³ /t]	Production '97 [t/a]	
Mill 1, uncoated fine paper, SE	0.63	0.3	n/a.	0.2	2.6	150000 ('98)	Trickling filter + moving bed reactor
Mill 2, uncoated fine paper, Netherlands	1.5	0.4	n/a.	0.3	14	n/a.	n/a.
Mill 3, coated/uncoated fine paper, Germany	0.44	0.1	0.0007	n/a.	4.5	1000020	Trickling + activated sludge
Mill 4, coated fine paper, Netherlands	0.93	0.17	< 0.01	0.23	13.8	n/a.	n/a.
Mill 5, coated paper, Sweden	0.95	0.17	0.0025	0.26	9.53	180000	Moving bed reactor + chemical precipitation
Mill 6, coated fine paper, France	0.4	0.1	n/a.	0.2	14	125000	Activated sludge
Mill 7, coated fine paper, France	0.8	0.3	n/a.	0.2	14	125000	Trickling + activated sludge
Mill 8, coated fine paper, France	0.4	0.2	n/a.	0.4	11.5	160000	Activated sludge
Mill 9, tissue paper, (virgin fibre) France	1.5	0.4	n/a.	0.2	20	n/a.	Activated sludge
Mill 10, tissue paper, (virgin fibre), D	0.67	0.11	0.005	n/a.	11.5	97000	Activated sludge

Table 6.30: Examples of achieved annual average emission levels to water after biological treatment of some well performing paper mills in Europe (reference year: 1997).

The list of mills is a selection of mills where data were available or provided and is therefore not intended to be complete. The data are derived from personal communication. The method of analysis is the one used in the respective country. In Sweden the values for BOD are given as BOD₇.

Assuming adequate design and capacity of the wastewater treatment plant and appropriate operation and control by skilled operators, emission levels associated with a combination of BAT are considered to be those given in Table 6.31. The effluent loads exclude the contribution of pulp manufacturing.

In spite of the huge number of different kinds of paper products manufactured it can be stated that paper mills that have implemented BAT achieve relatively similar emissions to water. As regards the discharges after suitable wastewater treatment from the various paper production categories, further significant differences between paper grades were not identified (except those from special paper mills; see Section 6.4.3)

Parameters	Units	Uncoated fine paper ¹	Coated fine paper ²	Tissue ³
BOD ₅	kg/t	0.15-0.25	0.15-0.25	0.15-0.4
COD	kg/t	0.5-2	0.5-1.5	0.4-1.5
TSS	kg/t	0.2-0.4	0.2-0.4	0.2-0.4
AOX	kg/t	< 0.005	< 0.005	< 0.01 ⁴
Total P	kg/t	0.003-0.01	0.003-0.01	0.003-0.015
Total N	kg/t	0.05-0.2 ⁵	0.05-0.2	0.05-0.25
Wastewater Amount	m ³ /t	10-15 ⁶	10-15	10-25 ⁷

Notes:

- 1) The fibre furnish might be e.g. 100 % bleached kraft pulp and fillers and sizes might amount to 15-30 %. For mass sized paper the upper ranges for COD and BOD have to be considered.
- 2) The fibre furnish might be e.g. 100 % bleached kraft pulp and fillers and coating colour might amount to 20-40 %. Upgrading of paper consists of both surface sizing and application of coating colours.
- 3) Fibre furnish 100 % purchased chemical pulp. For tissue manufactured of a fibre mix of recycled and virgin fibre, see also Chapter 5.4.2
- 4) The higher AOX value can be caused by wet strength agents that contain chlorinated organic substances
- 5) For coloured grades the nitrogen-releases can be higher when N-containing azo dyestuffs are used
- 6) For mills which are producing coloured or strong coloured grades fresh water consumption can normally not be brought below 17 m³/t
- 7) A change of basis weight and speed of the paper machine have a significant effect on the specific water consumption (SWC). Lower basis weights (down to 12 g/m²) and lower speeds correspond to higher SWC.

Table 6.31: Yearly average emission and consumption levels associated with the use of BAT for non-integrated uncoated fine paper mills, non integrated coated fine paper mills and non-integrated tissue mills.

The emission data refer to non-integrated paper production. However, there is an increasing number of mills in Europe which are only partly integrated i.e. for a part of the furnish there is a pulp production whereas the other parts consists of purchased pulp. In that case, the emissions from pulp processing have to be added to paper production according to the contribution of pulping activities.

The Table 6.31 should be read together with the following additional explanations:

BOD: In well designed treatment plants BOD is removed almost completely (95% + removal) from paper mill wastewater when the carbon-phosphorus-nitrogen ratio and oxygen supply is maintained sufficient and well controlled. In case of disturbances or if some of the running parameters are moving away from the target level, the BOD concentration in effluents will start to increase. This calls for adjustment of the running parameters and/or analysis of the biomass. BOD₅ levels will usually be below 25 mg BOD₅/l and can reach values down to 5 mg/l (almost completely removal). However, BOD levels around 5 mg/l are hardly to measure accurately and reproducible. Depending on the water flow this corresponds to 0.15 kg BOD₅/t (at 10 mg/l and 15 m³ flow/t) and 0.25 kg BOD₅/t respectively (at 25 mg/l and 10 m³ flow).

COD: Depending on the paper grade manufactured, the applied techniques for prevention and control of emissions and the water flow per tonne of product, the wastewater from paper mills after treatment contains between 50 - 150 mg COD/l.

TSS: Under normal operation conditions, the water from the secondary clarifier is fairly clear and its suspended solids content in the range of 20 to 30 mg/l. This corresponds to discharges of 0.2 - 0.4 kg TSS/t. The values depend on the surface load of the secondary clarifier and the characteristics of the biomass. With biofiltration also lower concentrations are normally achievable.

AOX: Nowadays, discharges of chlorinated organics are very low as the purchased pulp used in non-integrated paper mills is normally either ECF or TCF bleached pulp. Activated sludge treatment result in a further AOX reduction between 30 and 50 %. However, this reduction is partly achieved by stripping of these compounds during wastewater treatment. Depending on the purchased pulp and chemical additives used paper mills discharge chlorinated organic compounds below 0.005 kg/t.

N and P: Mineral nutrients are usually added to the biological treatment plant to keep the balance C : P : N which is of crucial importance for the growth of active biomass. To find and keep a balance between biodegradable carbon, nitrogen- and phosphorus-compounds a certain fine-tuning of the added nutrient feed is required. Usually, phosphorus is added as phosphorus acid and nitrogen in form of urea. When the system is well optimised nutrients discharge of well below 1 mg tot-P/l and 5 mg tot-N/l are achievable. The corresponding loads are 0.003 - 0.001 kg P/t and 0.05 - 0.2 kg N/t respectively.

Measures for reducing of emissions to air

Air emissions from non-integrated paper mills are mainly related to steam boilers and power plants. These plants are generally standard boilers and do not differ from any other power plants. It is assumed that they are regulated like any other plants of the same capacity. Therefore, generally acknowledged BAT are mentioned only briefly in this section.

1. Installation of low NO_x technology in auxiliary boilers
2. Reducing SO₂ emissions from steam boilers by using low sulphur oil and coal or controlling S emissions
3. Use of combined heat and power generation
4. Using renewable sources like wood or wood waste to reduce the emissions of fossil CO₂ (only applicable if papermaking is integrated with virgin pulp production).

Emission levels associated with BAT from auxiliary boilers incinerating own biofuels and/or different fossil fuels are given in the following table. It has to be noted that auxiliary boilers within the pulp and paper industry are of a very variable size (from 10 to above 200 MW). For the smaller only the use of low-S fuel and combustion techniques can be applied at reasonable costs while for the larger also control measures. This difference is reflected in the following table. The higher range is considered BAT for smaller installations and is achieved when only quality of fuel and internal measures are applied; the lower levels (in brackets) are associated with additional control measures like SNCR and scrubbers and are regarded as BAT for larger installations.

Released substances	Coal	Heavy fuel oil	Gas oil	Gas	Biofuel (e.g. bark)
mg S/MJ fuel input	100 - 200 ¹ (50 - 100) ⁵	100 - 200 ¹ (50-100) ⁵	25-50	<5	< 15
mg NO _x /MJ fuel input	80 - 110 ² (50-80 SNCR) ³	80 - 110 ² (50-80 SNCR) ³	45-60 ²	30 -60 ²	60 -100 ² (40-70 SNCR) ³
mg dust/Nm ³	10 - 30 ⁴ at 6% O ₂	10 - 40 ⁴ at 3 % O ₂	10-30 3% O ₂	< 5 3% O ₂	10 - 30 ⁴ at 6% O ₂
Notes:					
1) Sulphur emissions of oil or coal fired boilers depend on the availability of low-S oil and coal. Certain reduction of sulphur could be achieved with injection of calcium carbonate.					
2) Only combustion technology is applied					
3) Secondary measures as SNCR are also applied; only larger installations					
4) Achieved values when electrostatic precipitators are used					
5) When a scrubber is used; only applied to larger installations					

Table 6.32: Emission levels associated with the use of BAT for different fuels

The specific atmospheric emission loads per tonne of paper are site specific. The differences in air emissions per tonne of product are caused by two major aspects: the kind of energy supply including the fuel used and air abatement applied and the amount of steam and power consumed per tonne of product. Paper grade, specific energy requirements to achieve a certain paper quality and use of energy efficient technology have an influence on the specific steam and electricity demand.

The first aspect, the choice between gas, fuel oil or coal, wood or electricity is very dependent on the prevailing economic conditions and it is considered outside the scope of this document to specify which of these fuels represents BAT. However, where a natural gas supply is accessible and where economic conditions permit the use of natural gas is considered to represent BAT. Where fuel oil is used then a sulphur content of 1% or less is considered to represent BAT.

The energy demand of efficient mills is discussed further below.

From the combination of steam and power supply system, choice of fuel, air abatement applied and energy consumption the product specific emissions can be derived.

For coated paper grades a careful choice of coating colour recipes is considered BAT. By this measure the emission of volatile organic carbons and of some single substances of concern as e.g. acrylonitrile or formaldehyde that can occur in the exhaust air of coating machines can be avoided or reduced. Especially coating colour recipes that contain carcinogenic compounds should be avoided.

Measures for reducing solid waste

1. Minimisation the generation of solid waste and recover, re-use and re-cycle re-usable materials as far as possible.
2. Separate collection of waste fractions at source and, if necessary, intermediate storage of residuals/waste, to allow for a greater proportion to be reused or recycled rather than land-filled.
3. Reduction of fibre and filler losses.
Earlier and in old paper mills sedimentation tanks were the dominating technique. The separation efficiency can be improved considerably by a disk filter or a micro-flotation unit.
4. Recovery and recycling of coating wastewaters.
The application of ultra-filtration for coating wastewater recovery has proven successful in many mills and minor or no negative effects have been reported on fine and art paper quality when using concentrate in pre-coating. In magazine paper mills small amounts of UF concentrate can be used without drawbacks in quality. However, a lot of technical and logistical aspects have to be considered when applying this techniques which makes it difficult for smaller mills.
5. Pre-treatment of sludge (de-watering) before further utilisation or final disposal.
Several techniques are available for de-watering of the residues and sludge. The resulting dry solid content depends on the characteristic of the sludge and the de-watering techniques applied. Higher dry solids usually mean less transport requirements and higher calorific value of the sludge that is especially interesting in case where the residues are burnt. In case of disposal, biological stabilisation might precede dewatering.
6. Reduction of the amount of waste to be landfilled. Identification of possibilities for recovery operations and - if feasible - utilisation of waste for material recycling or incineration with energy recovery.
In some cases, supporting fuels or adding of residues with higher calorific value (e.g. bark, wood waste) are required when the amount of land-filling is reduced by combustion techniques.

The amount of waste to be landfilled depends mainly on the degree of utilisation and the treatment options chosen. The choice of the treatment options is influenced by factors as local infrastructure, costs and competition with residues from other industries. It should be noted that

there is little detailed and reliable information available on achievable amounts of solid wastes. There is a lack of statistical data and various terms for different waste fractions are used in Europe. Therefore, it is refrained from presenting values for product specific amounts of solid waste to be landfilled.

Energy saving measures

In general in this sector BAT is considered to be the use of energy efficient technologies. A lot of options for energy saving in many stages within the manufacturing process are available. Usually these measures are linked with investments to replace, rebuild or upgrade process equipment. Because of economies of scale, smaller mills are less able to invest in new energy efficient technologies. It should be noticed that energy saving measures are mostly not applied only for energy saving. Production efficiency, improvement of product quality and reduction of overall costs is the most important basis for investments. Energy saving technologies can therefore be regarded as techniques that are incorporated into many other aspects of papermaking.

In order to reduce the consumption of steam and power a number of measures are available:

1. Implementation of a system for monitoring energy usage and performance. Based on reliable energy performance information appropriate action can be taken. Energy management includes setting, controlling, reviewing and revising energy performance targets.
2. More effective dewatering of the paper web in the press section of the paper machine by using wide nip (shoe) pressing technologies (this does not apply to tissue mills).
3. Use of energy efficient technologies as e.g. high consistency slushing, best practice refining, twin wire forming, optimised vacuum systems, speed adjustable drives for fans and pumps, high efficiency electric motors, well sizing of electric motors, steam condensate recovery, increasing size press solids or exhaust air heat recovery systems.
For some of these techniques implementation may only be possible at a rebuild or when a replacement of equipment is planned anyhow.
4. Reduction of direct use of steam by careful process integration by using pinch analysis.

In many European countries, information on energy balances of paper mills is poorly available in public. Different reporting schemes, if any, for energy consumption are used. Energy demand also depends on the product quality (especially in tissue mills) and partly on local conditions. Therefore, it is difficult to present energy consumption values associated with the use of BAT. The ranges of energy consumption of paper mills shown in Table 6.33 should only be taken as an indication about the approximate need of process heat and power at energy efficient paper mills. Further examples of energy efficient paper mills including the specific conditions might be possible to add in a reviewed version of the BREF.

Type of mill	Process heat consumption (net) in GJ/t	Power consumption (net) in MWh/t
Non-integrated uncoated fine paper	7.0 - 7.5	0.6 - 0.7
Non-integrated coated fine paper	7.0 - 8	0.7 - 0.9
Non-integrated tissue mill	5.5 – 7.5 ¹⁾	0.6 - 1.1
Notes:		
1) In tissue mills the energy consumption depends mainly on drying system used. Through air drying and creping consume significant additional process heat up to 25 GJ/t [according to ETF]		

Table 6.33: Indication for energy consumption associated with the use of BAT for different types of paper production per tonne of product

It should be noted that steam consumption may be between 10% and 25% higher depending on the size of the mill. Electricity consumption may be between 5% and 20% higher depending on the size of the mill. The degree of refining has also a significant effect on the electricity demand.

Noise attenuation

1. BAT is the reduction of noise levels audible in the vicinity of paper mills. The measures applied will depend to a large extent to the specific noise problem of a mill and the targets set. Usually they will be much stricter when the mill is located adjacent to a residential area.

Chemical usage

In general BAT for chemical usage is considered to be:

1. Ensure the availability of a database for all used chemicals and additives containing information on the chemical composition of the substances, degradability, their toxicity for men and environment and potential of bio-accumulation.
2. Application of the principle of substitution i.e. less hazardous products are used when available.
3. Measures to avoid accidental discharges to soil and water from handling and storage of chemicals.
Design and operation of facilities in such a way that dangerous substances cannot escape.

6.4.3 BAT for special paper mills

Special paper mills build an extremely diverse group covering a high amount of different products. There are often smaller mills but many of them exceed the threshold that calls for an IPPC permit (20 t/d). The pulp composition for individual products can vary considerably and may include bleached and unbleached chemical pulp, chemical and mineral fibres or other fibres (e.g. cotton, linen, hemp, jute, straw, rags or algae).

On the one hand, most of the techniques that are generally considered as BAT for paper mills are also applicable to these mills but often to a different extent. For the emissions to water some additional explanations are given below.

On the other hand, some of the products of special paper mills have their specific "environmental problems" (as e.g. use of solvents, specific additives, colours, very high amount of fresh water demand, etc.). Best available techniques for those specific concerns are not described in this document.

Biological treatment of wastewater is considered BAT for special paper mills with higher organic loads caused for instance by intensive refining (during which a part of the organic material is dissolved) or chemical additives used that end up in wastewater. For other mills, the organic load might be too low for biological treatment. Similar concentration values for BOD (25 mg/l) and TSS (20 - 40 mg/l) are achievable in special paper mills than in other paper mills. The resulting load - this includes organic loads expressed as COD - to the recipient will be often higher than in other paper mills because of higher water flows.

The specific water quantity used can vary significantly dependent on the product properties and processes involved. But also special paper mills have possibilities for minimising water consumption. However, water can only be recirculated to a limited extent because of the production technology for this papers (e.g. increased temperatures because of intensive

refining), quality demands on individual paper types (e.g. electric conductivity, transparency etc.) or incompatibility of some paper chemicals dissolved in different water circuits. Special papers are also often produced in smaller quantities with more than one change of type (e.g. grammage, composition, colour, width) per day and paper machine. As an example, a speciality paper mill could have more than 5 changes per day. Depending on the quality requirements it may be necessary to completely empty and wash the water systems after a change.

Some special paper mills use a large variety of additives to achieve certain product properties. These chemicals might include substances that contain chlorinated organic compounds or organic bound nitrogen that leads to higher releases of nutrients and AOX.

The ranges of emissions presented in Table 6.34 below are not based on the same background information as the corresponding emission levels for the other paper grades discussed in this document. They should rather be taken as an indication for emission levels to be expected from some type of non-integrated special paper mills.

Parameters	Units	Range
BOD ₅	kg/t	0.15-1.3
COD	kg/t	0.4-7.0
TSS	kg/t	0.3-1.0
AOX	kg/t	< 0.005-0.01
Total P	kg/t	0.01-0.04
Total N	kg/t	0.15-0.4
Wastewater Amount	m ³ /t	15-50 ¹⁾
Notes:		
1) The specific water consumption sometimes exceeds 100 m ³ /t		

Table 6.34: Indications for emission levels to be expected from some type of non-integrated speciality papers mills based on purchased chemical pulp

6.5 Emerging Techniques

In this section, some “promising techniques” are addressed that can not (yet) be considered BAT due to the stage of development of these techniques. Nevertheless, in due time, they may qualify as BAT and therefore they are described briefly here. It should be noted that the description of promising techniques in this chapter is not intended to give a complete overview of all relevant developments.

Introduction

Recent developments and anticipated technology shows that the paper mill of the future can be probably described by the following characteristics:

- Decrease in paper mill water consumption and specific emissions by means of increasing water re-use, closed water loops and internal water treatment
- Increase in electricity consumption (specific to production)
- Decrease in paper mill noise level

Dynamic simulation and total site integration tools will provide new help in complex optimising task to manage the entire paper mill process. Automation and "intelligence" in paper machines will increase rapidly and become embedded in the paper machine. Sensors for instance will predict paper properties with help of few appropriate measurements and this will enable fast and efficient control of the process e.g. in grade change situations. New measuring methods are needed to manage fast processes. Besides consistency and flows measurements also on-line chemistry monitoring systems will become tools for process optimisation.

Cost of investing in new, more complex technologies is a significant factor in paper mills' profitability and is in favour of big units. The current trend to big mills is expected to continue. Increasing effectiveness and decreasing of emissions go hand in hand. The complexity of water treatment technologies tends to increase. To take care of these techniques and maintain them properly is again a challenge for smaller mills.

In the following sections promising novel techniques for reduction of raw material use and emissions are presented. These techniques are still under development. Some are currently researched with a promising perspective for future applications, others run already on full scale in a few applications.

Information include a short description of the technique, an assessment of the status of development, environmental benefits and cross-media effects, economical considerations, if data are already available, and a reference.

6.5.1 Minimum effluent paper mills - optimised design of water loops and advanced wastewater treatment technologies

Description: Advanced wastewater treatment in pulp and paper industry is mainly focused on additional biological- membrane-reactors, membrane filtration techniques such as micro-, ultra- or nano-filtration, ozone treatment and evaporation. Due to relatively less full-scale experience, sometimes relatively high costs and increased complexity of the water treatment, there are only a few full-scale applications of tertiary treatment of wastewater mill effluent up to now.

