“BEST AVAILABLE TECHNIQUES”

FOR THE CEMENT INDUSTRY

A contribution from the European Cement Industry to the exchange of information and preparation of the IPPC BAT REFERENCE Document for the cement industry

December 1999

CEMBUREAU

CEMBUREAU

CEMBUREAU - the European Cement Association, based in Brussels, is the representative organisation for the cement industry in Europe. Its Full Members are the national cement industry associations and cement companies of the European Union and the European Economic Area countries plus Poland, Switzerland and Turkey. Associate Members include the national cement associations of Czech Republic, Hungary, Slovakia and the sole cement company in Estonia.

The Association acts as spokesman for the cement sector towards the European Union institutions and other authorities, and communicates the industry’s views on all issues and policy developments likely to have an effect on the cement market in the technical, environmental, energy and promotion areas. Permanent dialogue is maintained with the European and international authorities and with other International Associations as appropriate.

Serviced by a multi-national staff in Brussels, Standing Committees and issue-related Project Groups, established as required, enable **CEMBUREAU** to keep abreast of all developments affecting the cement industry.

CEMBUREAU also plays a significant role in the world-wide promotion of cement and concrete in co-operation with member associations, and the ready-mix and precast concrete industries. The Association regularly co-hosts conferences on specific issues aimed at improving the image of concrete and promoting the use of cement and concrete products.

Since its foundation in 1947, **CEMBUREAU** has developed into the major centre for the dissemination of technical data, statistics and general information on the cement industry world-wide. Its publications serve as the principal source of information on the cement industry throughout the world. It is the editor of the “World Cement Directory” providing data on cement companies and works based in some 150 countries.

CEMBUREAU

Association
Européenne
du Ciment
The European
Cement
Association

Rue d’Arlon 55 - B-1040 Brussels — Tel.: + 32 2 234 10 11 - Fax: + 32 2 230 47 20
E-mail: secretariat@cembureau.be — *http://www.cembureau.be*

PREFACE

This Document, prepared by a CEMBUREAU Working Group of cement technology experts, is a contribution from the European cement industry to the exchange of information organised by the Commission in accordance with Article 16, Paragraph 2 of Council Directive 96/61/EC of 24th September 1996 concerning integrated pollution prevention and control (IPPC Directive).

This edition was issued in December 1999. It contains editorial changes to the first edition from November 1997. Chapters 3 and 4 have been modified whereas the text in the other chapters has not been up-dated although some technical development have occurred, for instance concerning abatement techniques for NO_x and SO_2.

TABLE OF CONTENTS

PREFACE

CHAPTER 1

INTRODUCTION

The Directive lays down procedures for granting operation permits for larger installations. The permits shall include emission limit values for certain substances. The emission limit values shall be set by national authorities based on "best available techniques" for the relevant industrial sector.

The aim of this Document is to provide background information on the cement industry and cement manufacturing technology, and to determine "best available techniques" for the installations for production of cement.

In preparation of this Document the cement industry has carefully studied the IPPC Directive and has based its work upon it (see Chapter 5). Two paragraphs have been noted as being of particular importance: Article 9, Paragraph 4 and Article 2, Paragraph 11.

Article 9, Paragraph 4 specifies that national authorities shall take site specific characteristics and best available techniques into consideration when specifying emission limit values in the permits. This is of major importance to the cement industry as levels of emissions to a large extent are determined by the available raw materials and the state of the art when the capital intensive main equipment was installed.

Article 9, Paragraph 4 also states that the permit conditions shall ensure a high level of protection for the environment as a whole. This allows for a global view and optimisation of the interdependent emissions and consumptions found in the cement manufacturing process.

Article 2, Paragraph 11 defines "best available techniques". Each of the words "best", "available" and "techniques" is defined and reference is made to Annex IV of the Directive. The definition of "available" is of particular importance as the huge investments and long pay-back periods for process modifications make the cement industry very careful in selecting and developing new technologies. "Available" is defined as follows:

> " 'available' techniques shall mean 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, "

Economically and technically viable conditions are different for new and existing plants. They also strongly depend on site specific parameters.

The content of this Document is the following:

Chapter 2 of this Document provides a general overview of the European cement industry and general statistical information.

Chapter 3 provides an overview of the cement production process and an overview of main environmental matters in the cement industry. It describes the main sub-processes involved in cement production and defines the group of sub-processes which is to be covered by the BAT Reference Document for the cement sector. Details of current national emission limits are included.

Chapter 4 contains descriptions of special characteristics of the cement production process as these are of particular relevance in defining "best available techniques".

Chapter 5 summarises aspects of the Directive which are of direct importance to the cement industry and describes how consideration of Article 9, Paragraph 4 and Article 2, Paragraph 11 means that a wide range of Candidate BATs needs to be identified.

Chapter 6 presents an overview of techniques used for the main sub-processes in the manufacture of cement. Each technique is evaluated against criteria for selecting BAT options.

Chapter 7 presents an overview of techniques used for emission control in the manufacture of cement and these techniques are also evaluated against criteria for selecting BAT options.

Chapter 8 summarises the information on "best available techniques" for controlling emissions. Techniques are grouped in clusters of BATs for controlling different emissions.

Chapter 9 contains descriptions of techniques which may be effective in achieving a high level of protection of the environment but are not yet available (as defined by the IPPC Directive).

CHAPTER 2

THE EUROPEAN CEMENT INDUSTRY

Cement has played a key role as a construction material throughout the history of civilisation. In Europe the use of cement and concrete in large civic works can be traced from antiquity through modern times. Portland cement was patented in 1824 and by the end of the 19th century concrete, based on Portland cement, had become a highly appreciated construction material throughout Europe.

China	30%
Other Asia	23%
European Union	12%
Other Europe	6%
Japan	7%
USA	5%
Other America	8%
Former USSR	4%
Africa	4%
Oceania	1%

Table 2.1: World cement production 1995

Cement manufacturing is a major mineral commodity industry. In 1995 the world production of cement was 1,420 million tonnes. See Table 2.1 for geographical distribution. Total cement production in the European Union amounted to 172 million tonnes in 1995 and consumption was 168 million tonnes. Imports amounted to 23 million tonnes and exports to 27 million tonnes. These figures include trade between EU countries. Table 2.2 gives production and consumption figures for the EU countries. The cement consumption per capita was 452 kg. Since 1990 cement consumption in the European Union has fallen by around 13% and production has fallen by 11%. In 1973 the cement industry in the European Union produced 27% of the cement produced in the world. In 1995 the percentage was 12%.

	Production	Consumption
Austria	3,777	4,987
Belgium	8,223	5,735
Denmark	2,051	1,185
Finland	907	1,089
France	20,697	19,822
Germany	33,302	38,486
Greece	14,480	6,851
Ireland	1,730	1,860
Italy	34,019	34,639
Luxembourg	708	511
Netherlands	3,180	5,300
Portugal	8,123	7,886
Spain	28,491	25,460
Sweden	2,539	1,505
United Kingdom	11,805	12,740

Table 2.2: Cement production and cement consumption in 1995
(Figures in 1,000 tonnes)

In the European Union cement is produced in 320 plants of which about 70 are grinding plants without kilns. See Table 2.3. The total number of kilns in the EU countries is 437. They are not all of them currently in operation. Only very few kilns have a capacity less than 500 tonnes per day. In recent years a typical kiln size would be 3,000 tonnes/day, although kilns of widely different sizes and ages exist. Detailed information on cement companies is found in Reference (1) and information on production and sales in Reference (2).

Presently, about 78% of Europe's cement production is from dry process kilns, a further 16% of production is accounted for by semi-dry/semi-wet process kilns, and about 6% of European production now comes from wet process kilns due to the nature of the available raw materials.

The cement industry contributes significantly to local and regional economies through the wide geographic spread of its plants which are mainly located in rural areas.