However, these techniques especially have a potential to be applied as in-line treatment as so-called "kidneys" to eliminate well aimed those substances that negatively interfere with the efficiency of paper production or paper quality.

An example of how to apply a combination of membrane filtration, ozonation and evaporation for process water treatment in a paper mill are shown in Figure 6.25. However, the choice and arrangement of the kidneys in the production process has to be determined case by case.

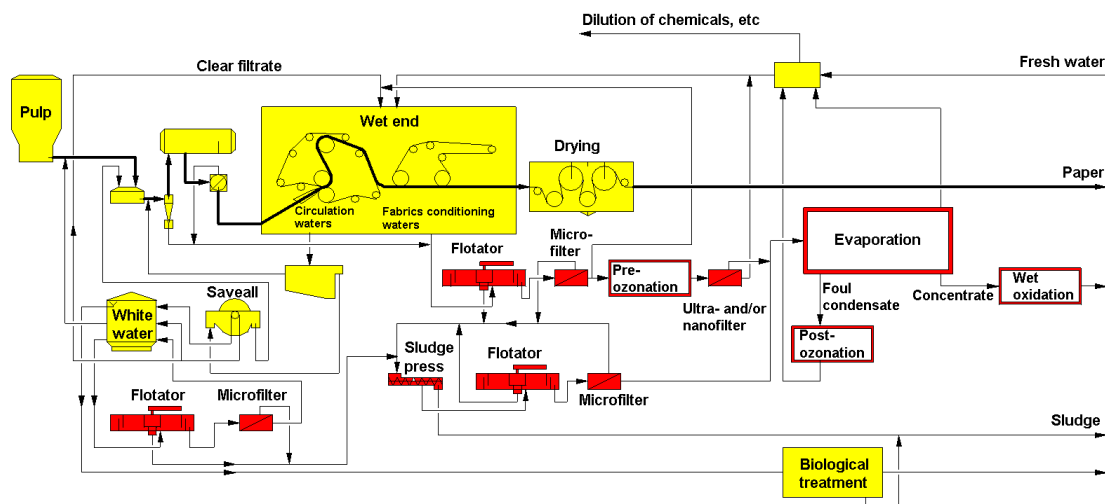


Figure 6.25: Toolbox for possible internal treatment and reuse of paper machine waters [Edelmann, 1997]

Status of development: Some of these techniques are only applied in pilot-scale. Full-scale experiences in paper mills are limited to a few examples in the world. Depending on the technique applied there are still operation problems and relatively high costs. The latter depend on the application and the local conditions.

However, when building new mills or upgrading and increase capacity of existing mills these techniques can be considered seriously. This techniques for water reclamation can also be used to reduce the fresh water consumption in existing mills without having the intention of completely closing the water system. It is expected that these techniques will have further applications in the paper industry in the near future. There is a trend to shift from end-of-pipe treatment to in-line treatment of partial streams of the process water. It can be expected that the pioneers using these techniques are located at recipients where they face very strict requirement or where the water body does not allow increasing the pollutant load. If this mills wishes to increase capacity they have to apply one or the other of the above mentioned techniques.

The status of water treatment technologies in paper industry can be summarised as the following:

- Save-alls filters (common technique). The output of super clear filtrate for re-use can be increased
- Flotation (industrially proven)
- Washing presses (industrially proven)
- Reject and sludge de-watering technique (industrially proven)
- Conventional biological treatment in different variants as e.g. activated sludge (single-stage or two-stage, with and without carrier material), trickling filter (combined with activated sludge), stand-alone submerged biofilters (one- or two-stage) or combined with activated sludge. All these techniques can be considered as industrially proven.
- Biological in-line treatment (first industrial applications realised)
- Pre-filtration + membrane filtration (UF, NF) (first industrial applications realised)
- Pre-filtration + evaporation (first industrial applications realised). If fresh water is replaced with evaporated water there are probably no effects on chemistry and on papermaking.

- Ozonation (first industrial application are to be expected soon). If fresh water is replaced with partially purified water there is a potential of built-ups of disturbing substances. For example, the inorganic salts are not affected and they can interact with process chemicals and equipment. Ozonation is still considered as relatively expensive and less expensive techniques must be developed. These potential effects have to be controlled and the knowledge on the water quality needed have to be increased.
- Enzymatic treatment of process water (under research phase)

Environmental implications: The objective of advanced waste/process water treatment technologies is usually to further remove pollutants that are not removed by common biological treatment as for instance by use of activated sludge plants. Those pollutants are residual COD, colour, nutrients or suspended solids. Advanced water treatment processes produce a high water quality. As a consequence there is a better chance to re-use the "effluent" in the process as fresh water. Thus, advanced wastewater treatment can contribute to further water system closure. However, it can also be applied to achieve lower discharge loads to the recipient.

Very often it is a significant increase of capacity of mills that give the incentive to look for new technical solution with less pollution. Some authorities in Europe require that the amount of effluent and waste of mills that wants to increase capacity must not exceed the level before the investment. This means that new ways had to be found to decrease the fresh water usage and to minimise the amount of solid waste.

Economical considerations: No data available

Literature:

[Edelmann, 1997], [Borschke, 1997]

6.5.2 Impulse technology for dewatering of Paper

Description: The driving force in developing new dewatering techniques in pulp and paper industry, as impulse technology, has been improvements in paper properties. This technology also has the potential for energy saving.

Impulse technology may provide opportunities to achieve high solids content after the impulse unit and thus saving heat energy for subsequent drying. In an ordinary press section the paper web reaches a dryness of about 40 %. In extended nip presses the web may reach dryness levels of about 50 %. From impulse drying, some reports have stated dryness levels of 55-65% before the drying section, which gives a possibility to decrease the heat consumption. Higher dryness levels means that less water has to be evaporated in the drying section by means of steam, and the drying section could be made smaller (shorter). The technology is also expected to provide a smooth paper surface with a high mechanical integrity and a sheet that retains a high bending stiffness. This combination of properties is of great value both in packaging materials and in printing papers.

Impulse technology tries to combine pressing and drying into a single compact process. The wet paper web is exposed to an intense impulse of heat energy under pressure between a press element and a heated element in a paper machine. This induces a sudden increase of the surface temperature of the paper to considerably higher temperatures than employed in traditional technology.

When the paper web gets into contact with the hot surface, generated steam starts to displace water in the paper web. The hot side of the web will be compressed due to thermal softening and may be subject to chemical modification. The web enters a second impulse stage immediately after the first unit. In the second stage, which acts from the reverse side, water is

displaced in the reverse direction. The two impulse steps must be adequately balanced to produce a symmetrical sheet.

Status of development: Some different concepts have been investigated and tried under various names such as hot pressing or pressure drying. The development work is still at an early stage.

Many obstacles have been experienced in the development work and the technology has not yet resulted in full-scale implementation. It should be realised that this technology has been investigated and developed since the beginning of the 1970s without any final break-through.

Environmental implications: By increasing the dryness of the paper sheet from 50 to 51 %, there will be about 35 kg less water/t of paper to evaporate. Thus, the impulse drying technology has the potential of reducing the amount of water to evaporate by 175-350 kg/t of paper. This would simply save the amount of steam consumption by 175-350 kg/t or about 0.44 - 0.9 GJ/t of paper (assuming 2.5 MJ/kg steam), corresponding to about 10-25 % of present steam consumption in papermaking.

However, when calculating the energy saving, the energy needed for the impulse drying itself has to be taken into account. While for impulse drying high temperatures are needed, steam cannot be utilised. On the other hand, paper mills normally have excess amount of steam available which is also a less expensive energy. Thus, the need for high value energy, like electricity decreases the possible benefits for environment and the potential for profitability.

Economical considerations: No data available

Literature:

[Talja, 1998], [SEPA Report 4712-4, 1997]

6.5.3 Condebelt process

Description: The Condebelt[®] drying process is a new way to dry paper and board. Initially, the process was simply intended to improve drying of paper and board and it was only later that the big increases in strength properties became evident. In the Condebelt[®] drying process the paper web coming from the press section is dried between two steel belts instead of traditional steam cylinders, as is shown in Figure 6.26.

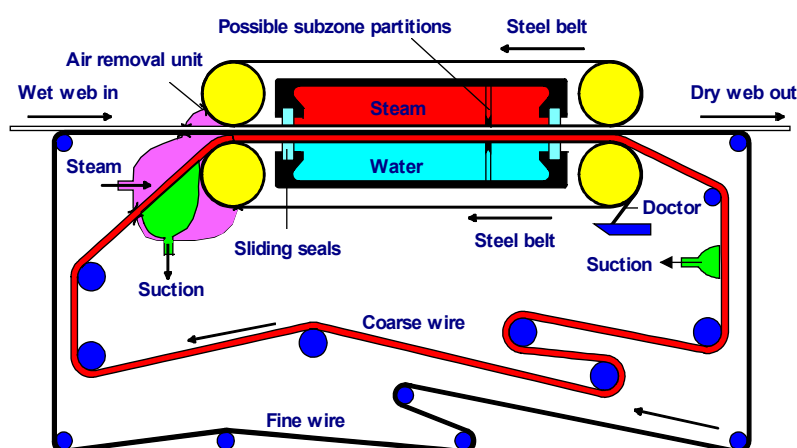


Figure 6.26: Schematic of the Condebelt[®] drying process (high Z-pressure type)

The web travels between a steam-heated upper, and a water-cooled lower steel belt. The hot upper belt evaporates the moisture in the web and which again will condense on the cooled

lower belt. Water is carried away by the steel belt and coarse wire. The fine wire between the web and the coarse wire reduces wire marking on the backside. The web surface against the hot belt becomes very smooth. The high pressure and high temperature within the web result in a softening of the hemicellulose and lignin in the fibre material which "welds" the fibres together. This results in higher strength and better protection against adverse moisture effects. Thus, surface sizing could often be dispensed with, although normally they would be used.

Condebelt[®] drying improves significantly strength (20-60%), surface smoothness, dimensional stability and resistance against humidity. In Condebelt[®] drying, with recycled fibres it is possible to achieve the same strength values as with virgin fibres in conventional drying.

Status of development: At the moment (1999) there are two Condebelt[®] drying processes in commercial operation. The first one has been running since May 1996 at Stora Enso's Pankakowski mill, Finland, producing core board, linerboard and special boards. The second one started-up in January 1999 at Dong Il Paper Mfg. Co.Ltd.'s Ansan mill in South Korea producing linerboard and fluting.

Bearing in mind that there are two commercial units in full-scale operation, Condebelt[®] can also be considered as available technique that has reached commercial stage and not anymore as "emerging technique". However, the major driving force to invest in Condebelt[®] drying is not protection of the environment, but greatly improved product properties.

Environmental implications: The use of this new drying technology does not result in significant direct energy savings. However, the strength improvements give the potential for savings through reduced basic weight. That means, more square meters from the same amount of fibres can be manufactured without losing product quality. Furthermore, because of the improved paper sheet properties with Condebelt drying, it seems to be possible to use lower grade fibre material or high yield pulp (e.g. 10% less wood per tonne of liner). Higher strength and better protection against adverse moisture effects can have the effect that surface sizing could often be dispensed with, although normally they would be used.

Although the specific consumption of electric energy and primary steam roughly equals that of traditional drying there are greater opportunities to save heat energy. This is because almost all of the evaporated water and its latent heat can be recovered from the cooling water at a fairly high temperature (normally about 80°C). This energy can be used in other parts of the process also using heat pumping.

To summarise: The environmental benefits are potential savings of raw material (fibres, sizing agents) and a somewhat higher potential for energy recovery.

Economical considerations: No data available

Literature/References

[Retulainen, 1998], [Ojala, 1999]

6.5.4 Internal Heat Pumps

Description: Heat pumps are used for pumping heat from one medium (e.g. air) to another (e.g. water) Figure 6.27 shows an example of application for a paper machine.

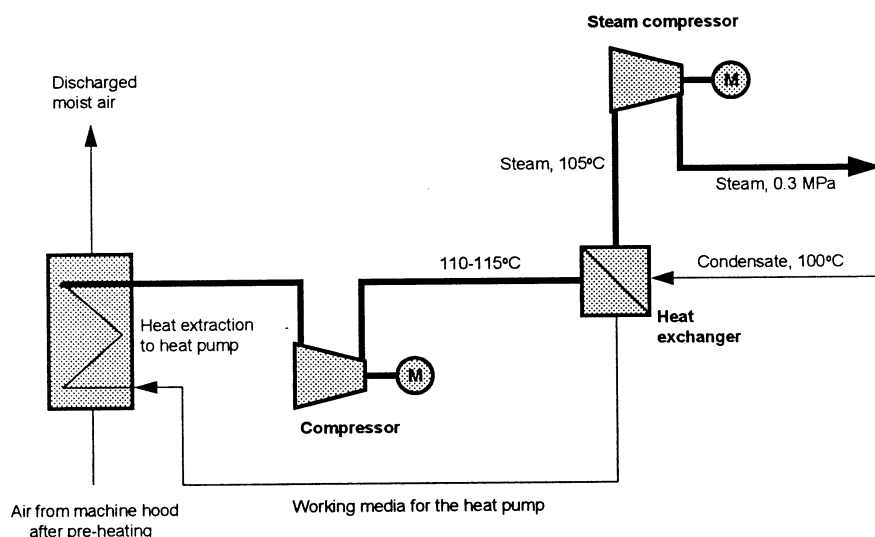


Figure 6.27: System with heat pump for generating process steam
The heat source consists of moist air from a paper machine

Status of development: There are many applications in the pulp and paper industry for heat pumps, but the investment costs are quite high which has hampered the use of this kind of equipment. Furthermore, the environmental problems that are associated with the conventional working media have made the use of heat pumps even more difficult even if the thermodynamics of the heat pump is very advantageous.

Environmental implications: As an example the discharged moist air may hold a temperature of 105°C with a dew point of 61°C. In such a case a heat pump may produce heat corresponding to 750 kWh/t or 2.7 GJ/t by means of only 1/3 or 250 kWh/t of power to the compressor motors. This is based on a coefficient of performance of 3, which is quite normal.

Economical considerations: The potential of this technology is large but the number of actual installations in the pulp and paper industry is small due to the investment cost as well as the mentioned difficulties with suitable working media. Since this is conventional technology, a breakthrough requires the discovery or development of a new suitable media, and also more cost-effective equipment, especially on the compressor side.

Literature: [SEPA-Report 4713-2,1997]

6.5.5 Total site integration tools

Description: Because of the complexity of the papermaking process technological development in the sector has been realised through step by step actions. The complexity of the process can be illustrated by an example on the use of water. Increased recycling of water will lead to a different process chemistry, lower utilisation of secondary heat, different water management practises, new reject streams, changes in the operation of effluent treatment, increased consumption of electricity and reduced consumption of heat. On the other hand, energy consumption is affected also by the production speed of the machine and by unit operation development of the paper machine. The technological choices will have effects on the energy balance of mill site. It can be concluded that intelligent process solution in the future will try to combine the whole energy - water - fibre - chemicals - system to create a good integration of the mill.

Status of development: Several computer-based tools capable to analyse the complex system including cross media effects described below (item 1 to 9) are under development and first analytical studies have been made with integrated paper mills.

However, it has to be pointed out that total site integration tools do not fully eliminate the need for pilot plant studies.

Environmental implications: The key issue is how to come up with process and mill concepts capable to lower emissions to air and water and at the same time to reduce the formation of solid waste and energy. The requirements for the new process are better paper quality and runnability, and better process management. This calls for more knowledge on the behaviour of the processes. Also the changes to the process caused by adoption of new techniques have to be identified so that compatible process technology can be developed.

Consequently, it is clear that new optimisation tools can support the development of future papermaking processes. Some computer-based tools contain the following items or functions:

1. Information on contaminant concentrations in the different parts of the process
2. Behaviour models for the contaminants
3. Process parameters for separation and treatment methods
4. Methods to optimise water treatment concepts with respect to contaminant concentrations and behaviour
5. Identification of heat sinks and sources
6. Methods to optimise the use of heat through careful process integration
7. Information on the emissions from the new mill concept to air and recipient and formation of solid wastes
8. Detailed process design based on the choices made
9. Methods to analyse and to develop the operational runnability of the process

Economical considerations: No data available. The total site integration tool software is not a big investment. But skilled people are needed that have to spend many man-hours to adapt the software to the given characteristic of a mill.

Literature

[Edelmann, 1999]

7 CONCLUSIONS AND RECOMMENDATIONS

This Conclusions and Recommendations Chapter concern timing of the work; sources, availability and quality of information; general remarks on best available techniques; extent of consensus amongst experts of the TWG; and recommendation for future work.

Timing of the work

The drawing up of this BREF took nearly three years. The major steps have been:

- The first Technical Working Group (TWG) Meeting held over 2 days between 5 to 6 May 1997.
- The first draft of an introductory part of the document was sent in November 1997 to the TWG experts. It covered some general informations on the sector, some applied techniques, and current consumption and emission levels of some parts of the sector. TWG Members made comments.
- Change of bureau expert responsible for pulp and paper industry in January 1998.
- A second draft of the document was produced in August 1998 (chemical pulping, mechanical pulping, recovered paper processing) and September 1998 (paper production and related process). Comments from this round of consultation produced additional data and reports.
- The second TWG meeting was held 25 to 27 November 1998. The discussion was very contentious and the TWG concluded on the method and style of presentation of BAT conclusions. Some issues such as emission levels associated with the use of BAT for kraft pulp mills were strongly debated. It became evident that additional data from real world example mills were needed to support the proposed BAT emission levels. New data were supplied.
- A part of the Pulp and Paper draft BREF, which has been largely redrafted in the light of the discussion held at the second TWG and the comments received thereafter was circulated in January 1999. It demonstrated by use of the example of kraft pulp processing how the BAT conclusions are based on good information. TWG Members made comments.
- The BAT conclusions and IPPC principles were presented and discussed at the Fifth Meeting of the IPPC BAT Information Exchange Forum, 18-19 February 1999. The IEF endorsed the approach and agreed that the conclusions are soundly based.
- A third draft of the complete document was produced in August 1999. Comments from this round of consultation produced again valuable additional information. Information provided during the consultation has been incorporated in the final report.
- The final draft BREF was produced in February 2000.
- The final document and the remaining points of disagreements amongst experts of the TWG were presented and discussed at the Seventh Meeting of the IPPC BAT Information Exchange Forum, 28-29 February 2000.

Sources of information

A lot of information and studies on single environmental aspects of pulp and paper industry are available. Single countries and international organisations have published a number of BAT documents, guidance documents and technical background material on various environmental issues. In a number of European countries special regulations for pulp and paper mills are applied whereas other countries use guidance documents in case-by-case permits (however, a few countries do not have either a specific regulation for the pulp and paper industry, nor guidance documents). In the framework of different Conventions on the Protection of the Marine Environment recommendations and decisions are adopted. These recommendations deal with BAT for reduction of emissions to water and air from pulp and paper mills. Also on behalf of the European Commission several studies on BAT for pulp and paper industry have been carried out in the last decade. All this information was useful for the description of single aspects of BAT described in the BREF. However, emission reduction measures that are

frequently described separately from each other, needed to be updated, supplemented and merged to an integrated approach that covers all major aspects to consider in determination of BAT according to Annex IV of the Directive.

To support the work of the European IPPC Bureau (EIPPCB) some Member States and industry have conducted or commissioned studies aiming at a more integrated description of BAT in the pulp and paper sector. The Confederation of European Paper Industries (CEPI) has carried out three BAT studies to support the work, Groupement Ondulé (European Association of Makers of Corrugated Base Paper) has commissioned a report on BAT for production of case making materials made from recycled fibres. Finland has provided two BAT studies including BAT emission levels, Sweden has submitted two studies on possibilities for energy saving and implications on costs, and the Netherlands have submitted a report on BAT for pulp and paper production from recycled fibres. The comments and contributions of the Members of the Technical Working Group were of great use for the outcome of the information exchange on BAT.