	Cement Plants (with kilns)	**Cement Plants** (with cement mills only)
Austria	11	1
Belgium	5	3
Denmark	1	–
Finland	2	–
France	38	5
Germany	50	20
Greece	8	–
Ireland	2	–
Italy	64	29
Luxembourg	1	1
Netherlands	1	2
Portugal	6	1
Spain	37	5
Sweden	3	–
United Kingdom	23	1
Total	**252**	**68**

Table 2.3: Number of cement plants in EU countries (1995)

Today four West European groups of companies (Holderbank, Lafarge, Heidelberger and Italcementi) rank among the top five world cement producers with Cemex (Mexico). They, like many other key players, have also branched out into several building materials subsectors such as aggregates, concrete products, plasterboard, etc.

Cement is a binder in the form of a powder which hardens when mixed with water. Cement is used to produce concrete which is an artificial stone made from cement, aggregates, sand and water. Concrete is an essential material for the construction of roads, bridges, harbours, residential houses, schools, hospitals, etc. The use of cement has contributed to the welfare of society and its rising economic standards for generations.

The draft European standard for common cements lists 27 different Portland cement types in 5 groups. In addition there is a range of special cements produced for special applications.

The domestic deliveries by cement types are shown in Table 2.4.

	1994
Portland Cement	43%
Portland-composite Cement	44%
Blastfurnace Cement	7%
Pozzolanic Cement	5%
Other Cements	1%

Table 2.4: Domestic deliveries by cement type in the European Union and European Economic Area

The cement industry is an energy intensive industry with energy typically accounting for 30-40% of the production costs (i.e. excluding capital costs). Historically, the primary fuel used is coal. A wide range of other primary fuels are also used, including petroleum coke, natural gas and oil. In addition to these fuel types the cement industry has used selected wastes as alternative fuels in cement kilns for more than 10 years. The use of waste as fuels in cement kilns saves fossil fuels, reduces globally the emissions to air and eliminates the need for disposal of slag and ash.

Use of the various types of fuel is shown in Table 2.5.

	1995
Coal	36%
Petcoke	39%
Lignite	6%
Fuel Oil	7%
Gas	2%
Alternative Fuels	10%

Table 2.5: Fuel consumption of the European cement industry

Releases from the cement kiln come primarily from the physical and chemical reactions of the raw materials and secondarily from the combustion of fuels. The main constituents of the exit gases from a cement kiln are nitrogen from the combustion air, CO_2 from calcination of $CaCO_3$ and from combustion of fuel, water from the combustion process and the raw materials, and excess oxygen.

The exit gases also contain small quantities (far less than 1%) of dust, sulphur dioxide, NO_x and other compounds. The contribution of emissions from the production of cement to the total emission inventory in Europe is however very low.

The cement industry is a capital intensive industry. In the context of the wider international competitive situation account must be taken of the particular nature of cement manufacture – its long term largely unchanging product and manufacturing process and very slow rate of obsolescence. The cost of cement plants is usually above 150 M ECU per million tonnes of annual capacity, with correspondingly high costs for modifications. The cost of a new cement plant is equivalent to around 3 years of turnover which ranks the cement industry among the most capital intensive industries. Long time periods are therefore needed before investments can be recovered, and plant modifications have to be carefully planned and must take account of this long-term nature of the industry.

The present configuration of manufacturing and abatement plant and equipment reflects the state of the art at the times at which the plants were built or modified. The benefits from these technologies will have some time to run before it becomes economically and competitively feasible to replace them with equipment benefiting from later technological development. The same situation will continue to apply as further technology develops.

REFERENCE LIST

1) "1996 World Cement Directory", pp. 354-495. Published by CEMBUREAU – The European Cement Association, Brussels 1996.

2) 1995 Statistics. Published by CEMBUREAU – The European Cement Association, Brussels 1997.

CHAPTER 3

GENERAL DESCRIPTION OF THE CEMENT PRODUCTION PROCESS

3.1 INTRODUCTION

The purpose of this chapter is to give an overview of processes and sub-processes used to make cement, and of the environmental effects which may result from these manufacturing processes.

Before detailing the technological processes a brief description is given of the nature and requirements of the raw materials, fuels and mineral additions which are needed to manufacture the final products, i.e. clinker and cement. The choice of the technological process applied is to a certain extent governed by the physical nature – especially the moisture content – of the raw materials available.

Finally, information is given on resources consumption and emissions typically found with cement kiln systems in operation.

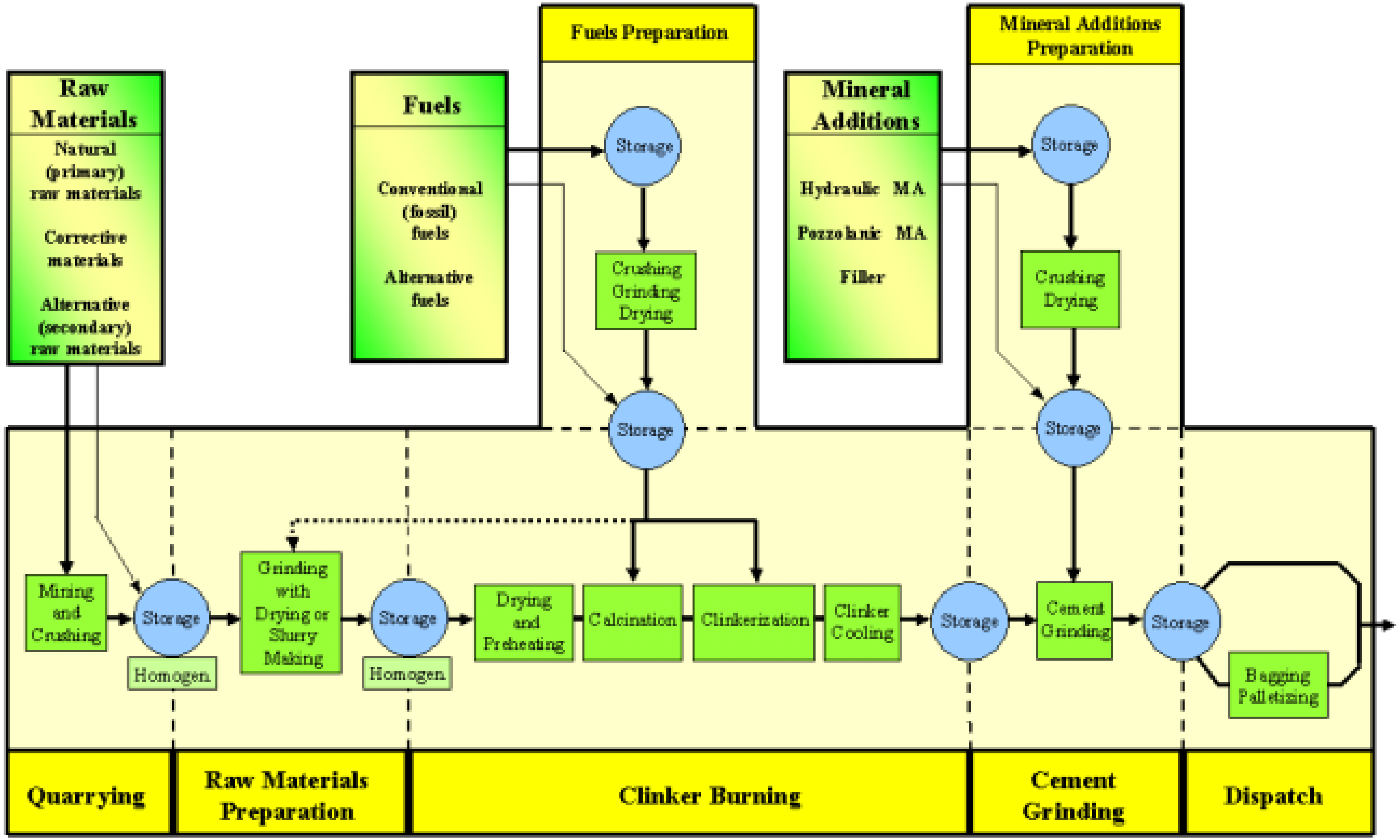
3.2. MAIN PROCESSES, SUB-PROCESSES AND SYSTEM BOUNDARIES

There are **four main process routes** in the manufacturing of cement – the dry, semi-dry, semi-wet and wet process. The main features of these processes are described in more detail in Chapters 3.4 and 3.5.