There is good information available on reduction measures for emissions to water and the atmosphere reflecting the world-wide trend that efforts to reduce atmospheric and water emissions that have dominated the environmental work at pulp and paper mills. Less information is available on the assessment of energy efficient technologies and different options on solid waste minimisation in pulp and paper industry.

During the work it became evident that there was a lack of information on sufficiently qualified plant specific emission data. Frequently, in the technical background material the environmental performance of internal and external measures is described relatively vague. Plant specific information and qualified figures for best performances have been difficult and sometimes even impossible to get. There was often a need to supplement environmental performance data, add information on cross-media aspects and also on costs. A lot of useful information was however compiled from the TWG Members and provided to the EIPPCB that helped to fill in most information gaps.

The transparency of the environmental performance of the European paper industry is still limited to a few countries. For instance, Sweden and Finland are publishing regularly environmental statistics available for the public that specify the environmental performance of single mills. As of the year 2000 in the Netherlands paper mills have to provide environmental performance data to the public by means of a yearly environmental report. Also in Ireland all monitoring data and reports supplied by companies and also the monitoring data of the Environmental Protection Agency is made available on public file. The aim of industry and society is to create objective and transparent knowledge about the results achieved in reducing environmental impacts from paper production. A strategy of more openness and informing the public could support this aim (will create more public support).

It has to be noted that often insufficient information was given for submitted data on sampling and analysis methods. Reference time intervals (e.g. daily or yearly average values), computation methods and reference conditions were often missing or incomplete. Therefore, the comparability of environmental performance data varies and needs to be improved in the future. In order to improve the comparability it is recommended to carry out a European survey on how the environmental performance data of pulp and paper mills are compiled, whether or not the different practices are relevant, and if so, to which extent, and in which respect. For instance, for determining diffuse atmospheric emissions (total reduced sulphur emitted from many small sources in low concentrations and high volumes) there seems to be different collection and measurement systems in place in European kraft pulp mills. Calculations and reports on energy consumption could also benefit from such a study. Technical and waste fraction terms and waste fractions distinguished also vary between European pulp and paper mills. Therefore it not always clear which waste materials are included or excluded when figures about the amount of solid

waste are reported. Other parameters such as COD, BOD, TSS, SO₂ and NO_x seem to differ less because international norms for determination of these parameters exist.

Sufficiently qualified cost data that are reliable, transparent and allow linking techniques and costs and savings are still missing. As a result it is difficult to compare costs of techniques. There is some cost data available but in general it is not known what exactly is included in the figures or how they are calculated. Moreover, costs will vary considerably between mills for the same measure e.g. due to different technical starting points and different timing for process investments. Therefore costs given in this document can only be indications of magnitudes not exact figures. The cost for the individual mill can only be calculated in the permitting situation.

Best available techniques

Concepts, which are more or less similar to BAT in the IPPC Directive, were introduced in pulp and paper industry quite some time ago. Technologies and strategies have been developed in order to minimise the use of raw materials, chemicals, energy and fresh water and to reduce emissions to water, air, and land. Especially during the last two decades, substantial investments and modifications at production facilities have been carried out in many pulp and paper mills in Europe. The impact of pulp and paper mills on the environment as a whole could be reduced substantially through internal as well as external measures. However, improvements and efforts still have to be made in order to achieve the long-term aim of sustainability.

So far, legislation and control by environmental authorities have mainly focused on atmospheric and water emissions. Regulation and enforcement have been important driving forces for the substantial improvements that have been achieved so far. However, not only authorities but also investors, customers, the general public including political groups, environmental pressure groups, and media are participating as stakeholders, demanding the mills to reduce their environmental impact. The attention for specific topics varied over time to a certain extent. Issues such as efficient use of raw materials and energy, solid waste minimisation, use of environmentally less hazardous chemicals, and transport to and from mills have become more important topics in recent years. Sustainable forestry management and transport are normally not dealt with in granting permits and are outside the scope of this document.

In many companies a more holistic view on the environment as a whole has been introduced. New methods for analysing the interaction between products and production processes and the environment in a life-cycle perspective ("paper chain") have been developed and applied.

The exchange of information has allowed conclusions on BAT on sector level. With the application of a combination of best available techniques certain emission and consumption levels are associated. Both available techniques and these levels are specified in the BREF. The Executive Summary contains the key findings concerning all these conclusions on BAT. The BAT elements are described in more detail in the BAT chapters and additional explanations are given there.

Degree of consensus

This BREF has met support from most members of the TWG and participants at the 7th meeting of the Information Exchange Forum. However, CEPI – representing the pulp and paper industry – and a few Member States did not express their full support for this final draft and contested some of the conclusions presented in the document. Their reasons for this are given below.

A few Member States and CEPI expressed their view that the BAT associated emission levels should be presented separately for new and existing mills. What seems to be logical on the first view is more problematic from a practical point of view. Difficulties are caused by the fact that in pulp and paper mills, the applicability of a technique is not only driven by the fact whether a mill is new or existing. Pulp and paper mills are characterised by the trend that machinery is

rebuilt over years rather than replaced whole-scale (modular rebuilding and development of plants). Thus, due to progressive rebuilding, updating, process control and environmental management systems, there are many existing mills with comparable or even better environmental performance (at least for some parameters) than recently built mills. Furthermore, BAT statements for new mills are to a certain extent speculation. Consequently, all descriptions and data of this document are based on existing mills.

Another point of disagreement is that a few Member States and CEPI wish to have different BATs and BAT associated emission levels for smaller and bigger mills. The difficulty here is that there was no information provided by the TWG-experts which techniques are not applicable for smaller mills from a technical and economical point-of-view. Well-founded information on appropriate BAT levels for smaller mills have not been provided either and it is thus unclear which yardstick to use for this purpose. On the other hand, there are also some smaller mills that achieve good environmental performance. The impact, if any, of the size of the mill will be taken into account by the permitting authority in the Member State in question. Therefore, no distinction of BAT between smaller and bigger mills should and has been made in the BREF. The size of the mill can be considered when determining BAT in the specific case. Generally, it can be stated that the specific costs for smaller mills are relatively higher (economies of scale), smaller mills might have less financial possibilities for technical changes, and it might happen that material or lay out of older equipment does not fit for a higher degree of water closure. Smaller mills might sometimes not have the knowledge available which would be necessary to run and control more complex process solutions most efficiently.

Notwithstanding the above arguments, CEPI and one Member State took the view that the economic difference between new/existing and large/small mills had not been sufficiently considered and that clear differences should have been established in the BREF. Moreover, the Member State concerned felt that not enough consideration was given to problems for mills using the same equipment to produce different grades of paper.

There has also been a debate about whether or not it is possible for a typical mill to, at the same time, reach all the presented emission and consumption levels associated with the use of a suitable combination of the various techniques that are considered as BAT. CEPI and three Member States believe that a typical mill will not be able to achieve this. In their view, no sufficiently integrated assessment of all parameters has been carried out. One reason cited for this, is the lack of reference data based on integrated assessment. However, this view is not shared by most members of the TWG and mills were identified who achieve, at the same time, all of the levels associated with BAT. This debate highlights the different understandings of BAT as defined in the Directive and emphasises the need to read the BREF in light of the preface to the document.

Apart from these general issues, there are also a few specific issues where the final conclusions did not receive unanimous support. CEPI and two Member States consider that for TSS for bleached kraft pulping, the upper end of the range associated with the use of BAT should be 2.0 kg/Adt instead of 1.5 kg/Adt. CEPI and one Member State also consider that some of the ranges associated with the use of BAT for uncoated fine paper, coated fine paper and tissue are too stringent. Another Member State expressed the view that for auxiliary boilers, the measurement data available were not comparable thus undermining the validity of the conclusions on BAT associated emission levels from boilers. Conversely, there are TWG members who consider that certain concluded BAT associated levels are excessively lenient (e.g. regarding COD levels for kraft pulp mills).

The European Environmental Bureau – representing environmental organisations – expressed some further dissenting views, including that ECF-bleaching in kraft pulp mills does not meet the BAT criteria regarding the precautionary and the prevention principles and that, in general, tertiary treatment of effluents should include treatment with ozone, peroxide or UV radiation followed by a biofiltration step.

Recommendation for future work

The section "emerging techniques" in all chapters gives some examples of promising techniques, which have reached different status of development. Some of these new technologies have been recently introduced in the sector. This is true for instance for new evaporation techniques, membrane applications, ozonation, in-plant water treatment systems, projects dealing with how to implement closed loop water circuits, and new options for waste treatment. A number of full-scale plants are going to come into operation. It is expected that within a few years results from long time trials will be available from various mills. These experiences could be incorporated when reviewing the BREF and other relevant emerging techniques added.

Closed water loops with in-line biological process water treatment is reality at a few full-scale applications in Europe for non de-inked grades. The TWG discussed whether it should already be considered as general BAT. The experts refrained from that at sector level because some technical problems are still awaiting resolution. However, for "brown papers" one may already consider the effluent-free mill as a realistic target. In a few years, it can be expected that some more experiences from real world examples will be available when the mills that are going to invest in these techniques will be in a position to report on their operational experiences. These experiences are worth incorporation in the next revision of the BREF.

At present, only limited or in-sufficiently qualified information on costs and/or savings on BAT has emerged from the exchange of information in the Technical Working Group. However, it is recommended to collect more detailed and operational information in a future information exchange. This should include information on specific costs and savings such as amortization time of measures, and unit costs (e.g. related to a tonne of product manufactured, a tonne of pollutant reduced, or a m³ water treated).

The reduction of the amount of solid waste in general and the decrease of waste fractions to be landfilled is the general target. This can be achieved by application of a variety of environmentally sound techniques some of which are described in the BREF. However, the best available techniques for waste recovery, recycling and re-use vary across Europe and more information is needed on the best waste management and preferred treatment options in the Member States. A review of the BREF could have a closer look at available options, their advantages and drawbacks and achieved results. It might then be possible to propose BAT associated ranges for solid waste that still needs to be land-filled.

Little information is available on the assessment of energy efficient technologies and practical experiences of their results in the pulp and paper industry. When energy data and balances are reported the assumptions and conditions are often not sufficiently qualified. More work on that important issue and the derivation of production specific energy consumption figures are needed before the next review.

Limited information was made available on local issues such as noise/vibration/odour and related measures to minimise them. The same is true for potential soil contamination (environmentally sound decommissioning of plants, prevention of hazardous substances from escaping during storage, transportation and use) and health & safety aspects. If information is available this could be incorporated in the review of BREF.

There seem to exist different practices in collecting, sampling, measuring and calculating fugitive atmospheric emissions from kraft pulp mills that may escape from various small sources (measured as total reduced sulphur). More work is needed to understand whether or not these different practices lead to relevant differences.

There were some strong views in the TWG about the general comparability of data across Europe especially concerning measurement of total suspended solids in water, determination of

particulate emissions to the air. Annex III gives more details but does however not support the view that data on total suspended solids is not comparable. Apart from these examples it is considered that the comparability of data is not as big an issue as some suggest noting that there are European norms for several parameters. However, it is clearly desirable to harmonise future data by using further European standard methods and by investigating the real differences and important factors influencing the reported results. This should include flow measurements, sampling, pretreatment and storage of samples as well as differences in calculating and reporting environmental performance (averaging time, reference conditions).

When emission data is reported in the future it should include specific volumes and concentrations (i.e. per tonne of product) of gases and waste water so that specific emissions can be better understood by sceptical readers. Sufficiently qualified specific emission data are the preferred information for comparison of the environmental performance of various installations across Europe.

The information on techniques to consider in the determination of BAT are generally much weaker for sulphite pulp mills than for kraft pulp mills. Therefore, from the limited information supplied by the members of the TWG in the course of the information exchange on BAT only a few techniques could be described to the same extent as for kraft pulping. If Member States see a need to explore further the differences between kraft and sulphite pulping processes, then more information needs to be provided for a review of this section.

A future BREF review could have a closer look at the specific conditions of smaller mills and the special paper group. It might be beneficial to set up a network between smaller mills to organise an exchange of information between them and to look for support for solutions that are especially appropriate to their conditions.

When experience with IPPC and the use of the BREF is gained it should be used to assess whether there is a need for a more detailed description of other product related factors. These factors may include special raw materials, specific qualities of the end product, and associated operational factors.

It is recommended by the TWG to start updating this BAT reference document around the year 2005 to assess the above points and reported developments in achieved emissions per tonne of product in particular. Before an update of this BREF is carried out, Member States and Industry should make information on emissions and energy consumption together with associated techniques and their costs more readily available and transparent. An important step to support this work would be if Member states and industry openly publish data on production, emissions and energy consumption for each mill. In this respect it could be useful to start with a survey on different practices in determining environmental performance and reporting results of European pulp and paper mills.

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GLOSSARY OF TERMS AND ABBREVIATIONS

Units and Conversion factors

- a = annum, year, 365 days
- d = day, 24 hours
- h = hour(s)
- 1 kWh = 3.6 MJ
- 1 MJ = 0.2778 kWh
- 1 kg steam = Assuming a pressure of 2.5 bar in the steam pipings the heat of steam which can be used corresponds to about 0.7 kWh/kg steam or about 2.5 MJ/kg steam
- ppm = Value multiplied by Molecular Weight divided by 22.41 = mg/m³; e.g. 1 ppm NO₂ = 2.05 mg NO₂/Nm³ or 1 ppm SO₂ = 2.85 mg SO₂/Nm³
- t = metric tonne (1 * 10⁶ gram)
- m³n or Nm³ = normalized (standard) cubic metre; the volume a gas occupies at atmospheric pressure (1013 mbar) and 273.15 K (= 0°C)
- I-TEQ = PCDD/F international toxicity equivalents
- °C = degree Celsius
- μ = micro = 1 * 10⁻⁶

Abbreviations

ADt	Air dry metric tonne of pulp meaning dry solids content of 90 %. Please note that an air dry tonne of paper is defined as paper with 6% moisture content.
AOX	Adsorbable Organic Halides measured according to the ISO 9562: 1998 standard method for wastewaters
BAT	Best Available Techniques, as defined in Article 2(11) of the IPPC Directive
BOD₅/BOD₇	Biological Oxygen Demand indicating the amount of biodegradable organic matter in the wastewaters assessed using a standard 5 day or 7 day test.
BREF	Best Available Techniques Reference Document
C	Chlorination bleaching stage using molecular chlorine dispersed and dissolved in water
COD	Chemical oxygen demand indicating the amount of chemically oxidisable organic matter in the wastewaters (normally referring to analysis with dichromate oxidation)
CSF	Canadian Standard Freeness - a measure of the rate at which water drains from a pulp, the smaller the number the slower draining is the pulp.
CTMP	Chemi-thermo-mechanical pulp
D	Chlorine dioxide bleaching stage using a water solution of chlorine dioxide (ClO ₂)
DAF	Dissolved Air Flotation
D/C	Bleaching stage with chlorine dioxide and chlorine where chlorine dioxide dominates over chlorine (which can be specified with percentages of active chlorine e.g. D ₉₀ /C ₁₀ meaning 90 % chlorine dioxide and 10 % chlorine)
DIP	Deinked pulp – pulp produced from recovered printing paper, e.g. newsprint, through de-inking process
DS	Dry solids
DTPA	Diethyl Triamine Penta Acetic acid, complexing agent
E	Extraction bleaching stage using sodium hydroxide (NaOH)
ECF	Elemental Chlorine Free (bleaching).
EDTA	Ethyl Diamine Tetra Acetic acid, complexing agent
e.g.	for example (exempli gratia, latin)
E/O	Extraction bleaching stage using sodium hydroxide with subsequent addition of gaseous oxygen as a reinforcing agent
EOP	Extraction bleaching stage using sodium hydroxide with subsequent addition of oxygen and hydrogen peroxide solution as a reinforcing agent
E/P	Extraction bleaching stage using sodium hydroxide with subsequent addition of hydrogen peroxide solution as a reinforcing agent
EPA	Environmental Protection Agency
EQO	Environmental Quality Objective

ESP	Electrostatic precipitator
ETS	European Tissue Symposium, European Association of Tissue Manufacturerers
Euro	European currency unit
FAS	Formamidine sulfonic acid; reductive bleaching agent
FEI	Finnish Environment Institute
GW	Groundwood pulp
HC	High consistency - pulp concentration in the interval 30 - 50% dry solid content
H₂O₂	Hydrogen peroxide
i.e.	that is (id est, latin)
IPPC	Integrated Pollution Prevention and Control
ISV	Sludge Volume Index; Volume in ml occupied by 1 gram of activated sludge after settlement under specified conditions for a specified time, usually 30 minutes.
% ISO	Brightness unit according to ISO, the International Organisation for Standardisation
LC	Low consistency - pulp concentration in the interval 3 - 5% dry solid content
LWC	Lightweight coated paper
MBR	Membrane Bioreactor
MC	Medium consistency - pulp concentration in the interval 8 – 15% dry solid content
MEuro	1 million euros, a European currency unit
Mg	Magnesium
MLSS	Mixed Liquor Suspended Solids
MWC	Medium weight coated paper
NCG	Non-condensable gases referring to malodorous gases of chemical pulping
Ndg	normal dry gas related to standard conditions
Nsp	net sealeable paper
NO_x	The sum of nitrogen oxide (NO) and nitrogen dioxide (NO ₂) expressed as NO ₂
NPE	Non Process Elements that can accumulate when closing up the water circuits in pulp mills such as Al, Si, Ca, Ma, Mn
NSSC	Neutral Sulphite Semi Chemical pulp is the most common type of semichemical pulp which is produced by a combination of chemical and mechanical pulping. In the process wood chips are partially digested to weaken the bonds between fibres and lignin. The chips are then mechanically treated in a refiner
O	oxygen bleaching stage
P	Alkaline bleaching stage with hydrogen peroxide (H ₂ O ₂) as liquid
PCDD/F	Polychlorinated Dibenzo-p-Dioxins/Furans
PGW	Pressurised ground wood (pulping)
Q	Acid bleaching stage where chelating agent EDTA or DTPA has been used for removal of metals
RCF	Recycled fibre(s); pulp obtained from recovered paper processing
RMP	Refiner mechanical pulping
S	1) Sulphur 2) Acid bleaching stage with sodium hydrosulphite (NaHSO ₃)
SC	Supercalendered paper
SEPA	Swedish Environmental Protection Agency
SGW	Stone groundwood (pulp)
SNCR	Selective Non-Catalytic Reduction
SO₂	Sulphur dioxide
SS	Suspended solids
TCF	Totally chlorine free (bleaching)
TMP	Thermo-mechanical pulp
TRS	Total reduced sulphur meaning the sum of the following reduced malodorous sulphur compounds generated in the pulping process: hydrogen sulphide, methyl mercaptan, dimethylsulphide and dimethyldisulphide expressed as sulphur.
TSS	Total suspended solids (in wastewater)
TSP	Total solid particulates (in flue gases), dust
VOC	Volatile Oranic compounds
WWTP	Wastewater treatment plant
Z	Ozone bleaching stage using gaseous ozone (O ₃)