Common to all these processes are the following **sub-processes** (see Fig. 3.1 for illustration):

- Quarrying.
- Raw materials preparation.
- Fuels preparation.
- Clinker burning.
- Mineral additions preparation.
- Cement grinding.
- Cement dispatch

Figure 3.1 : Processes / Sub-processes Identification and System Boundaries of Cement Production



Quarrying:

Natural ("primary") raw materials such as limestone/chalk, marl, and clay/shale are extracted from quarries which, in most cases, are located close to the cement plant. After extraction, these raw materials are crushed at the quarry site and transported to the cement plant for intermediate storage, homogenization and further preparation.

"Corrective" materials such as bauxite, iron ore or sand may be required to adapt the chemical composition of the raw mix to the requirements of the process and product specifications. The quantities of these corrective materials are usually low compared to the huge mass flow of the main raw materials.

To a limited extent, "secondary" (or **"alternative") raw materials** originating from industrial sources are used to substitute for natural raw materials and correctives. In the same way as traditional raw materials, they may be fed to the quarry crusher or – more commonly – directly to the cement plant's raw material preparation system.

Today, modern **computerised methods** are available to evaluate the raw material deposits and to optimise the long-term and short-term production schedule.

Raw Materials Preparation:

After intermediate storage and pre-homogenisation, the raw materials are dried and ground together in defined and well-controlled proportions in a raw mill to produce a **raw meal** for the dry (and semi-dry) process. In the wet (and semi-wet) process, the raw materials are slurried and ground with addition of sufficient water to produce a **raw slurry**.

Depending on the technological process applied, additional steps may be required such as preparing raw meal "pellets" from dry meal (semi-dry process) or "filter cake" by dewatering of the slurry in filter presses (semi-wet process).

The resulting intermediate product – i.e. raw meal or raw slurry (or their derivatives) – is stored and further homogenised in raw meal silos, storage bins or slurry basins to achieve and maintain the required uniform chemical composition before entering the kiln system.

As a rule of thumb, approximately 1.5 – 1.6 tons of (dry) raw materials are required to produce one ton of the burnt product clinker. More detailed figures on raw materials consumption are given in Chapter 3.11.4.

Fuels Preparation:

Conventional (fossil) fuels used in the European cement industry are mainly coal (lignitic and hard coal), petcoke (a product from crude oil refining), and heavy oil ("bunker C"). Natural gas is rarely used due to its higher cost.

"Alternative" fuels – i.e. non-fossil fuels derived from industrial ("waste") sources – are widely used today to substitute in part for the traditional fossil fuels.

Fuels preparation – i.e. crushing, drying, grinding, and homogenising – usually takes place on site. Specific installations are required such as coal mills, silos and storage halls for solid fuels, tanks for liquid fuels, and the corresponding transport and feeding systems to the kilns.

The thermal fuel consumption is largely dependent on the basic process design applied in the burning of clinker. More detailed information is given in Chapters 3.4 and 3.11.

Clinker Burning:

The prepared raw material (“kiln feed”) is fed to the kiln system where it is subjected to a thermal treatment process consisting of the consecutive steps of drying/preheating, calcination (e.g. release of CO_2 from limestone), and sintering (or “clinkerisation”, e.g. formation of clinker minerals at temperatures up to 1450° C). The burnt product “clinker” is cooled down with air to 100-200° C and is transported to intermediate storage.

The kiln systems commonly applied are rotary kilns with or without so-called “suspension preheaters” (and, in more advanced systems, “precalciners”) depending on the main process design selected (see Chapters 3.4 and 3.5). The rotary kiln itself is an inclined steel tube with a length to diameter ratio between 10 and 40. The slight inclination (2.5 to 4.5%) together with the slow rotation (0.5 – 4.5 revolutions per minute) allow for a material transport sufficiently long to achieve the thermal conversion processes required.

Exhaust heat from the kiln system is utilised to dry raw materials, solid fuels or mineral additions in the mills. Exhaust gases are dedusted using either electrostatic precipitators or bag filter systems before being released to the atmosphere.

Cement Grinding:

Portland cement is produced by intergrinding cement clinker with a few percent of natural or industrial gypsum (or anhydrite) in a cement mill. **Blended cements** (or “composite” cements) contain other constituents in addition such as granulated blast-furnace slag, natural or industrial pozzolana (for example, volcanic tuffs or fly ash from thermal power plants), or inert fillers such as limestone.

Mineral additions in blended cements may either be interground with clinker or ground separately and mixed with Portland cement.

Grinding plants may be located remotely from the clinker production facility.

The different cement types have to be stored separately in cement silos prior to bagging and dispatch.

Mineral Additions Preparation:

Mineral additions from natural or industrial sources intended to be used in blended cements may need to be dried, crushed or ground in separate installations on site. Separate "grinding plants" where mineral additions and blended cements only are produced may also be located remote from the clinker production facility.

Cement Dispatch:

Cement may be shipped as bulk cement or – usually to a lesser extent – packed into bags and palletised for dispatch. Transport methods used (i.e. road, railway, waterways) depend on local conditions and requirements.

System Boundaries:

The sub-processes of quarrying and cement dispatch are beyond the system boundaries selected due to the following reasons:

- They are not intrinsic or specific for the cement manufacturing process.
- They may be dealt with in separate BAT Reference Documents.

3.3. MATERIAL TECHNOLOGICAL CHARACTERISTICS IN CEMENT PRODUCTION

3.3.1 PORTLAND CEMENT CLINKER

Portland cement clinker is produced from a mixture of raw materials containing calcium, silicon, aluminium, and iron as the main elements. When mixed in the correct proportions, new minerals with hydraulic properties – the so-called **clinker phases** – are formed upon heating up to the sintering (or clinkerisation) temperature as high as 1450° C. The main mineral components in clinker are silicates, aluminates and ferrites of the element calcium.

Main Clinker Phases:

Tri-calcium silicate	$3\ CaO \times SiO_2$	C_3S	Alite
Di-calcium silicate	$2\ CaO \times SiO_2$	C_2S	Belite
Calcium aluminate	$3\ CaO \times Al_2O_3$	C_3A	Aluminate
Calcium ferrite	$4\ CaO \times Al_2O_3 \times Fe_2O_3$	C_4AF	Ferrite

The clinker formation process can be divided into 4 steps. i.e.:

- ***Drying and preheating*** (20 – 900° C): release of free and chemically bound water
- ***Calcination*** (600 – 900° C): release of CO_2: initial reactions with formation of clinker minerals and intermediate phases
- ***Sintering or clinkerisation*** (1250 – 1450° C): formation of calcium silicates and liquid phase
- ***Kiln internal cooling*** (1350 – 1200° C): crystallisation of calcium aluminate and calcium ferrite

Minor mineral constituents in cement clinker include uncombined calcium oxide (“free lime”) and magnesium oxide, as well as alkali sulphates. Additional chemical elements present in the raw materials such as manganese, phosphorus, titanium or heavy metals are mainly incorporated in the mineral structure of the major clinker phases.

The properties of clinker (and thus, of the cement produced from it) are mainly determined by its mineral composition and its structure. The chemical and mineralogical composition of Portland cement clinker is given in Table 3.1.

Some elements in the raw materials such as the alkalis, sulphur and chlorides are volatilised at the high temperatures in the kiln system resulting in a permanent internal cycle of vaporisation and condensation **(“circulating elements**”). A large part of these elements will remain in the kiln system and will finally leave the kiln with the clinker. A small part will be carried with the kiln exhaust gases and will be mainly precipitated with the particulates in the dedusting system.

At a high surplus of volatile elements, the installation of a preheater “bypass” may become necessary where part of the dust laden exhaust gases of the rotary kiln is extracted from the system. Both filter and bypass dust can totally or partially be recycled to the cement manufacturing process.

3.3.2 RAX MIX COMPONENTS

A well designed raw mix in clinker manufacturing typically consists of

- ***Calcareous components*** rich in calcium, e.g. > 75% of carbonates (limestone, chalk, marble, calcareous marl),
- ***Argillaceous components*** rich in aluminium, silicon and iron (marl, marly clay, shale, clay) and
- ***Corrective components*** specifically enriched in one of the four main elements (bauxite, iron ore, sand, high-grade limestone, etc.). Correctives are used in small quantities only to adjust the chemical composition of the raw mix to the required quality targets.