Definition of terms	
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Air dry	Air dry tonne of pulp (Adt) meaning dry solids content of 90 %
Absolute dry	Dry solids content of pulp of 100%; also called bone dry (b.d.) or oven dry (o.d.)
Achievable value	When using a particular technique or combination of techniques achievable level means that a certain emission level may be expected to be achieved over a substantial period of time (e.g. a year) in a well designed, well maintained and well operated installation or process using those techniques
Bleaching	the process of brightening the fibre by removal of the coloured substance or by decolourising it
Broke	Paper that has been discarded anywhere in the process of manufacture
Brownstock	the suspension of unbleached pulp
Chemical pulp	Fibrous material obtained by removal from the raw material of a considerable part of those non-cellulosic compounds that can be removed by chemical treatment (cooking, delignification, bleaching)
Consistency	The weight percent of air-dry (or oven dry) fibrous material in a stock or stock suspension. Low consistency (3% - 5%, LC), medium consistency (10% - 15%, MC) and high consistency (30% - 50%, HC) are distinguished
Couch pit	chamber beneath press section end of formation table to receive edge trim and sheet breaks in papermaking
Cross media effects	Possible shift of environmental pressure from one environmental compartment to the other. This is for example the case when a filter is installed to abate atmospheric emissions; the air is cleaned but a waste is generated
Daily production capacity	The weight of products (air dry mass) an installation can produce during one day
Deinking	the process of removing ink from printed wastepapers, but also involving general removal of other undesirable materials
Disperging	mechanical treatment of wastepaper fibres to disperse ink particles
Dry end	Part of the papermaking process after formation of the paper web
Fillers	papermaking additives, usually mineral clays or calcium carbonates
Fines	small particle sized material in papermaking usually defined as material below 75 microns
Furnish	The mixture of various materials that are blended in the stock suspension from which paper or board is made. The chief constituents are the fibrous material (pulp), fillers, sizing agents, wet-strength or other additives, dyes, and dyes
Grammage	the areal mass of the paper/board, usually expressed as g/m ²
Hardwood	Group of wood species including the following pulpwoods: aspen, beech, birch and eucalyptus
Head box	Pulp feed to the paper machine starts here
Installation	A stationary technical unit where one or more products are produced
Integrated production	An installation in which the production of paper and/or board is directly connected with the production of pulp
Kappa number	A measure of residual lignin content in unbleached pulp, determined after pulping and prior to bleaching. The lower the Kappa number the less associated lignin
Kraft pulp	Chemical pulp which has been manufactured using sodium sulphate as the main cooking chemical
Levels associated with BAT	Emission (and consumption) levels that represent the environmental performance that could be anticipated as a result of the application of BAT, bearing in mind the balance of costs and advantages inherent within in the definition of BAT
Lignin	this is the binding substance in natural fibres and is a complex organic polymer with an irregular structure
Magnefite	magnesium base sulphite pulping process
Mechanical pulp	Paper making pulp made entirely by mechanical means from various raw materials i.e. by grinding wood against an abrasive surface (ground wood pulp) or by processing wood chips or sawdust through a refiner (refiner

	mechanical pulp). Mechanical pulp contains considerable part of non-cellulosic compounds
MF resin	melamine formaldehyde resin
Non integrated production	An installation in which the production of paper and/or board is not directly connected with the production of pulp. Either pulp or paper and/or board is produced
Paper	Sheet of fibres with a number of added chemicals. According to the basic weight it can be distinguished: Paper < 150 g/m ² < paper-board (or board) < 250 g/m ² < cardboard
Pitch	a resinous material in virgin pulps
Pulping	the process of converting raw fibre (eg wood) or recycled fibre to a pulp usable in papermaking with minimal further treatment
Refining	process of mechanically treating fibres to develop strength
Save-all	An apparatus used for reclaiming fibres and fillers from white water. It usually operates on a filtration, sedimentation, flocculation, or flotation principle
Soap	The product of reaction between the alkali in kraft pulping liquor and fatty acid portions of the wood, which precipitate out when water is evaporated from the spent pulping liquor
Softwood	Group of wood species including the following pulpwoods: pine and spruce
Specific water consumption	the amount of fresh water consumed during production (surface water, ground water), which is taken out from external resources. This fresh water demand is related to air dry net production and is expressed as m ³ /t. Fresh water that is only used for cooling purposes (i.e. water that had no contact with fibres and additives) and that is directly discharged into the recipient is not included. Also wastewater generated in steam and power plants on site is not included.
Stickies	Materials that stick together; adhesive contaminants in recovered paper
Stock	the mixed suspension of fibre and other materials used to form the paper
Sulphite pulp	Chemical pulp where various sulphites or bisulphites are used as main cooking chemical
Thermo-mechanical pulp	Papermaking pulp made entirely by mechanical means from various raw materials, but usually wood. In the thermo-mechanical pulping process the raw material is subjected to thermal pre-treatment. Thermo-mechanical pulp contains considerable part of non-cellulosic compounds
Turpentine	A mixture of terpenes, principally pinene, obtained by the steam distillation of pine gum recovered from the condensation of digester relief gases from the cooking of softwoods by the kraft pulping process
UASB	upflow anaerobic sludge blanket reactor/process
UF resin	urea formaldehyde resin
Recycled fibre pulp	Fibrous material that has already passed through paper and/or board production
Wet-end	Part of the papermaking process prior to formation of the paper web
White water	A general term for all waters of a paper mill that have been separated from the stock or pulp suspension, either on the paper machine or accessory equipment, such as thickeners, washers, save-alls, and from pulp grinders. It carries a certain amount of fibre and may contain varying amounts of fillers and dyestuffs
Wood-containing paper and/or board	Paper and board having considerable part of non-cellulosic compounds (more than 5%) as an essential constituent of its fibre composition
Woodfree paper and/or board	Paper and board having in principle only chemical pulp in its fibre composition; in practise however it may contain a small amount of other fibres or pulps (less than 5% non-cellulosic compounds)
Yankee cylinder	large single cylinder used mainly to dry tissue/towels
Yield	the amount of useful fibre after pulping and/or bleaching or deinking expressed as a percentage of the raw fibre

ANNEX I CHEMICALS AND ADDITIVES IN PAPER MANUFACTURING

In the paper industry a large number of chemicals are used. On the one hand process chemicals for the production of pulp are required, on the other hand chemical additives and auxiliaries are applied in paper production. Only chemical additives and auxiliaries will be discussed here. Chemical additives are used to give paper various characteristics while chemical auxiliaries are used to increase efficiency and reduce disruption of the production process.

Since chemical additives are designed to give paper a particular characteristic, for reasons of cost and efficiency they generally have a high level of retention to the cellulose fibres. Most of the chemicals are therefore retained in the paper. Chemical auxiliaries, on the other hand, often have a low level of retention and a large proportion is discharged with the wastewater. A product with a chemical additive often contains chemical auxiliaries designed to facilitate the use of the product, e.g. emulsifiers that ensure better accessibility for substances in the water system, which are difficult to dissolve in water. These chemical auxiliaries also have little affinity to cellulose. Depending on the chemicals' degradability and the wastewater treatment plants' ability to deal with them they may end up in the outside environment.

The most common groups of chemicals used in the paper industry are examined below from the environmental point of view. The text below focuses on the most common groups of substances which are only an extract out of a longer list of chemicals that are actually in use (according to a Swedish survey in all around 1300 products involving around 800 substances are used in the Swedish paper industry). The discussion includes always information on the function, the substances involved and the expected emission and effects. Where available an indication is given about possibilities to control releases or to reduce the impact on the environment.

The following chemical additives are discussed on the following pages:

- Fillers
- Sizing agents
- Wet strength agents
- Dry strength agents
- Coating chemicals
- Brighteners or fluorescent whiteners
- Dyes
- Retention aids
- Defoamers
- Dispersion agents and surfactants
- Biocides for incoming water
- Biocides (slimicides) for the process water circuits

In different countries surveys were carried out to identify substances which on environmental grounds are candidates for replacement in accordance with the substitution principle. The substitution principle means that when using chemicals, hazardous products should be avoided if they can be replaced by less hazardous ones. A substance's environmental hazardousness is determined by assessing its intrinsic characteristics with regard to the environmental parameters toxicity, biodegradability and bioaccumulation. Unfortunately, much of this information is still lacking for both the candidate for replacement and the suitable alternative. Therefore, there is a need to develop a kind of survey on a European level that can be used by operators and inspectors as well. This survey should aim at candidates for replacement i.e. "high risk" chemicals that should be removed and replaced with "low risk" types, without impairing the papermaking process.

Fillers (product aids)

Function: Papermaking fillers are added to give opacity, brightness and surface smoothness as well as being cheap extenders replacing fibre.

Chemicals: China clay (kaolin) and calcium carbonate are used, typically, at up to 300 kg/ADt. Provided that it is compatible with the paper specification, calcium carbonate would normally be preferred to clay due to the higher and more consistent overall retention achievable. Titanium dioxide, talc, and plastic microspheres are used as in smaller quantities as speciality fillers. Fillers are added at the wet end and 50 - 80% is retained in the paper web depending on whether appropriate retention aid chemicals are also used.

Emission and effects: The retention after fibre and filler recovery is typically in the order of 98%. Those fillers that reach the effluent will be removed to a considerable extent by the primary treatment. However, some discharges to receiving waters may occur, particularly as accidental or temporary discharges. The inorganic fillers are principally insoluble and inert products. The organic fillers have a very low degradability. When released to water fillers may affect light penetration in water bodies (turbidity) and built deposits on sediments.

Sizing agents (product aids)

Function: Sizes are added to improve the paper's resistance to aqueous liquids i.e. makes the paper hydrophobic. Sizes are applied either at the wet end (internal sized paper) or at the size press (surface sizing). They are used in newsprint, printing and writing and packaging papermaking.

Chemicals: Natural products as modified natural resins (resin size), starch or modified starch as well as synthetic products as alkyl ketene dimer (AKD) and other polymers (e.g. copolymers based on acrylic acid esters, maleic acid esters, acrylonitrile and styrole) are used. AKD is the most widely used sizing chemical and its use may be preferable where product specifications allow. When AKD is used 0.1% active substance (referred to dry stock) is sufficient to achieve the effect of fully sizing. To a less extent paraffine wax, polyethylene waxes and fluoro chemicals are applied. Usually emulsifiers and others additives are added to achieve good sizing results.

Emissions and effects: About the retention of furnish added chemicals little is known. As the chemicals have a low solubility, they will most likely adhere to the paper product or be removed to a large extent in effluent treatment plants. For surface sizing chemicals the retention is very close to 100%.

With high addition rates of sizing chemicals in the pulp, operators should show the anticipated release rates through the ETP and the fate of the substances applied.

AKD: biodegrades, low toxicity to bacteria, may bioaccumulate [UK Note IPR 6/9], [J. Pöyry, 1994b]

Resin products: toxic to bacteria, fish bioaccumulation [UK Note IPR 6/9], [J. Pöyry, 1994b]

Modified starches: biodegradable, non-toxic [UK Note IPR 6/9]. No risks of environmental effects are reported.

Wet strength agents (product aids)

Function: These are added at the wet end to the furnish to improve the strength properties of the paper in wet conditions. They are used in such applications as towel products, kitchen rolls, napkins, sack papers, labels, currency, maps and filter papers.

Chemicals: Polymers binding the fibres together as urea formaldehyde (UF) resins, melamine formaldehyde (MF) resins and polyamidoamine-epichlorhydrin based resins (PAA-E) are mainly used. Depending on the area of application the amounts of wet strength agents used vary. Up to 5% solid substance (referred to air dry stock) is added.

Emissions and effects: The retention on the paper machine has been estimated to be > 90%, which means that < 10% leaves the system with the wastewater [J. Pöyry, 1994b]. However, there are current experiences that UF-MF resins are retained at 50-70% only [Wallonia Authority]. UF and MF resins have shown moderate toxicity to fish and are only partly biodegradable.

The UF and MF resins contain some free formaldehyde (typically 2-5%) and more will be released from the cross-linking reaction associated with resin curing. Because of the high solubility of formaldehyde, the majority of the free formaldehyde will remain with the water and pass to the wastewater treatment plant where it is readily biodegradable. However, that water which is evaporated during drying, will release its formaldehyde to atmosphere. The concentration and mass flow for the free formaldehyde released should be determined by measurement of the formaldehyde content of the air leaving the drying section. Where the mass flow is found to be significant then consideration should be given to its capture.

An assessment of the maximum ground level concentrations and the adequacy of the height of the release point would also be required.

Low/free formaldehyde resins (<0.5%) are available, which can be used with little loss of wet strength efficiency in some cases. With some furnishes, however, increased quantities are required, negating the benefits gained. Operators should have thoroughly investigated the possibility of these alternatives.

The PAA-E resins do not release any volatile components during use but they contain organically combined chlorine that will be released to effluent when they are not retained in the paper or the sludge. They are toxic to aquatic organisms and are not biodegradable. During synthesis of the PAA-E resins, epichlorhydrin can also react or form dichloropropanol (DCP), a suspected carcinogen, and chloropropanediol (CPD). For both these reasons, a wide range of PAA-E resins is now commercially available with reduced AOX and DCP/CPD levels and these resins should preferably be used.

Direct spills of these resins can cause fish mortality by attaching to the gills. Systems must be engineered to preclude the possibility of direct releases.

Once fully cured, wet strength papers are more difficult to re-pulp than ordinary papers. Re-pulping of UF/MF-treated papers may lead to formaldehyde releases. Operators should be required to carry out monitoring of these operations to establish the magnitude of releases.

Dry strength agents (product aids)

Function: These chemicals can be added at the wet end or to the paper's surface to improve the strength properties of the paper in dry conditions. They are mainly used for printing and writing paper and to some extent for tissue.

Chemicals: Starch or modified cationic starches are used, as are galactomannans, cellulose derivatives (e.g. carboxymethyl cellulose (CMC)), polyacrylamides, and polyvinyl alcohol (size press only). The dominating type used as dry strength agent is starch or cationic starch.

Emissions and effects: Typically, usage of dry strength agents is 10 kg/ADt at the wet end, where retention is poor at 70-90%, but up to 40-50 kg/ADt at the size press. Starch used in a paper mill is to a certain extent released to the white water system. Thus they are contributing to the BOD load of a paper mill being mostly biodegradable and non-toxic. Those, which can be shown to give the highest retention in the plant, should be used where the constraints of the product allow.

Coating chemicals (product aids)

Function: Application of a so-called coating colour to the finished paper in a separate coating machine has the purpose of giving the paper certain surface properties e.g. higher brightness, opacity, gloss and smoothness.

Chemicals: Coatings are mostly an aqueous mixture of pigment and binders. The white pigments largely determine the quality and the cost of the coating. Pigments usually account for at least 80% of the total dry coating weight. Common pigments used are china clay (kaolin), ground and precipitated calcium carbonate and to a lesser extent calcium sulfoaluminate (satin white) and titanium dioxide. The pigment most often used is coating clay but finely ground grades of calcium carbonate have become particularly important, and the amounts used are now comparable to clay.

The function of the binder or adhesive is to bind the pigment particles to each other and to fix the coat to the base paper. Their proportion by weight in the coating colour amount to 5 - 20% based on the pigment. Binders from water-soluble natural raw materials and non-water-soluble synthetic binders can be distinguished. The most widely applied natural binders are starch and its derivatives and cellulose ethers such as carboxymethyl cellulose (CMC) which are reasonably biodegradable. The use of natural binders is however limited. As synthetic binders polymer dispersions of non water-soluble coating binders as styrene butadiene latex, polyacrylates and polyvinyl acetate are used and with limited acceptance poly vinyl alcohol (PVA). The styrene-butadiene dispersions are most widely used worldwide. Polymer dispersions used as synthetic binders may contain volatile organic compounds as residual monomers up to quite high levels (<1%) typical levels being dependent on the monomer and processes used. There are also stripped products containing very low VOC levels available.

In addition, a variety of auxiliary agents are used in the formulations: dispersing agents to chemically stabilise the slurry towards reagglomeration for the pigments, wet strength agents (hardeners), products for the control of viscosity and water retention, foam-inhibitors and defoamers, optical brighteners, shading dyes, lubricants to improve paper calendaring and biocides. Coating speciality papers could involve the use of solvents, which are partly emitted to air as volatile organic compounds (VOCs). Lubrication agents include ammonium and calcium stearates, waxes and soaps.

It can be concluded that coating colours may be fairly complicated multi-component systems. There are a large number of different compositions.

Emissions and effects: Coating colours are almost all water based. However, where still applied organic solvent-based coatings should be replaced with water-based ones. Where the mass flow is found to be significant VOC-containing emissions should be collected from the various points by a fan system, followed by incineration or combustion in the power boiler.

During normal operation there is no discharge of coating colours. Losses from spills, washing out and from re-pulping of coated broke should be controlled. Some binders have a negative effect on the external effluent treatment plant and therefore appropriate measures should be provided to deal with it (see 6.3.3 and 6.3.6). The most immediate effect of a larger discharge of coating colour is a change of colour of the receiving water.

Optical brighteners or fluorescent whiteners (product aids)

Function: Optical brighteners are added to enhance the white impression of paper by transferring absorbed UV energy into a blue fluorescent light.

Chemicals: These are normally derivatives of 4,4'-diaminostilbene-2,2'-sulphonic acid and are used in many white papers. Optical brighteners are added to the furnish at the wet end, at the size or film press or as component of coating colours.

Potential emissions, environmental effects and possibilities to control releases: Typically, usage is 5-10 kg/ADt and retention poor at 50 - 90%. They are not biodegradable, but will adsorb partly to the sludge of the wastewater treatment plant. That which is released to water bodies will partially photo-degrade (only transformation of the chemical structure). Optical brighteners are weakly/moderately toxic to fish [J. Pöyry, 1994b]. They should be used in the most retentive form and applied at size press where possible. In the production of food packaging paper and

board special attention should be given to the use of optical brighteners. Optical brighteners may contain up to 30% urea as a stabilising agent. When not accounted for, this may result in overdosing of nitrogen in the biological wastewater treatment plant.

Dyes (product aids)

Function: Dyes are added to give a certain colour or tint to the paper.

Chemicals: Dyes are mainly added to the furnish at the wet end but also at the size press. For dyeing of paper nearly exclusively organic dyes are used. Basic, acid and direct dyes and pigment can be distinguished. Dyes used are mainly water-soluble versions of azo, stilbene, di & tri phenylmethane, xanthene, acridine, quinoline, azolidene, oxazolidine, thiazolidine, anthraquinone, indigo and phthalocyanine dyes. In addition all dyes contain one or more additives (inorganic and organic chemicals). There is little use of reactive dyes. Solid pigments (e.g. iron oxides, carbon black) are used for high light-fastness. As they do not form bonds with the fibres, there are high losses to water, which must be abated by sedimentation, flocculation or chemical precipitation. Typically, usage of dyes is from 0.1 kg/ADt for tints, up to 100 kg/ADt for very deep shades.

Potential emissions, environmental effects and possibilities to control releases: The retention varies from 70-98%. Due to the high fibre affinity of basic and direct dyes and the additional use of fixation agents for direct dyes the process water should be free of dyes if dosed carefully. However, for some applications significant emission may occur. It is not possible to give a complete summary of the risks of environmental effects of dyes due to the large number of different substances, and due to the fact that these effects are incompletely known. However, the following should be born in mind:

- Many dyes are known to be toxic to fish and other aquatic organisms
- Dyes are generally known to be hardly biodegradable under aerobic conditions
- Metal ions are incorporated in some dyes.

Where dyes are applied with coatings the coating filter backwash, and the shower water and washout drains in the coating area should be separately collected and membrane technology used to recover the coating colour. The permeate should also be recycled.

Where problems of final effluent toxicity exist despite the above steps, i.e. the effluent has not been rendered harmless, further measures, which can be taken, are:

- Where the dyes (and/or coatings) have been applied at the coating station (i.e. not in the stock), the concentration of these materials in the broke will be high. Consideration should be given to the need to wash the re-pulped broke, before returning to stock preparation, and to treat separately the concentrated washwater.
- Tertiary treatment in the external wastewater treatment.

Dyes which cannot be bleached for re-pulping, either as broke or as wastepaper should be avoided where possible, to minimise waste production.

A wide range of dye additives is incorporated in dye formulations. The majority is either biodegradable or inorganic and might increase the COD. The operator should obtain the information to confirm that this is the case for the formulations employed. Dye fixation agents are often use to support the fixation of direct dyes on the fibres.

Retention aids (process aids)

Function: Retention aids function through a coagulation/flocculation mechanism to increase the retention of particulate solids (fibre, fibre fragments, fines and fillers plus adsorbed chemicals) on the wire. Retention aids reduce the loss of raw materials and increase production.

Chemicals: Most commonly used are synthetic polymers as modified polyacrylamides (PAM), applied at around 0.1-0.5 kg of active ingredient per ADt, and cationic polymers as polyethyleneimines (PEI), (1-2 kg/ADt). Also used are inorganic chemicals as aluminium sulphate (alum), sodium aluminate and polyaluminium chloride. However, they have the drawback to increase the salt content in the white water.

Potential emissions and environmental effects: Overall retention of the retention aids themselves is high (97-99%) and release after treatment is assumed to be low. Typically, retention aids are toxic to water organisms due to their cationicity (stick to the gills of fish) and are not readily biodegradable. The toxicity will be remarkably reduced whenever organic carbon is present as e.g. biomass in the wastewater treatment plant. PEI has moderate biodegradability. While free PEI monomer, is toxic, it largely biodegrades or binds to the biomass in the ETP. Polyacrylamide is non-biodegradable. Free monomer acrylamide has a moderate toxicity to fish but is biodegradable.

Since the main routes for any component of the stock are either to leave with the product or pass down eventually to the effluent treatment plant, the degree of retention of materials into the paper product is important. The best achievable retention varies depending on the product type but the operator should be able to demonstrate that he is using the appropriate retention system for his particular application.

De-foamers (process aids)

Function: De-foamers are used at the wet end of the paper machine and in the preparation of coating colour to prevent foaming and to destroy produced foam respectively. Air causes problems with initial paper sheet formation and may give rise to foaming on the machine, which used to be dealt with by chemical means. De-foamers are used in the main circuit and in aerated wastewater treatment plants.

Chemicals: Substances used are organic compounds with surface-active properties. Mineral and vegetable oil products, fatty acids and derivatives, phosphoric acid esters, higher alcohols and silicone oils are used.

Potential emissions, environmental effects and possibilities to control releases: The main part of the defoamers added to the wet end is probably discharged with the effluent. Defoamers used in coating preparation are mainly added to the paper, or partly evaporated in the dryer.

Depending on the type of chemicals used biodegradability of defoamers is variable. Mineral oil products have a low biodegradability and will be discharged to the water bodies. Only fully biodegradable products with known, safe products of biodegradation should be used. Released to water defoamers have generally low toxicity to fish. However, some chemicals are lipophilic and are likely to bioaccumulate. Spills can suppress bubble formation and the aeration mechanism in aerobic effluent plants. This should be guarded against by means of a suitably engineered handling system.

Dispersion agents and surfactants (process aids)

Function: The tensides, which are also called surfactants, have primarily the function of surface tension reduction. Tensides consist of one hydrophilic and one hydrophobic (lipophilic) part. The process functions of the use of tensides in paper mills are mainly the following:

- Cleaning of felts, wires and machine parts, continuously during production
- Cleaning of water circuit systems, discontinuously during production stops
- Dispersion of ink particles in de-inking of recovered fibres
- Dispersion of resins, slime (agglomerations of bacteria) and other deposits

Chemicals: Tensides and dispersion agents form a very large group of chemicals and a big number of different variations have been used. The group of tensides consists of anionic, cationic and non-ionic types referring to the chemical character of the hydrophilic part of the molecule. As anionic compounds for the hydrophilic group e.g. sulphonate, sulphate or carboxylate can be used, as non-ionic groups e.g. polyoxyethylene, sucrose or peptides), as cationic groups e.g. quaternary ammonium. Compounds of fatty acids, acid soaps or alcohols can also be used as well as paraffine hydrocarbons, olefine hydrocarbons, alkyl benzenes (e.g. nonyl phenol, nonyl phenol ethoxylates and alkyl phenol ethoxylates), naphthalene groups and polymerised propylene oxide. Nonyl phenols are suspected endocrine disruptors. Therefore, the use of nonyl phenol ethoxylates (also as emulsifiers in additives) should be avoided.

Potential emissions, environmental effects and possibilities to control releases: Applied at around 0.5 kg/ADt (of active ingredient), all of the surfactants are potentially harmful by attacking cell structures and most will be discharged to effluent treatment where their biodegradability varies. Therefore, care should be taken in their selection. Biodegradable tensides are available. Operators should demonstrate that they are using only those of very high biodegradability and with known products of biodegradation. Nonyl phenol ethoxylates, which can be decomposed to nonyl phenol should be avoided. Nonyl phenol is a bioaccumulative and toxic compound with low biodegradability. There is also some evidence that some alkyl phenol ethoxylate degradation products show oestrogenic activity. ¹⁵PARCOM has recommended (PARCOM Recommendation 92/8) to phase out industrial cleaning agents that contain nonyl phenol ethoxylates.

Biocides for the incoming water (process aids)

Function: Depending on the water source, treatment of the incoming water may be required. Since often surface water is used for process and cooling water, microorganisms will be entrained in the system. These microorganisms can rapidly colonise the surfaces of pipings and cooling water systems. For biofouling control different possibilities are available many of them using biocides.

Chemicals: Chlorine and sodium hypochlorite are widely used, as are bromine compounds such as hypo-bromous acid.

Emissions and effects: The use of liquid chlorine carries with it the risk of a hazardous release. All of these will result in the production of a wide range of potentially harmful halogenated organics. Clearly the more organics there are in the incoming water the greater will be the generation of these compounds. Therefore, chlorine should not be applied. However, in some cases where surface water is used as process water it might be necessary to apply substances like sodium hypochlorite. Where organics are high, the use of chlorine dioxide can be considered, as there will be less halogenated organics formed. Ozone is another option although it has no residual biocidal action and the exposure hazard due to liberation of ozone gas in closed areas needs to be controlled. The intake water can be pre-treated (e.g. sedimentation, precipitation, filtration). The amount of biocide required for successfully treatment can thus be reduced.

Biocides can have major negative effects on the wastewater treatment plant and the environment. Therefore operators should show how they minimise the use of biocides commensurate with effective biocidal action.

Biocides (slimicides) for the process water circuits (process aids)

Function: Slime is biological matter and connected chemical deposits, anywhere settled in the system. It represents a serious trouble for the good management of the paper mill. It gives staining and holes, making the produced paper more susceptible to breaks with relevant loss of production. The phenomenon is usually controlled by the dosage of biocides (slimicides) which

¹⁵ Renner, R., European bans on surfactant trigger transatlantic debate, *Env. Sci. Technol.* 31 (7), 1997, p. 316-320.

deactivate bacteria, together with dispersion agents. Many mills, but not all, will also routinely wash-up the system.

Chemicals: As active components a large number of different organic chemicals are used as sulfo-organic, bromo-organic and organo-nitrogen compounds as e.g. dithiocarbamates, isothiazolinones, bromohydroxyacetophenone and many others. The biocide formulation may also include dispersants, surfactants and solvents.

Emissions and effects: Applied typically at 30 mg/l in the water circuit, most will be released to the water environment and are inherently potentially harmful, as may be their degradation products. The products that should preferably be used should be selected on the basis of minimising the environmental hazard through an understanding of the products used with regard to degradation, bioaccumulation and de-activation. Furthermore the degradation products should be known. The optimum performance of a biocide is besides others dependent upon half-life and is a compromise between time to degrade, point of application and the quantity of chemical which needs to be added. The aim is to use the minimum biocide to prevent problems between shutdown cleans, rather than to attempt to maintain a "sterile" circuit. The assessment should show that these factors, and any relating to the other substances in the formulation, have been taken into account. The operator's assessment should take into account persistent biocides, which may also end up in the sludge.

Batch cleaning of a machine on shutdown involves the re-circulation of a higher than normal concentration of biocides and system cleaners, usually at elevated temperatures, around the water system. The applicant should show how this concentrated stream is handled to avoid overloading and as a consequence disturbances of the wastewater treatment plant.

Because of some adverse effects in their handling or for environmental reasons other approaches have been proposed as suitable alternatives in anti-slime treatment, for example enzymes, oxidisers (e.g. peroxide), dispersants and biofilm inhibitors (as e.g. ligno-sulfonates). A possible strategy for reducing biocide consumption is to abate slime forming with combinations of dispersants and biocides. Depending on the installed equipment, process-lay out, and product requirements, a considerable reduction in biocide use can be achieved. Also the location of biocide dosing can have a great impact on the quantity of biocides needed. In a few cases, paper mills succeeded in production with total omission of biocides.

ANNEX II EXISTING NATIONAL AND INTERNATIONAL LEGISLATION AND AGREEMENTS

National Emission limits for the production of pulp and paper within the European Union

Environmental limit or guideline systems for pulp and paper industry vary significantly between European countries, despite efforts to create a more uniform system.

Some European countries (e.g. AT, DE, ES, FR, IT, PT) have a permitting system where national legislation/authorities have set general (minimum) limits presenting limits that are to be met all the time. These values are the maximum emissions accepted. Permit authorities can set stricter limits based on the environmental conditions (an Environmental Impact Assessment is usually required for big installations). For each permit adjustment is made by the permitting authorities, based on the local environmental conditions and the technical characteristics of the installation. In other countries (e.g. FI, NL, NO, SE, UK) the limits are based on technically and economically feasible measures on case-by-case basis, considering the environmental conditions. However, the Nordic Countries have also issued policy guidance documents and other means to direct individual permit decisions (e.g. Recommendations of the Nordic Working Group on the pulp and paper industry, National guideline values for the key control parameters).

Permits normally have limit values for emissions and requirements for technical measures (both processes internal and external). In a few countries, permit limits include maximum loads to the environment (kg/d). Emissions can be regulated by limits in concentration (mg/l or mg/m³), specific load (kg/t), and load to the environment (kg/h, kg/d). Generally, emissions must be controlled so that the emission limit is met, and the ambient environment quality standards are not exceeded.

Most countries have separate permitting systems for air emissions, wastewater discharges and solid wastes, but especially after the adoption of the European Union IPPC Directive, a more integrated approach is aimed at.

It is important to note that in European countries the consequences and call for action are different when limit values are not met. The interpretation of the limits can vary e.g. with regard to what kind of exceedence of limits is clear non-compliance that requires action (for instance if a permit limit value is exceeded in a period of 2 hours, a day, ten days, 30 days, a year). There is a difference between limit values that must not be exceeded all time and guideline limits, that can be temporarily exceeded and only continuous exceedance can result in penalties. In some countries only limit values that must not be exceeded all time are considered and any exceedance, even if occasionally happened, is persecuted by law. Therefore, it is of crucial importance to note the framework and legal context of permit limit values, whether they are based on maximum daily values or maximum monthly (or yearly) averages and whether or not penalties in case of non-compliance are foreseen.

Some countries (AT, DE, FR) have issued on the national/federal level sector emission regulations for different types of pulp (e.g. kraft pulp, sulphite pulp, etc.) and paper mills (e.g. coated and uncoated woodfree paper, wood-containing paper, paper based mainly on recycled fibres, etc.). These regulations consider different raw materials, processes and end products. Other countries (e.g. ES, IT, PT) have set general limit values (concentration limits) for paper mills - irrespective of the specific pollution generated. In Italy the limit values are set for the industry as a whole, without focusing on each industrial sector.

As an example for this complex area an overview of discharge limits for emissions to water from some pulp and paper grades in selected countries is given in Table II.1 to Table II.3. The tables are based on the legal requirements and do not consider questions of implementation. The tables contain only values for those countries where data were available or provided. Limits

applicable to bleached kraft pulp are shown in Table II.1, limits for bleached sulphite pulp in Table II.2, and limits for different types of paper mills in Table II.3.

Country	COD	BOD ₅	TSS	AOX	Remarks
Austria	existing: 30 kg/t new/modified: 20 kg/t	existing: 3 kg/t new/ modif.: 2 kg/t	exist: 5 kg/t new: 2.5 kg/t	exist: 0.5 kg/t new: 0.25 kg/t	daily monitoring value ("4 out of 5")
France ¹⁾	exist: 65 (32.5) kg/t new/modif.: 50 (25)kg/t	exist: 3.98 (2.6) kg/t new: 3 (2) kg/t	exist: 6.5 kg/t new: 5 kg/t	1 kg/t (yearly average)	monthly limit value = ½ maxim. daily
Germany ²⁾	exist: 40 kg/t new/modif.: 25 kg/t	exist: 35 mg/l new/ modif.: 30 mg/l	no values (part of COD)	exist: 0.35 kg/t new: 0.25 kg/t	daily monitoring value ("4 out of 5")
Ireland ³⁾	No limit	90% removal or 50 mg/l	No limit	0.1 mg/l	24-h composite sample
Italy ⁴⁾	160 mg/l	40 mg/l	80 mg/l	No requirements	3-h average
The Netherlands ⁵⁾	Not applicable	Not applicable	Not applic.	Not applicable	Not applicable
United Kingdom ⁶⁾	No achievable guidance levels proposed	10 – 50 mg/l	10 – 50 mg/l	< 1.5 kg/t	monthly average
Notes:					
1) The first value always refers to bleached softwood pulp. The values in parenthesis refer to bleached hardwood pulp					
2) Limits under discussion, draft status. No distinction between kraft and sulphite pulp					
3) The limits are set out in the Irish Draft BATNEEC Guidance Note for Pulp and Paper Manufacture					
4) For the main pollutants the Italian legislation fixes emission limit values for emissions to water based on concentration parameters without any distinction of the industrial sector concerned. The values shown in the table are referring to discharges to surface waters. Discharges to the public sewers have to be met other values.					
5) Bleached kraft pulp is not produced in the Netherlands					
6) Achievable releases – new processes. They are usually not generally considered as applicable to existing mills but have to be considered for setting appropriate limits. They are not mandatory release limits. No distinction between different methods of chemical pulping					

Table II.1: Current national discharge limits for production of *bleached kraft pulp*

For countries that do not apply national minimum requirements (e.g. BE, DK, FI, NL, SE) no generally binding limit values are presented. The permit requirements in these countries are set on a case-by-case basis and are site specific. From countries that do have generally binding requirements and are nevertheless not presented in the table no information was provided

Country	COD	BOD ₅	TSS	AOX	Remarks
Austria	existing: 40 kg/t magnefite: 50 kg/t new/modified: 25 kg/t magnefite: 30 kg/t	existing: 3 kg/t new/ modif.: 2 kg/t	exist: 5 kg/t new: 2.5 kg/t	exist: 0.2 kg/t new: 0.1 kg/t	daily monitoring value ("4 out of 5")
France ¹⁾	exist: 45.5 kg/t new/modif.: 35 kg/t	exist: 6.5 kg/t new: 5 kg/t	exist: 6.5 kg/t new: 5 kg/t	1 kg/t (yearly average)	monthly limit value = ½ max. daily
Germany ²⁾	exist: 40 kg/t new/modif.: 25 kg/t	exist: 35 mg/l new/ modif.: 30 mg/l	no values (part of COD)	exist: 0 kg/t	daily monitoring value ("4 out of 5")
Ireland ³⁾	No limit	90% removal or 50 mg/l	No limit	0.1 mg/l	24-h composite sample
Italy ⁴⁾	160 mg/l	40 mg/l	80 mg/l	No requirements	3-h average
The Netherlands ⁵⁾	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
United Kingdom ⁶⁾	No achievable guidance levels proposed	10 – 50 mg/l	10 – 50 mg/l	< 1.5 kg/t	monthly average

Notes:

- 1) The first value always refers to bleached softwood pulp. The values in parenthesis refer to bleached hardwood pulp
- 2) Limits under discussion; draft status. No distinction between kraft and sulphite pulp
- 3) The limits are set out in the Irish Draft BATNEEC Guidance Note for Pulp and Paper Manufacture
- 4) For the main pollutants the Italian legislation fixes emission limit values for emissions to water based on concentration parameters without any distinction of the industrial sector concerned. The values shown in the table are referring to discharges to surface waters. Discharges to the public sewers have to be met other values.
- 5) Bleached sulphite pulp is not produced in the Netherlands
- 6) Achievable releases – new processes. They are usually not generally considered as applicable to existing mills but have to be considered for setting appropriate limits. They are not mandatory release limits. No distinction between different methods of chemical pulping

Table II.2: Current national discharge limits for production of *bleached sulphite pulp*

For countries that do not apply national minimum requirements (e.g. BE, DK, FI, NL, SE) no generally binding limit values are presented. The permit requirements in these countries are set on a case-by-case basis and are site specific. From countries that do have generally binding requirements and are nevertheless not presented in the table no information was provided

Country	COD	BOD ₅	TSS	AOX	Remarks
Austria ¹⁾	existing: 2-5 kg/t (incl. mechan./RCF pulping)	existing: 20-25 mg/l	exist: 50 mg/l	exist: 10-30 g/t	daily monitoring value ("4 out of 5")
France	exist: 4-8 kg/t new/modif.: 2.5 - 4 kg/t	exist: 1 - 2 kg/t new: 0.7 kg/t	exist: 1.5 kg/t new: 0.7 kg/t	---	monthly limit value = ½ maxim. daily
Germany ¹⁾	exist: 2-6 kg/t (incl. mechan./RCF pulping)	exist: 25 mg/l	no values (part of COD)	exist: 10-40 g/t	2-h composite sampling ("4 out of 5")
Ireland ²⁾	No limit	90% removal or 50 mg/l	No limit	0.1 mg/l	24-h composite sample
Italy ³⁾	160 mg/l	40 mg/l	80 mg/l	No requirements	3-h average
The Netherlands ⁴⁾	200 mg/l	20 mg/l	30 mg/l	No emission standards	24-h composite sample
United Kingdom ⁵⁾	No achievable guidance levels proposed	10 – 50 mg/l	10 – 50 mg/l	< 1.5 kg/t	monthly average

Note:

- 1) Special paper with more than one change of type per working day, highly comminuted paper or vegetable parchment have higher limits. Where ranges are presented they depend on the paper grade produced
- 2) The limits are set out in the Irish Draft BATNEEC Guidance Note for Pulp and Paper Manufacture
- 3) For the main pollutants the Italian legislation fixes emission limit values for emissions to water based on concentration parameters without any distinction of the industrial sector concerned. The values shown in the table are referring to discharges to surface waters. Discharges to the public sewers have to be met other values.
- 4) In the Netherlands permit requirements are site specific. Therefore, typical emission standards are given for mills with a biological treatment plant on site. The data shown in the table refer to the average values of the rolling average of 10 samples. Typical maximum values after biological treatment are: 300 mg/l COD; 30 mg/l BOD; 60 mg/l TSS.
- 5) Achievable releases – new processes. They are usually not generally considered as applicable to existing mills but have to be considered for setting appropriate limits. They are not mandatory release limits. No distinction between different types of fibres or paper grades that are manufactured in a paper mill

Table II.3: Current national discharge limits for production of paper

For countries that do not apply national minimum requirements (e.g. BE, DK, FI, SE) no generally binding limit values are presented. The permit requirements in these countries are set on a case-by-case basis and are site specific. From countries that do have generally binding requirements and are nevertheless not presented in the table no information was provided

When comparing the limit values, it should be noted that the averaging time for the limits might be different from one country to another, e.g. daily, monthly, yearly averages, as are to a certain extent the analysis methods and reference conditions. Compliance criteria might also vary. Some countries have set different limit values for new and existing mills (e.g. AT, FR, DE). More stringent limits may apply in specific cases according to decisions of the permitting authority and needed to meet water quality standards.

For further information on limit values to other media (e.g. air, waste) and on environmental matters that are regulated in pulp and paper industry in European countries it is referred to a comprehensive study of the OECD that has been published at the end of 1999.¹⁶ This study is based on a series of Country Profiles, which describe the permitting procedures of the ten individual countries. The countries examined are Austria, Belgium (Wallonia), Canada, Finland, Germany, New Zealand, Norway, Sweden, Switzerland, and the United States of America. The final report provides an analysis of the environmental permitting of bleached chemical pulp and paper mills in the ten countries studied. The report describes the regulatory responsibility and procedures applied in permitting; the use of emission standards and limit values; the consideration given to best available technology (BAT) and environmental quality objectives (EQOs) when setting permit conditions; the technological response of mills to the permit conditions; and the views of the mills on the permitting process applied in their country.

¹⁶ OECD. Environment Directorate, Environmental Requirements for Industrial Permitting, Case Study on the Use of Best Available Technology (BAT) and Environmental Quality Objectives (EQOs) in the Environmental Permitting of Bleached Chemical Pulp and Paper Mills, Paris, France.

Readers are also referred to three other volumes dealing with "Environmental Requirements for Industrial Permitting" that have been published by the OECD in 1999.¹⁷

International Co-operation for the Protection of the Marine Environment

PARCOM (North Sea and North East Atlantic)

The PARIS Commission (PARCOM) was established by the Convention for the Prevention of Marine Pollution from land-based sources ("The Paris Convention"). On 25 March 1998 the OSPAR Convention entered into force. It supersedes both the Oslo Convention and Paris Convention. However, Decisions, Recommendations and all other agreements adopted under those Conventions will continue to be applicable, unaltered in their legal nature, unless they are terminated by new measures adopted under the OSPAR Convention. Consequently, the PARCOM Decisions and Recommendations for the the Pulp and Paper Industry mentioned further below are still in force under the new Convention.