Table 3.1: Chemical and Mineralogical Composition of Portland Cement Clinker

Components	[% by weight]
SiO_2	19.71 – 24.25
Al_2O_3	3.76 – 6.78
TiO_2	0.21 – 0.52
P_2O_5	0.02 – 0.27
Fe_2O_3	1.29 – 4.64
Mn_2O_3	0.03 – 0.68
CaO	63.76 – 70.14
MgO	0.00 – 4.51
SO_3	0.20 – 2.07
K_2O	0.31 – 1.76
Na_2O	0.03 – 0.33
Na_2O-equivalent	0.31 – 1.34
LOI 1)	0.09 – 1.56
CO_2	0.03 – 0.83
H_2O	0.04 – 1.11
Moduli 2)	
LS	90.5 – 104.1
SR	1.6 – 4.1
AR	1.4 – 3.7
GS	34.8 – 188.5
Bogue Clinker Phases [%]	
C_3S	51.5 – 85.2
C_2S	0.2 – 27.1
C_3A	6.8 – 15.6
C_4AF	4.0 – 16.2
CaO_{free}	0.08 – 5.58

1) Loss on ignition
2) LS = lime saturation
SR = silicia ratio
AR = alumina ratio
GS = degree of sulphatisation

Note: Representative chemical compositions as found in Germany (VDZ)

(Source : VDZ, Germany)

The chemical composition of commonly used natural raw materials and correctives are given in Table 3.2 together with the typical range of raw meal compositions.

Table 3.2: Chemical Composition of Primary Raw Materials, Correctives, Coal Ash and Raw Meal for the Production of Portland Cement Clinker

	Primary Raw Materials			**Correctives**			**Coal Ash 1)**	**Raw Meal**
	Limestone	**Calcareous marl**	**Clay**	**Sand**	**Iron ore**	**Bauxite 1)**		
SiO_2	0.5 – 3	3 – 50	37 – 78	80 – 99	4 – 11	2.9	44.3	12 – 16
Al_2O_3 + TiO_2	0.1 – 1	1 – 20	7 – 30	0.5 – 3	0.2 – 3	57.5	32.3	2 – 5
Fe_2O_3 + Mn_2O_3	0.1 – 0.5	0.5 – 10	2 – 15	0.5 – 2	19 – 95	22.8	4.8	= 5
CaO	52 – 55	5 – 52	0.5 – 25	0.1 – 3	0.1 – 34	2.4	7.8	40 – 45
MgO	0.5 – 5	0.5 – 5	= 5	= 0.5	= 1.5	0.04	1.2	0.3 – 3
K_2O	= 0.3	= 3.5	0.5 – 5	= 1	Traces	0.04	0.56	0.2 – 1.4
Na_2O	= 0.1	= 0.2	0.1 – 0.3	= 0.5	Traces	0.02	0.15	= 0.3
SO_3	= 0.1	0.1 – 4	= 3	= 0.5	Traces	0.12	5.5	= 1.2
Loss on ignition: CO_2 + H_2O	40 – 44	2 – 42	1 – 20	= 5	0.1 – 30	13.5	2.0	32 – 36

1) Single analysis (All values are given in % by weight)

Note: Representative chemical compositions as found in Germany and elsewhere (VDZ and other references)

Source: VDZ and other references

("S. Sprung: Technologische Probleme beim Brennen des Zementklinkers, Ursache und Lösung", Schriftenreihe der Zementindustrie, Vol. 43/1982, Editor: Beton-Verlag)

Depending on availability and chemical composition, both main and corrective raw mix components may also originate from industrial (“non-fossil”) sources (“**alternative” raw materials**). Examples are coal fly ash from power stations, steel slag, foundry sand, sewage sludge, lime sludge, FCC catalysts from oil refineries, and many more.