The Convention for the Protection of the Marine Environment of the North-East Atlantic ("OSPAR Convention") has been signed and ratified by all of the Contracting Parties to the Oslo or Paris Conventions (Belgium, Denmark, the Commission of the European Communities, Finland, France, Germany, Iceland, Ireland, the Netherlands, Norway, Portugal, Spain, Sweden and the United Kingdom of Great Britain and Northern Ireland) and by Luxembourg and Switzerland.

According to the OSPAR Convention, Contracting Parties shall "take all possible steps to prevent and eliminate pollution", including "the necessary measures to protect the maritime area against the adverse effects of human activities". Towards this end, Parties adopt programmes and measures and harmonise their policies and strategies. The OSPAR Commission has adopted a number of decisions and recommendations. An OSPAR decision is binding after a period of 200 days after its adoption has expired for those parties that voted for it. OSPAR recommendations have no binding force. So far, the work programme focused on the development of recommendations and decisions to better define the concept of BAT for specific sectors.

The following binding PARCOM Decisions with regard to the pulp and paper industry have been made:

- PARCOM Decision 96/2 on the Phasing-Out of Processes Using Molecular Chlorine (Cl₂) in the Bleaching of Kraft and Sulphite Pulp, adopted June 1996
- PARCOM Decision 95/2 on Discharge and Emission Limit Values for the Integrated and Non-integrated Sulphite Paper Pulp Industry, adopted June 1995
- PARCOM Decision 95/3 on Discharge and Emission Limit Values for the Integrated and Non-integrated Kraft Pulp Industry, adopted June 1995

The following PARCOM Recommendations with regard to the pulp and paper industry have been made:

- PARCOM Recommendation 94/2 on Best Available techniques and Best Environmental Practice for the Integrated and Non-integrated Sulphite Paper Pulp Industry, adopted June 1994
- PARCOM Recommendation 94/3 on Best Available techniques and Best Environmental Practice for the Integrated and Non-integrated Kraft Pulp Industry, adopted June 1994

A description of BAT and BEP with additional background information for the sulphite and kraft pulp industry can be found in OSPAR 1994, Industrial Sectors: Best Available Techniques (BAT) and Best Environmental Practice (BEP) Series. Progress reports on implementation are published in regular terms.

¹⁷ OECD. 1999. Environmental Requirements for Industrial Permitting: Vol.1 - Approaches and Instruments; Vol.2 - OECD Workshop on the Use of Best Available Technologies and Environmental Quality Objectives, Paris, 9-11 May 1996, Vol.3 - Regulatory Approaches in OECD Countries, ISBN 92-64-16193-7, see also www.oecd.org.

There are no PARCOM recommendations or decisions on BAT for paper mills but only on chemical pulp mills. The decisions, recommendations as well as additional information is available on the Internet at: www.ospar.org.

HELCOM (Baltic Sea)

The first Convention on the Protection of the Marine Environment of the Baltic Sea Area was signed in 1974 by the coastal states of the Baltic Sea at that time. In 1992, a new Convention was signed by all the countries bordering on the Baltic Sea and by the European Economic Community. The governing body of the Convention is the Helsinki Commission - Baltic Marine Environment Protection Commission - also known as HELCOM. The present contracting parties to HELCOM are Denmark, Estonia, European Community, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden. The Helsinki Convention of 1974, issued to protect the marine environment of the Baltic Sea, was the first international agreement to cover all sources of pollution reaching the Convention Area, both from land and from ships as well as airborne. To accomplish its aim, the Convention calls for action to curb various sources of pollution of the Baltic Sea. The Helsinki Convention contains provisions defining Best Available Techniques which are very similar to those of the OSPAR Convention. Decisions taken by the Helsinki Commission - which are reached unanimously - are regarded as recommendations to the governments concerned. They carry considerable moral and political weight.

The Helsinki Commission has forwarded a number of recommendations concerning the emissions from pulp and paper industry:

- HELCOM Recommendation 16/4 Reduction of Emissions into the Atmosphere from the Pulp and Paper Industry, adopted March 1995
- HELCOM Recommendation 17/8 Reduction of Discharges from the Kraft Pulp Industry, adopted March 1996
- HELCOM Recommendation 17/9 Reduction of Discharges from the Sulphite Pulp Industry, adopted March 1996
- A HELCOM Recommendation on the Reduction of Discharges from the Production of Mechanical Pulp, Thermo-Mechanical Pulp, Chemi-Thermo-Mechanical Pulp, Recycled Pulp and Paper and Board Manufacturing is in a draft status.

An overview of limit values recommended by the different decisions and recommendations is shown in Table II.4 for sulphite pulp mills and Table II.5 for kraft pulp mills.

	Limit values as yearly average, kg/tonne of air dry pulp (90% dry solids)			
	Existing mills, within 31-12-99 (OSPAR), within 01-01-2000 (HELCOM)		New mills, or capacity increased by more than 50% after 31-12-1996 (OSPAR) or 1- 01-1997 (HELCOM)	
	OSPAR	HELCOM ³	OSPAR	HELCOM ³
COD	80	70	35	35
TSS	8.0	---	4.5	---
AOX	---	0.5	---	0.1
Tot-P	---	0.08	---	0.04
Tot-N	---	0.06	---	0.4
SO₂	5.0 ¹	3.0 ²	3.0 ¹	---
NO_x	2.5 ¹	---	1.5 ¹	---

Note:

- 1) In OSPAR the air limits for sulphite pulp and paper mills cover only SO₂, and NO_x from recovery boilers but exclude emissions from auxiliary boilers.
- 2) The recommended limit value originally is 1.5 kg S/Adt; it has been converted to kg SO₂/Adt to render the values easier to compare. No separate value for new mills is recommended

Table II.4: Paris and Helsinki Commission limit values (yearly average) for integrated and non-integrated bleached sulphite pulp and paper industry

	Limit values as yearly average, kg/tonne of air dry pulp			
	Existing mills, within 31-12-99 (OSPAR), within 01-01-2000 (HELCOM)		New mills, or capacity increased by more than 50% after 31-12-1996 (OSPAR) or 1-01-1997 (HELCOM)	
	OSPAR	HELCOM ³	OSPAR	HELCOM ³
COD	50	30	30	15
TSS	8.0	---	4.0	---
AOX	---	0.4	---	0.2
Tot-P	---	0.04	---	0.02
Tot-N	---	0.4	---	0.35
SO₂-S	2.0 ¹	1.0 ²	1.0 ¹	---
NO_x	2.0 ¹	---	1.5 ¹	---

Notes:

- 1) In OSPAR the air limits for SO₂, and NO_x for kraft pulp mills apply to the sum of such emissions from recovery boilers, lime kilns and installations, if any, for separate combustion of strong odorous gases. Gaseous Sulphur (S) means sulphuric compounds calculated as S.
- 2) In HELCOM atmospheric emissions include all relevant sources except those from auxiliary boilers. No separate value for new mills is recommended
- 3) All analysis of effluents should be made on unsettled, unfiltered samples.

Table II.5: Paris and Helsinki Commission limit values (yearly average) for integrated and non-integrated bleached kraft (sulphate) pulp and paper industry

United States: The Pulp and Paper Industry "Cluster Rules"

In November 1997 the US EPA has finalised a new set of federal guidelines, the so-called cluster rules. The guideline is very complicated and contains limits for 12 different types of mills each of them distinguished by four different technical levels:

- Effluent limitations representing the degree of effluent reduction attainable by the application of the Best Practicable Control Technology Currently Available (BPT). The limit values must be achieved by any existing point source and comprise basic parameters like BOD₅, TSS and pH
- Effluent limitations representing the degree of effluent reduction attainable by the application of the Best Conventional Pollutant Control Technology (BCT). They can be required for conventional pollutants like BOD₅ and TSS (if justified) and are in practice usually the same as BPT.
- Effluent limitations representing the degree of effluent reduction attainable by the application of the Best Available Technology Economically Achievable (BAT) used for controlling of toxic and non-conventional pollutants as e.g. chlorophenolic-containing biocides.
- New Source Performance Standards (NSPS) are used for new plants combining BAT for non-conventional and conventional pollutants.

Limit values are given as pollutant load expressed as kg pollutant per tonne of product distinguishing maximum values for any 1 day and average values of daily values for 30 consecutive days.

For discharges of toxic pollutants as e.g. chlorophenolic-containing biocides into a publicly owned treatment works (POTW) the mill must achieve Pre-treatment Standards for Existing Sources (PSES) and Pre-treatment Standards for New Sources (PSNS).

The regulations apply to any pulp, paper, or paperboard mill that discharge process water pollutants to waters or into a publicly owned treatment works. The following table presents the codified subcategorization scheme. For each mill category effluent limitations to discharges are given:

Subcategory	Types of products covered in the subpart. Within each subcategory different limit values are given
Dissolving Kraft Pulp	Dissolving pulp at kraft mills
Bleached Papergrade Kraft and Soda	Production of market pulp at bleached kraft mills; integrated production of paperboard, coarse paper and tissue paper at bleached kraft mills; integrated production of pulp and fine papers at bleached kraft mills and the integrated production of pulp and paper at soda mills
Unbleached Kraft Pulp	Pulp and paper at unbleached kraft mills including linerboard or bag paper and other mixed products; pulp and paper using the unbleached kraft neutral sulphite semi-chemical (cross recovery) process
Dissolving Sulphite Pulp	Pulp at dissolving sulphite mills for the following grades: nitration, viscose, cellophane and acetate
Papergrade Sulphite Pulp (Ca ²⁺ , Mg ²⁺ - or Na ⁺ -based pulps, NH ₄ ⁺ -based pulps, speciality grade pulps)	Pulp and paper at papergrade sulphite mills where blow pit pulp washing techniques are used and pulp and paper at papergrade sulphite mills where vacuum or pressure drums are used to wash pulp
Semi-Chemical Pulp	Pulp and paper at semi-chemical mills using an ammonia base or a sodium base
Mechanical Pulp	Pulp and paper at groundwood chemi-mechanical mills; pulp and paper at groundwood mills through the application of the thermo-mechanical process; pulp and coarse paper, molded pulp products and newsprint at groundwood mills; pulp and fine paper at groundwood mills
Non-Wood Chemical Pulp	Pulp and paper at non-wood chemical pulps
Secondary Fibre, Deink	Pulp and paper at deink mills including fine papers, tissue papers or newsprint
Secondary Fibre, Non-Deink	Paperboard from wastepaper from non corrugating medium furnish or from corrugating medium furnish; tissue paper from wastepaper without deinking at secondary fibre mills; molded products from wastepaper without deinking; builders' paper and roofing felt from wastepaper
Fine and Lightweight Paper from Purchased Pulp	Fine papers at non integrated mills using wood fibre furnish or cotton fibre furnish; lightweight papers at non integrated mills or lightweight electrical papers at non integrated mills
Tissue, Filter, Non-Woven and Paper-Board from Purchased Pulp	Tissue papers at non integrated mills; filter and non-woven papers at non integrated mills; paperboard at non integrated mills

Table II.6: Subcategorization Scheme of the US Pulp and paper Industry "Cluster Rules"

Compared to recent permit requirements in Europe, the limitations for existing mills set in the US cluster rules are lenient. But, to encourage individual mills to achieve greater reductions beyond the requirements of the rules, EPA is setting up a voluntary incentives program. Mills volunteering for the program will be subject to more stringent reductions and, in return, receive rewards for their participation, such as additional compliance time. The so-called "Ultimative Voluntary Advanced Incentives Program BAT Limitations" which must be achieved six (Tier I), eleven (Tier II) and sixteen years (Tier III) from the date of publication of the cluster rules are comparable most easily with the BAT Reference Values compiled in the BREF. For some subcategories the New Source Performance Standards (e.g. for BOD₅ and AOX) are also comparable to emission levels observed at existing mills in Europe.

The rules and additional information are available on the Internet at:
www.epa.gov/ostwater/pulppaper/reg.html.

Canada

Canada has two levels of legislation and authorities: the state and the provinces. The national legislation/authorities set general guidelines, but the actual limits and guidelines can be different in each province. Most provinces require that an Environmental Impact Assessment (EIA) needs to be conducted when building or expanding pulp and paper mills, and this EIA has an influence on the actual limits.

The wastewater limit systems in Canada are mostly based on load kg per tonne production. Different limits are applied for different types of mills. Some parameters can be measured as concentrations. Toxicity limits are also used. During the past few years the Canadian limits for pulp and paper mills have been developed, e.g. to include toxic substances, such as dioxins and furans.

Air pollution control in the Canadian mills is based on achieving ambient air quality standards. Emission limits are typically given to main parameters and main emission sources (e.g. SO₂ from recovery boiler).

Asia

Indonesia is one of the most important pulp and paper producing countries in Asia. It has a fairly developed environmental permit system with environmental impact assessments for major industrial plants. Two sets of national wastewater standards have been issued one to be applied by the year 1995 and the other by the year 2000. The limits are expressed both as concentration limits and as specific load (kg/t), also use of water is limited (m³/t). The new limits have been given for seven types of pulp mills and four types of paper mills.

There are national standards for atmospheric emissions from various sources in a pulp mill, expressed as mg/m³. The permit authority can issue stricter limits in certain areas. The world class pulp and paper mills in Indonesia tend to follow international guidelines for their environmental control systems.

South America

Brazil is the most important producer of pulp and paper in South America, and serves often as a model for other countries in the region. The Brazilian authorities tend to follow the US EPA guidelines when setting the environmental limits to the mills.

Effluent limits cover conventional parameters and are usually expressed as maximum specific loads (kg/t). Limits for modern mills are relatively strict.

Also the limits for gaseous emissions are relatively strict for new mills. Concentration limits are issued for main sources, and technological requirements (e.g. collection of malodorous gases) are often presented in the permits.

ANNEX III MONITORING OF DISCHARGES AND EMISSIONS IN EUROPEAN PULP AND PAPER MILLS

For more detailed information than presented below it is referred to the parallel ongoing work on a BREF "monitoring of emissions".

Analytical methods within the European Union

Current legislation in Europe requires that pulp and paper mills monitor emissions to water and air. Analysis of solid waste fractions and noise levels are usually also monitored and controlled. Monitoring practices vary between European countries to a certain extent because applied analytical methods including sampling and calculation of results are normally not fully harmonised. Therefore, the comparability of the results of measurements can not be guaranteed. On the other hand, in most European countries there are national standards available for parameters most relevant to emissions to water and atmosphere. This means that these methods are validated for the specific purpose and minimum requirements with regard to accuracy are met independent on the technical details of the analytical procedures, which are used. However, in case of group parameters such as TSS, COD, BOD, AOX, which can be considered operationally defined by the analytical procedure applied, a strong need for harmonisation on the European level is obvious. This is reflected by the activities of the technical Committee 147 Water quality of the International Standardisation Organisation ISO and the technical Committee 230 of the European Standardisation Organisation CEN which have already published appropriate standards or are working at it, respectively. To get a clearer picture about the comparability and accuracy of data presented in this document a brief overview of the methods in use within the European Union is given below. Nevertheless, it has to be stressed that the whole analytical methodology chain starting from sampling, analysing and calibration to reporting results has to be assessed to get a reliable information on main sources of errors and the comparability of data.

1. Comparison of wastewater discharge measurements

Typical wastewater monitoring parameters to be analysed for pulp and paper mills are as follows:

Wastewater flow, total suspended solids (TSS), temperature, chemical oxygen demand (COD_{Cr}), biochemical oxygen demand (BOD₅ or 7), total phosphorus (P), total nitrogen (N), pH, conductivity, adsorbable organically bound halogens (AOX) and toxicity. Also other parameters such as TOC, chlorate, EDTA/DTPA, and metals are monitored in some cases. Some of these measurements are highlighted in the following.

Chemical oxygen demand (COD)

Chemical oxygen demand in wastewater is measured as the corresponding oxygen consumption during oxidation with dichromate (COD_{Cr}). COD is determined in unsettled and unfiltered samples. The principle of COD_{Cr} is to add a known amount of dichromate to a certain volume of the water sample and heat the mixture for 2 h. Part of the dichromate will react with oxidisable compounds in the sample, and finally the remaining dichromate is determined, titrimetrically (Standard Method) or photometrically. The COD_{Cr} value is calculated based on the amount of dichromate reduced, and the result is expressed in mg O₂/l. The photometric methods (e.g. Dr. Lange, HACH, WTW) have simplified the COD_{Cr} analysis and have been approved by authorities in most countries as an equivalent alternative to the more complicated standard method.

The methods in use in European countries seems to be very similar but are referred to with different terms (e.g.: DIN 38 409-H41, BS 6068: Section 2.34, SFS 3020, SS 02 81 42). They are all based on the principles described in ISO-Standard 6060: 1989 Water quality - Determination of the chemical oxygen demand. The minor differences between the methods are not expected to give any significant differences between analytical results. In some cases COD

is analysed on filtered samples. This has to be considered in the assessment of the results because it can influence them significantly if a considerable amount is retarded on the filter.

Biochemical oxygen demand (BOD)

BOD is related to the content of substances that can be biochemically oxidised. The object is to measure the oxygen consumption, when substances in the sample are degraded by bacteria. BOD can be seen as the easily degradable part of COD. BOD is determined in unsettled and unfiltered samples.

The water sample is diluted with dilution water containing a seed of aerobic microorganisms. The dissolved oxygen concentration is determined before and after incubation during 5 days (in a few countries 7 days). Incubation takes place at a controlled temperature (20°C) in the dark, and in a completely filled and closed bottle. Generally, BOD is sensible to errors (dilution factor, time of storage, temperature, etc.). The oxygen content can be measured by either titrimetric or electrometric methods. BOD is the reduction in oxygen content and expressed as mg O₂/l

There are minor differences between the European countries although they are referred to with different terms or references (DIN 38 409-H51, BS 60 68: Section 2.14, SFS 5508, SS 02 81 43). All methods seem to be close to the ISO method and are based on the principles described in ISO-Standard 5815: 1989 Water quality - Determination of the biochemical oxygen demand after 5 days, dilution and seeding method. There are slight differences in practice as e.g. concerning seeding water used or the incubation flask volumes. There is no reasonable suspicion that those differences will have a significant influence on the analytical results.

Most countries apply the 5-day BOD, BOD₅, but Nordic countries use 7 days incubation time. According to investigations of the Finnish Environment Institute for pulp and paper mill effluents BOD₇ corresponds to 1.16 times BOD₅ (i.e. BOD₅ of 25 mg/l corresponds to a BOD₇ value of 29 mg/l).

Since 1998 a European standard method for determination of BOD exists: EN 1899-1 "Dilution and seeding method with allylthiourea addition".

Total suspended solids (TSS)

Suspended solids are particles that are suspended, i.e. they are able to settle in stagnant water. They consist of small fibre fragments, fillers, fines, non-settled biological sludge (agglomeration of microorganisms), and other small particles down to about 1 µm in size. The smallest of these particles settle very slowly under normal conditions and approach the area of colloid particles (< 0.4 µm).

Analysis of suspended solids is made by filtering a known volume of water through a filter with approximately defined pore size using vacuum suction, and then weighing the dry solids retarded on the filter. The type of filter used depends on the aim of the analysis. Depending on whether the objective is to find out the quantity of fibres and coarse particles (EN 871, determination of coarse particles and fibre with wire cloth with mesh width between 60-70 µm) or the quantity of all particles (EN 872, total suspended solids) different filters are required. Most countries use glass fibre filters, which approximately give the TSS value.

Today there is an international standard method for determination of suspended solids by filtration through glass-fibre filters (ISO 11923: 1997). There is also a European Norm EN 872 on determination of suspended solids. However, this norm does not specify a definite pore size for the glass fibre filters. In Germany for instance, filters with pore size between 0.3-1 µm are used according to DIN-EN 872. Glass fibre filter type Whatman GF/A (1.6 µm) or GF/C (1.2 µm) are suitable filters to determine the amount of total suspended solids (TSS) from pulp and paper mills.

Members of the TWG expressed uncertainty whether or not there are relevant differences in the analyses of suspended solids in different countries and whether TSS emissions in Europe are comparable. Therefore Table III.1 shows some information regarding the standard methods used for the analyses of suspended solids within the European Union. A specification what filters are used is also included [information provided by TWG Members].

Country	Analytical method	Parameter	Filter type	Comments
Austria	ÖNORM EN 872	Total suspended solids	Glass fibre filter	according to EN 872
Belgium	No information provided			
Denmark	DS 207	Total suspended solids	No information provided	
Finland	SFS-EN 872	Total suspended solids	Glass fibre filter	replaces SFS 3037
France	NF T 90 105	Total suspended solids	No information provided	
Germany	DIN EN 872	Total suspended solids	Glass fibre filter (0.3-1 µm)	according to EN 872
Greece	No information provided			
Ireland	B7 (unpublished in-house method based on the standard method)	Total suspended solids	Glass fibre filter	Based on APHA/AWWA Section 2540 D 19 th ed.
Italy	IRSA CNR N.2 2050	Total suspended solids	0.45 µm filter	
Netherlands	NEN 6484	Total suspended solids	0.45 µm filter	
Norway	NS 4733	Total suspended solids	Glass fibre filter GF/A	
Portugal	No information provided			
Spain	NFT 90-105	Total suspended solids	No information provided	
Sweden	SS 02 81 12 SS 02 81 38	Total suspended solids Coarse particles incl. fibre	Glass fibre filter (GF/A) 70 µm wire cloth	equals to DS 207 and SFS 3037
United Kingdom	No information provided			
Note: After publication of a European Standard (EN) the Member States are liable to publish it as national standard identical in content and presentation or to issue a national endorsement notice. National standards, which are contrary to the EN, have to be withdrawn.				

Table III.1: Standard methods for the analysis of Total Suspended Solids (TSS) within the European Union

Adsorbable Organically Bound Halogens (AOX)

In many countries AOX has been approved as a standard method to determine the total organically bound chlorine in pulp and paper mill effluents (the presence of other halogens than chlorine is insignificant in those wastewaters). In Scandinavia AOX is analysed according to the Scandinavian Pulp, Paper and Board Testing Committee standard method, SCAN-W 9:89, and often referred to as the "shaking method". The principle is to adsorb the organic constituents of the sample on activated carbon, separate the carbon from the sample by filtration, and burn the carbon with oxygen in a special AOX apparatus. HX are formed from the originally organically bound halogen and absorbed in an electrolyte in which they are determined by microcoulometric titration. The result is expressed as chloride in mg Cl/l.

The corresponding German AOX method, DIN 38409, H14, is basically very similar to the Scandinavian method. Since 1998, there is an ISO standard (ISO 9562:1998) and also the European Norm, EN 1485 - Determination of adsorbable organically bound halogens, available. Supposed that there is sufficiently qualified staff in the laboratory the minor differences between methods applied are not expected to give significant differences between analytical values.

Conclusions

There are minor differences between measurement methods for wastewater discharges from pulp and paper mills in European countries although the methods are referred to with different terms or references. All methods seem to be close to ISO methods and are based on the similar (or same) principles. It is therefore not expected that these minor differences will give significant variations of analytical values. Other matters as sampling methods, handling and storage of samples, sufficient qualification of staff, and measures of internal and external quality assurance in the analytical laboratories seem to have a much higher influence on the results than the differences in measurement methods used. But these factors might not only lead to

significant differences of the results of measurements of paper mill effluents between countries but also within a country.

Finally the frequency of samplings taken to determine environmental performances of mills as well as the reference periods (time intervals) from which the actual emission is computed (daily, monthly, yearly average) are expected to have a significant influence on the results (see ANNEX IV: Examples for variations of emissions).

2. Comparison of measurements of atmospheric emissions

In pulp and paper industry, emissions into the air originate from both the process and energy production. Process emission sources of kraft pulp mills are mainly the recovery boiler, the lime kiln and the cooking department. Other emission sources are e.g. bleaching, washing filters, the evaporation plant, the dissolving tank, the chip bin, and manufacturing of pine oil. Emissions in paper mills are mainly due to the flue gases from energy production. Energy production emission sources at a pulp and paper plant are the multi-fuel furnace or the bark boiler. At RCF paper mills, which are operating de-inking plants for recovered paper processing various sludge may be incinerated in a solid fuel boiler.

Typical waste gas monitoring parameters to be analysed at pulp and paper mills are as follows: Gas flow, sulphur oxides (sulphur oxides expressed as SO₂), nitrogen oxides (expressed as NO₂), particulates/dust, total reduced sulphur (TRS), and H₂S. In some cases or at certain intervals also carbon monoxide, chlorine, and polychlorinated dibenzodioxins, dibenzofuranes (PCDD/PCDF) are analysed as are HCl for sludge burning boilers. Some general aspects to consider and commonly used measurements are highlighted in the following.

Frequency of measurement, sampling, flue gas flow rate and emission calculation

Continuous measurements

Continuous measurements are carried out by the operators of the plant itself. The availability of monitoring time is regarded sufficient when the continuous emission monitoring is operative at least 90 % of the annual operating time. The results show total annual emissions as well as temporal variations of the emission during the operation.

In pulp mills sulphur dioxide, TRS, particles and carbon oxides are normally measured continuously. Continuous measurements are carried out when the flue gas flow is significant as it is for emissions from the recovery boiler, the lime kiln, the handling system for non condensable gases and energy production boilers. Continuous NO_x emission measurements are only applied in some countries (e.g. Sweden, Finland) as e.g. for recovery boilers or big steam boilers. As there is no reliable continuous measurement system for flue gas volume flow at present, there are certain difficulties in making the periodical values to describe the varying process situations. However, the flow can in many cases, e.g. recovery boilers and lime kilns, be calculated from fuel data.

Sampling and sample treatment are usually the weakest points of the measurements. Problems can occur in taking a representative gas sample. Instructions for choosing of the measurement point and instructions for sampling are presented in various standards. The measurements themselves are usually carried out according to currently valid standards (based on the related international or foreign standards) or type proved measurement equipment. ISO and CEN have published several standards and standard proposals for calibration.

Periodical/discontinuous measurements

Periodical measurements are used for small and separate emission sources. They are carried out as manual single measurements or as short period. Periodical emission measurements can be carried out once a week or once a month (and in special cases also once a year as e.g. for dioxin, furan) for the following emission components: SO₂, TRS, CO, CO₂, NO_x, Cl and particles, in some cases also for dioxin, furans and HCl emissions from sludge burning boilers according to the standard methods used in the given country. Chlorine compounds (Cl₂, ClO₂)

that can be determined in the bleaching chemical preparation area and in the removal vapours of the bleaching procedures are also measured periodically. Periodical measurements give the state of emissions over the chosen sampling time.

Parameters needed in every emission calculation, such as volume flow, temperature, oxygen content and humidity of the fume, are also determined at periodical measurements.

If the intention with discontinuous monitoring is to give a reliable picture of the total emissions over a certain period, e.g. a day, a month or a year it is crucial to have a statistically well founded number of samples. If the total emissions are counted on the basis of a few samples representing only a minor part of the total production time, they are likely to represent poorly the real situation. This is due to the fact that processes are not steady and prevailing process conditions, disturbances in processes etc. may affect significantly the results.

Flue gas flow rate

If the total or product specific emissions (e.g. kg SO₂/Adt) are to be determined the quality of measuring or calculating the flue gas flow is of crucial importance. If this is not done properly, also good quality of the analysis of the emission parameter can not give a realistic picture of the situation. If the aim is to determine the concentration of the component in the flue gas, only the flow of the sample gas has to be known, besides the mass of the substance to be determined.

Emission calculation

Material balance calculations may be used to supplement emission measurements in order to check the results of measurements as well as to create a general view of the total emission level of each component. Sometimes, the amount of diffuse emissions that is not recorded by emission measurements can be substantial (e.g. TRS emission of kraft pulp mills) and can be approximated by material balances of sulphur. A material balance calculation gives an impression of the expected magnitude of the emission of a specific substance but cannot show (or even replace) accurate measurements. Therefore, the usefulness of theoretical emission calculation for determination of environmental performance levels is questionable. Material balance calculations are often based on evaluated process flows and measured concentrations. However, if only little basic information is determined by measurements, possible errors may accumulate in the final results. Calculating of a reliable average emission levels for a plant means long term monitoring of the processes and statistical examination.

Sulphur oxides (SO₂), Nitrogen oxides (as NO₂) and particulates/dust

The atmospheric emissions from pulp and paper mills cover mainly classical pollutants as also released from power boilers: sulphur oxides, nitrogen oxides and particulates. In kraft pulp mills, additionally there are above all TRS emissions to consider that are released from a few main emission sources and a couple of others sources in lower concentrations (diffuse emissions).

International norms for determination of major air pollutants are worked out by the International Standard Organisation' s Technical Committee and the European Standardisation Organisation CEN. ISO standards for stationary source emissions and European Standards which have been published so far are shown in Table III.2. These standards normally include sampling and measurement. To a large extent, these standards have been adopted as national norms.

Number	Year of publication	Measured parameter	Remarks
ISO 7934	1989	Determination of the mass concentration of sulphur dioxide - Hydrogen peroxide/barium perchlorate/Thorin method	discontinuous measurement, note also amendment 1
ISO 11632	1998	Determination of mass concentration of sulphur dioxide - Ion chromatographic method	
ISO 7935	1992	Determination of the mass concentration of sulphur dioxide - Performance characteristics of automated measuring methods	
ISO/DIS 11564	1996	Determination of mass concentration of nitrogen oxides - Naphthylethylenediamine photometric method	
ISO 10849	1996	Determination of the mass concentration of nitrogen oxides - Performance characteristics of automated measuring systems	
ISO 10396	1993	Sampling for the automated determination of gas concentrations	
ISO 10780	1994	Measurement of velocity and volume flow rate of gas streams in ducts	discontinuous measurement
ISO/DIS 14164	1997	Determination of volume flow rate of gas streams in ducts - Automated method	
ISO 9096	1992	Determination of concentration and mass flow rate of particulate material in gas-carrying ducts - Manual gravimetric method	discontinuous measurement
ISO 10155	1995	Automated monitoring of mass concentrations of particles - Performance characteristics, test methods and specifications	
EN 1911	1998	Manual method of determination of HCl	
EN 1948	1996	Determination of the mass concentration of PCDDs/PCDFs	
Abbreviations: DIS = Draft International Standard; ISO = International Standard; prEN = draft European Standard; EN = European Standards			

Table III.2: Standards for determination of air pollutants from stationary source emissions published by International Standard Organisation (ISO)

It can be expected that achievable emissions quoted in the document are determined by ISO/CEN standards or, in cases where international standards are not yet available, by application of suitable national standards. For the determination of SO₂, today continuous methods are commonly used (e.g. absorption with IR- or UV-light, or fluorescence). However, for power boilers using gas or wood-based solid fuels (bark), the emission of SO₂ are so low that it is of minor interest to measure this parameter continuously.

For determination of SO₂ and NO_x it can be expected that the differences between the methods used within the Union will give no significant variations of analytical values. The frequency of samplings taken to determine environmental performances of mills as well as the reference periods (time intervals) from which the actual emission is computed (daily, monthly, yearly average) are expected to have a more significant influence on the results (see ANNEX IV).

For the determination of particles the different practices within the European Union might have a higher relevance because particles are not a well-defined parameter (such as SO₂ and NO_x) but defined by the procedure of measurement. It is essential and common practice that the sampling is carried out isokinetically i.e. the velocity of the gas in the sampling device has to correspond to that in the duct. The method used for sampling is dependent on the moisture content and the composition of the gas. The flue gas from power boilers using oil, coal, gas or solid fuel (wood) is normally dry enough to use dry filter method. The gas sample is collected with a pump connected to a gasometer to measure the gas flow of the sampled gas. The particulates collected on a suitable filter are determined gravimetrically.

To highlight possible differences in measurements of particles/dust in Table III.3 some information is collected regarding the standard methods used within the European Union. A

specification what measurement method are used is also included [information provided by TWG Members]

Country	Standard method applied	Year of publication	Principle for measurement	Remarks
Finland	SFS 3866	1990	Manual method	
Germany	VDI 2066	1993	in-stack filter, discontinuous	method for calibration
Ireland	BS 6069/ISO 9096	1992	Gravimetric	
Italy	UNI-UNICIM 10 623			
Netherlands	ISO/NEN 9096		Iso-kinetic suction followed by gravimetric determination	
Norway	NS 4863	1985	Optical Gravimetric	Continuous Discontinuous
Sweden			Continuous optical or discontinuously gravimetric	

Table III.3: Standard methods for the analysis of particles/dust within the European Union
The table includes only the countries that have provided information

Total reduced sulphur (TRS)

The malodorous, non-condensable gases in cooking of kraft pulp contain H₂S and reduced organic sulphur compounds (mainly methyl mercaptane CH₃SH, dimethyl sulphide (CH₃)₂S and dimethyl disulphide (CH₃)₂S₂), the odour thresholds of which are very low. These compounds are easily evaporative and they are present in high concentrations in some gases and condensates in the cooking and evaporation departments. Hydrogen sulphide gas (H₂S) can also be formed in incineration if there is shortage of oxygen in the combustion zone or when acids react with bisulphide ions in liquid phase. High concentration (low volume) gases origin in cooking, evaporation and condensate stripping. They are always incinerated. Low concentration high volume gases are released e.g. in washing, from chip bins, the dissolving tank, the evaporation plant, and thick liquor containers. In kraft pulp mills, diffuse sulphur emissions can be significant.

In order to monitor the total sulphur emissions and to determine the most important emission sources or the compounds that dominate the total emissions it is necessary to carry out measurements that cover the whole plant. These results are the basis for the decision where continuous measurements are necessary, where periodical measurements are valid, and which analyser to choose.

It can be expected that the different practices for determination of untreated TRS emissions that is released diffuse from a number of smaller emission sources will give significant variations of the results. The degree of collection and treatment of diffuse TRS-containing emissions might lead to relevant differences between Member States. Normally, TRS emissions are determined by estimations using results of discontinuous measurements of identified emission sources. Consequently, there is a certain uncertainty when comparing achieved environmental performance of TRS emission reduction in European countries.

3. Solid waste

The producer of waste has to be aware of the various waste fractions generated in the production. This includes information on the amount, quality, properties and origin of the waste generated (i.e. general requirement for bookkeeping). Knowledge about the environmental and health effects of the waste and of such properties that affect waste disposal should also be available. In Europe, the producer normally has an obligation to develop the production towards a less waste generating process (see Annex 4 of the IPPC-Dir.). Operators are required to keep book on wastes generated, collected, stored, transported, utilised or disposed as well as on wastes sold or transmitted. Also the delivery destinations and dates, transportation, utilisation and disposal manners have to be recorded when the waste is delivered elsewhere from the place

of generation. Annually, the authorities have to be informed about the amount, disposal, utilisation, storage or transportation of the wastes generated or obtained elsewhere. The report is drawn up on a special form using the EWC codes (European Waste Catalogue, 94/3/EC) for the wastes.

In most countries there are general requirements for landfills that include an evaluation of the suitability of wastes for landfilling. The general principles in landfill approval are that the composition, leachability and long term behaviour of the waste have to be known. The evaluation of the properties of the waste is based on investigations of the waste by carrying out a number of physico-chemical tests. These tests include an analysis of:

- the composition of the waste
- the organic content and degradation properties of the waste
- the content and leachability of compounds
- ecotoxicological effects of the waste and the landfill waters from the waste

The suitability of a waste for landfilling is usually tested by expert laboratories specialised on leachate and other test for determination the properties of waste. There is variation in the methods used for testing different wastes.

4. Noise

Noise is usually defined as unwanted sound. Sound is a wave motion, which occurs when a sound source sets the surrounding air particles into motion, causing variations in the density and pressure. Any noise source has a characteristic sound power, but the sound pressure it gives rise to depends on many external factors, such as distance, direction, temperature, moisture, wind and the environment.

Acoustic parameters are expressed as a logarithmic ratio of a measured value. The unit for this ratio has been called decibel (dB). The human ear is less sensitive to low frequency sound. In sound level meters a filter is used, which "corrects" the sound spectra in accordance with the ear's sensitivity. This is called the A-weighted sound level, expressed in dB(A).

The sound levels are usually determined according the following methods:

- field measurements: DIN 45 635 part 47: Measurement of airborne noise emitted by machines
- acoustics laboratory measurements: ISO 3741 Acoustics - Determination of sound power levels of noise sources - Precision methods for broad-band sources in reverberation rooms.

In environmental permits it is required that the noise levels must not exceed certain noise immission levels which are set on a case-by-case basis. These noise immission levels are often set separately for residential and recreational areas in daytime (7.00 - 22.00) and in night time (22.00 - 7.00). The operator of a plant normally has to give information of noise dissemination and measures taken for noise abatement.

ANNEX IV EXAMPLES FOR VARIATIONS OF EMISSIONS

Data presented in this document is considered typical for the sector as a whole. Most of the data presented in the BREF represents averages over a year. Where ranges are given, this represents variability across the sector and its dependence on raw materials, process type, different products and applied measures for pollution prevention and control.

However, the difference between emission data based on monthly or yearly average and for instance a daily average can be large, in the range of 100% or more. The variability of individual emissions over time will depend upon the type of installation, the source of the emission, the design and operation of the process, process control, maintenance, the substance concerned and other factors. Care must be exercised in comparing data.

In the following, examples of measured data from different sources of emission and for different parameters are presented and are shortly discussed. The examples are not intended to be complete or to cover all different cases but rather try to raise awareness on the influence of different averaging periods on the reported environmental performance of pulp and paper mills.

Example 1: Air emissions of a recovery boiler from a kraft pulp mill

As an example, the charts below show the variability of emissions from a Kraft recovery boiler firstly over a 3 days period and then over a longer 5 months period.

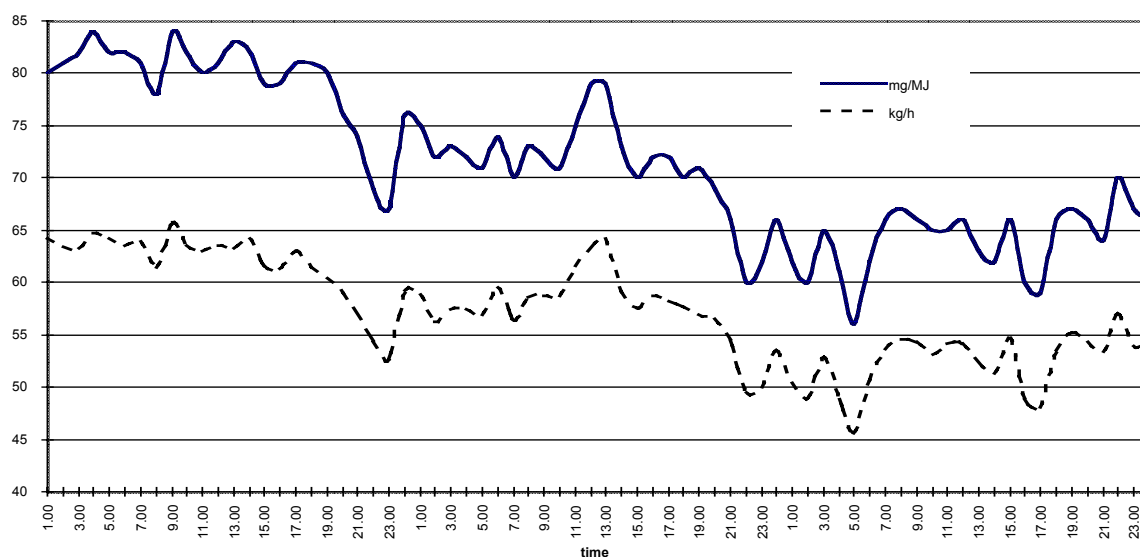


Figure IV.1: Continuous monitoring data of NO_x emissions from a kraft recovery boiler over a 3 days period

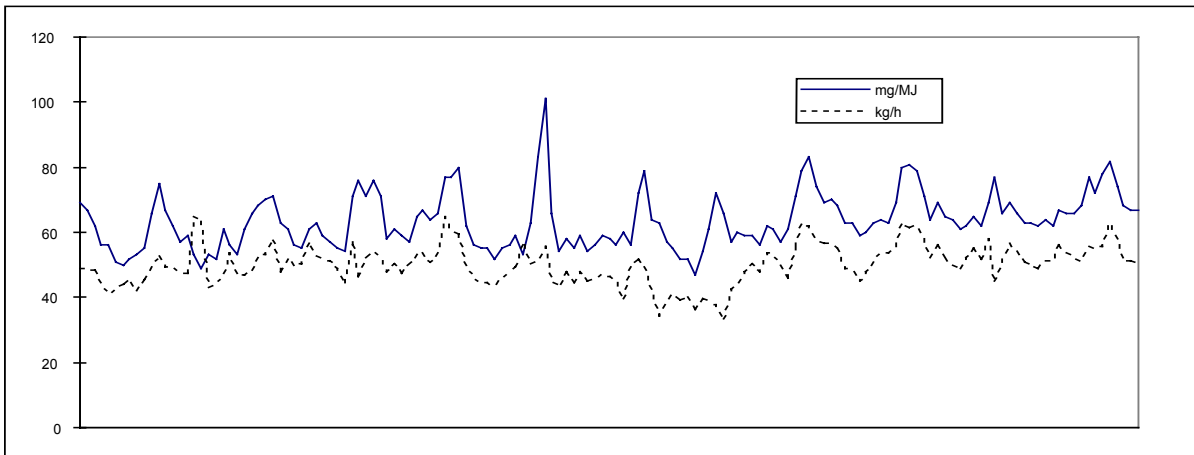


Figure IV.2: Daily average data of NOx emissions from a recovery boiler over a 5 months period

The data represented in Figure IV.1 and Figure IV.2 can be summarised as follows:

Period	Average [mg/MJ]	Maximum [mg/MJ]	Average [kg/h]	Maximum [kg/h]
Day - 1	79	84	61	65
Day - 2	71	79	57	64
Day - 3	64	70	52	57
3 days	71	84	57	65
5 months	64	101	50	65

Although longer sampling periods tend to include more extreme peak values examination of this data demonstrates that longer sampling periods result in lower average values. This is due to the fact that peak values are compensated by a bigger number of values that are close to the average level (normal operation) or below. However, it is difficult to derive arithmetical factors to multiply with between average values and the period of time of measurement.

Additionally, the different expressions either as specific emission per unit of energy or emissions per unit time can give slightly different impressions of performance over these periods although the comparison of average figures come to the same result. In this example, the extreme peak values are less significant when the emissions are expressed as emissions per unit of time.

Example 2: Wastewater discharge of a kraft pulp mill with primary treatment only

This example shows the variability of emissions to water of a bleach kraft pulp mill over a 1-month period and over a longer period. The mill has no biological wastewater treatment.

From the figures below it can be seen that there are significant variations over time. Figure IV.3 shows that in this example the lowest daily average COD load is 23 kg/Adt and the highest daily mean is 71 kg/Adt. The monthly average is 36 COD kg/Adt. There are three peak values. The COD load per day shows less variation. In this example this is because the specific load always increases when the daily production decreases.

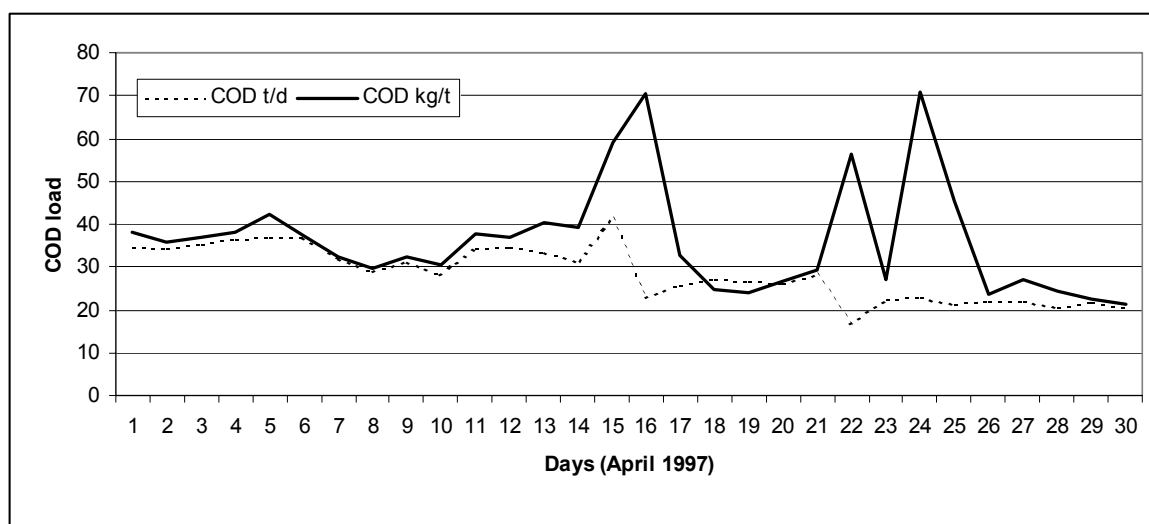


Figure IV.3: Daily average COD emissions to water from a kraft pulp mill over 30-day period

The results of daily average sampling of the same mill over a 6-month period are shown in Figure IV.4.

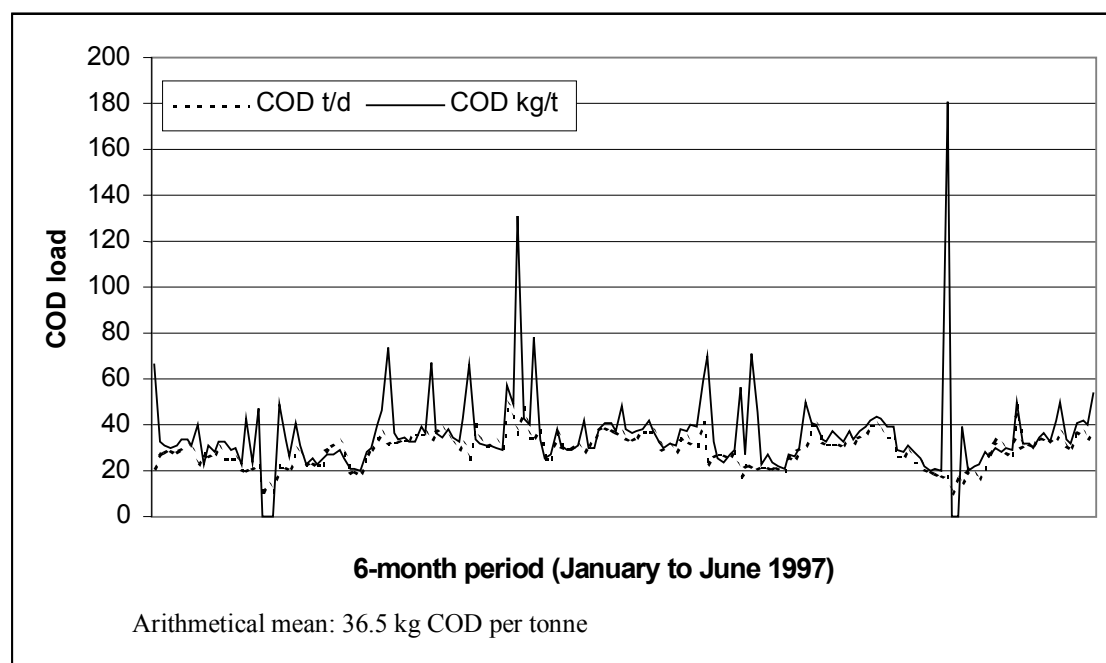


Figure IV.4: Daily average COD emissions to water from a kraft pulp mill over 5-month period

The data presented in Figure IV.4 can be summarised as follows:

Period	Production [tonnes per day]	COD average [kg/t]	COD Minimum [kg/t]	COD Maximum [kg/t]
January	804	33	23	66
February	935	35	25	74
March	921	31	25	131
April	846	36	21	71
May	920	33	20	50
June	859	40	20	181
6 months	881	36.5	20	181

Effluents from bleached kraft pulp mills without biological treatments tend to show a large number of extreme peak values. There is no equipment to buffer higher loads that are directly discharged to the recipient. In contrast, this effect can not be noticed when only longer averaging periods such as monthly or yearly averages are considered.

Example 3: Outflow of a wastewater treatment plant of an integrated sulphite pulp and paper mill

The wastewater treatment system of this example is described in Section 3.3.7.

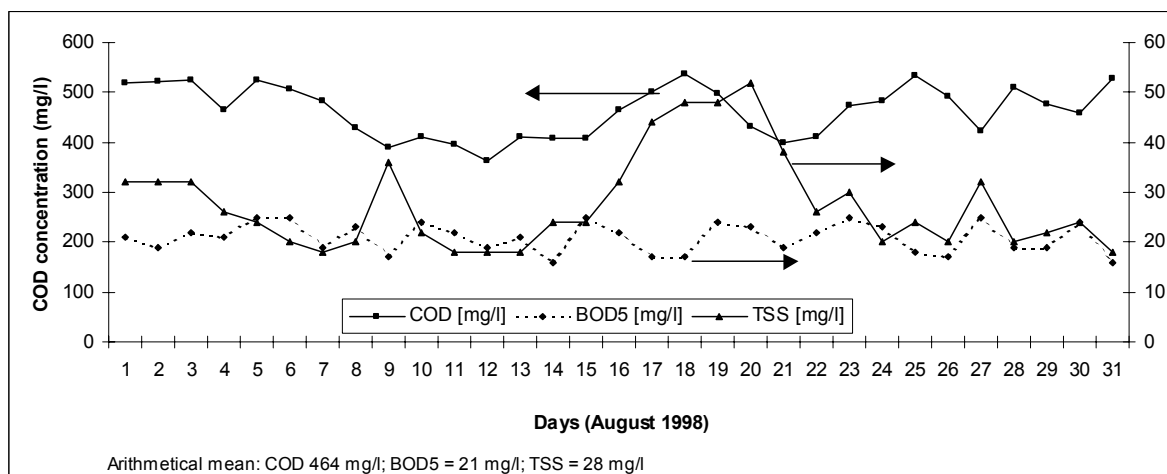


Figure IV.5: Daily average emissions to water from an integrated sulphite pulp and paper mill over a one-month period

The results of daily average sampling of the same mill over a 6-month period as shown in Figure IV.6.

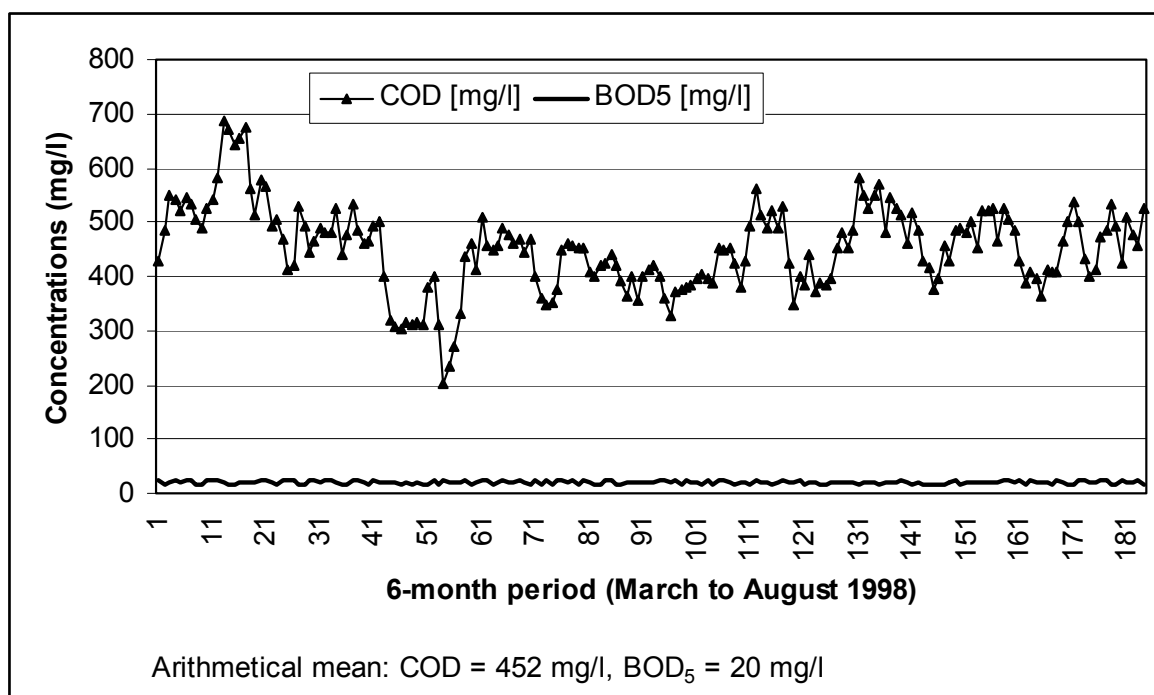


Figure IV.6: Daily average emissions to water from an integrated sulphite pulp and paper mill over a 6-month period

The data presented in Figure IV.5 and Figure IV.6 can be summarised as follows:

Period in 1998	COD [mg/l]			BOD ₅ [mg/l]			TSS [mg/l]		
	Average	Minim.	Maxim.	Average	Minim.	Maxim.	Average	Minim.	Maxim.
March	533	414	687	21	15	26	39	28	54
April	396	204	533	21	15	26	21	12	40
May	423	347	487	21	16	26	24	16	36
June	426	329	560	21	15	25	27	10	40
July	472	371	581	20	15	24	25	12	38
August	464	364	537	21	16	25	28	18	52
6 months	452	204	687	21	15	26	27	12	54

Effluents from sulphite pulp mills with biological treatment show little variations on BOD values independently from the averaging period. Also the TSS values fluctuate in a relatively narrow range that is however slightly more distinct than for the BOD values.

COD concentration can vary a little more. However, proper design and maintenance of the effluent treatment plant ensures that extreme peak values are rare. Figure IV.5 shows that in August 1998 the daily averages fluctuate between 364 and 537 mg/l with a daily mean of 452 mg/l. Most of the single monthly averages differ not more (or less) than 10% from the half-year average.

Example 4: Outflow of a wastewater treatment plant of a paper mill

In this example, the wastewater is generated in a paper mill manufacturing wood-containing printing paper with a share of 25% recycled fibre. The measured data given below are referring to the outflow of the two-stage biological treatment (activated sludge + biofiltration) plant. The values cover daily samplings over a whole year. The treatment plant is dimensioned relatively big. In 1998 there were virtually no disturbances. Values measured as 24-h composite sampling are shown in Figure IV.7. They are grouped to classes with same COD-ranges.

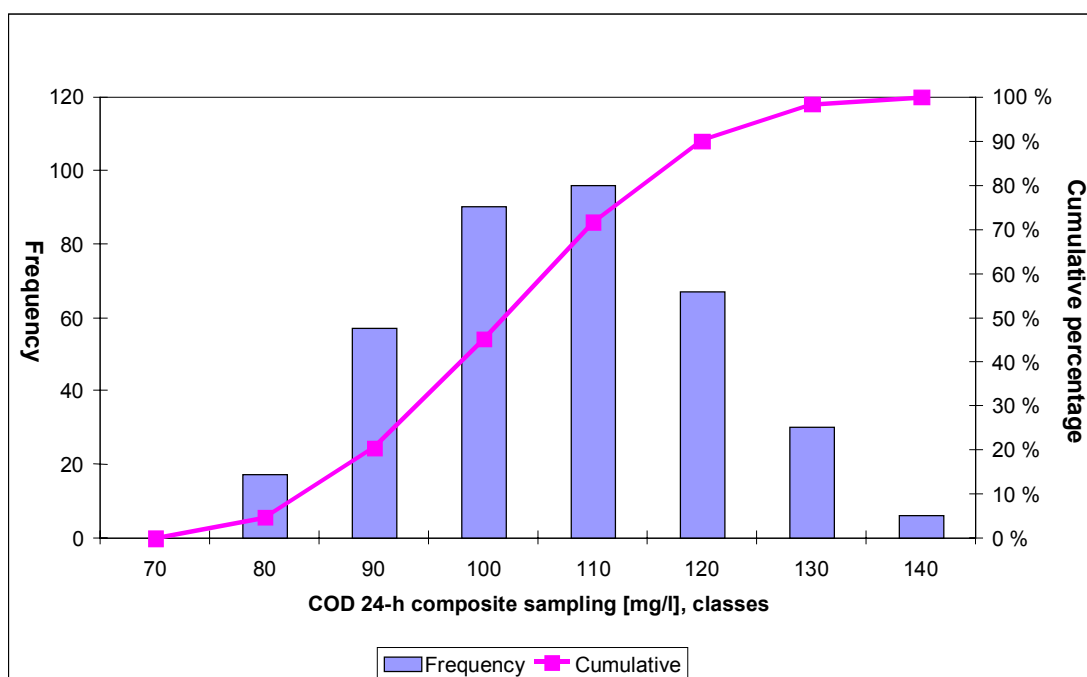


Figure IV.7: Histogram of COD outflow of a paper mill

The yearly average value for COD is 103 mg/l. Most COD values vary in a range between 90 - 120 mg/l. The highest daily average value is 139 mg/l, the lowest 68 mg/l.

If there are more disturbances in the operation of the wastewater treatment plant the difference between arithmetical mean and maximum value can be much higher. From environmental point of view a treatment system with less disturbances is preferable.

There is no "rule of thumb" how to convert yearly averages into monthly averages or daily composite samplings. Within a given range, it can be stated that the shorter the averaging period the bigger the variations of emission. Monthly average values normally vary from month to month to a certain extent (depending on production, wood quality, climatic conditions, etc.). Normally only the statistical analysis of every case gives a reliable answer about the real range of variations.

Variability factors

The variability factor is defined as the ratio of the daily maximum to the monthly average limit. There is no arithmetical method available which allows a direct comparison of short-term to long-term values or a derivation of the one from the other. However, there are some pragmatic approaches based on practical experiences in different countries, which can give a rough idea about the order of magnitude within which the results of measurements for different averaging periods may vary.

- In Germany, for water discharges of chemical pulp mills *after biological treatment* it is assumed that the monitoring value based on a daily mixed sampling is about 60% higher than the annual average value. For instance, a monitoring value based on a 24-h sampling of 40 kg COD/t of pulp equals to an annual average of 25 kg/t of pulp. The daily monitoring value is considered to be fulfilled if four out of five samplings are below the limit and no value exceeds the limit more than 100%.
- The French regulation concerning wastewater from pulp and paper mills makes the following assumption: The monthly average limit is 100% higher than the daily maximum value to meet the minimum requirements set in the regulations.
- In Sweden as a rule of thumb it is assumed that monthly averages can be expected to be up to 20% higher than the annual average for that year

- In Canada there is a fairly wide discrepancy in the variability factors used by each province. For the BOD limit for instance, the variability factor ranges from 1.6 in Québec's regulations to 2.0 in Alberta's permits and Ontario's regulations. A variability factor of 2 means that a daily maximum of 3 kg BOD/t equals to a monthly average of 1.5 kg BOD/t. The federal government has a variability factor of 1.66.
- In the framework of the US cluster rules for water discharge limits it is assumed that the maximum daily specific load (e.g. kg BOD/t of pulp, kg TSS/t of pulp) equals roughly double the value of the average load of a 30 day period.

Variability factors are an important consideration when setting limits since it is a reflection of the degree of stringency of the regulation. Since variability is an inherent characteristic of pulp and paper mill effluents, mills facing low or no (i.e. exclusively daily average limits) variability factors in its discharge limits will need to operate at a lower monthly average discharge level in order to stay within daily limits than mills facing high variability factors but similar monthly average discharge limits. Therefore, when comparing the stringency of discharge limits between countries, it is more important to compare the daily maximum limit than the monthly average limit. The daily limit is the one which mills are most likely to exceed.

In this document, for the description of the environmental performance of pulp and paper mills often annual average values are given. When these performance levels are transferred into limits the variations of emissions over time have to be considered.