A proper **raw mix design** is based on the given raw materials situation, on the process design and process requirements, on the product specifications, and on environmental considerations. A well designed raw mix, adequate fineness of the raw meal and constant chemical composition are essential both for a good product quality and for a smooth kiln operation. Homogeneity and uniformity of the raw mix composition has to be carefully controlled on a permanent basis by adequate sampling and chemical analysis.

3.3.3 FUELS

Main **fossil fuels** (“primary” fuels) in the cement industry are coal, petcoke, heavy oil, and – to a lesser extent – natural gas. Non-fossil “**alternative” fuels** derived from industrial sources such as tyres, waste oil, plastics, solvents and many more are commonly used as substitute fuels today.

The chemical components of the ash of solid fuels combine with the raw materials and will be fully incorporated in the clinker produced. Thus, the chemical composition of the ash has to be considered in the raw mix design. A typical ash composition of hard coal is given in Table 3.2.

In the same way as the major elements, metals which may be introduced with liquid or solid fuels will also be incorporated into the clinker structure to a large extent. Exceptions are metals which are partly or completely volatilised in the kiln system such as mercury, thallium or cadmium. These elements will be captured in the kiln (filter) dust or may to some extent escape with the stack emissions (mercury) if not managed appropriately.

3.3.4 CEMENT CONSTITUENTS

Portland cement is produced by intergrinding clinker with a few percent of natural or industrial **gypsum or anhydrite** (calcium sulphate) acting as a set regulator. In many European countries, the addition of up to 5% of “minor constituents” such as raw meal, limestone or filter dust is allowed.

In blended (or “composite”) cements, part of the cement consists of **mineral additions** originating from natural or industrial sources. These mineral additions may have hydraulic (granulated blastfurnace slag), pozzolanic (volcanic rocks, coal fly ash, microsilica, calcined clay) or filler properties (limestone). The composition of blended cements is specified in the European cement standard. The standard also includes quality specifications for the individual mineral additions used.

The chemical composition of some commonly used mineral additions is given in Table 3.3.

Table 3.3: Chemical Composition of Mineral Additions

Components	**Granulated Blast Furnace Slag**	**Burnt Oil Shale**	**Natural Pozzolan ("Trass")**	**Pulverised Fly Ash**
SiO_2	32.3 – 40.5	34.3 – 36.7	53.9 – 63.2	40 – 55
Al_2O_3	7.1 – 14.0	11.3 – 11.4	15.2 – 20.4	24 – 30
TiO_2	0.3 – 1.9	0.6 – 0.6	0.6 – 1.2	0.7 – 1.3
P_2O_5	0.0 – 0.2	0.2 – 0.2	0.1 – 0.2	0.1 – 1.5
Fe_2O_3	0.2 – 2.4	7.3 – 10.4	5.2 – 7.9	5 – 15
Mn_2O_3	0.2 – 1.7	0.1 – 0.1	0.1 – 0.3	0.1 – 0.4
CaO	35.3 – 45.9	27.3 – 31.6	2.7 – 8.5	1.5 – 8
MgO	0.0 – 11.7	1.8 – 2.0	1.1 – 2.7	1.5 – 3.5
SO_3	0.1 – 0.3	10.1 – 11.2	0.0 – 0.3	0.4 – 2.5
K_2O	0.2 – 1.1	2.0 – 2.1	1.5 – 6.0	1.0 – 4.5
Na_2O	0.2 – 0.6	0.3 – 0.3	1.5 – 4.3	0.4 – 1.5
LOI	0.1 – 1.9	4.2 – 8.0	7.1 – 11.6	0.8 – 5.0
CO_2	0.1 – 1.3	2.6 – 7.0	0.6 – 4.8	--
H_2O	0.1 – 1.1	1.0 – 1.7	--	--
S^{2-}	0.9 – 2.1	0.1 – 0.2	--	--
CaO_{free}	--	--	--	0.1 – 1.5

(All values given in % by weight)

Note: Representative chemical compositions as found in Germany and elsewhere (VDZ and other references)

3.4. THE FOUR MAIN "WHOLE PLANT CONCEPTS"

Historically, the development of the clinker manufacturing process was characterised by the change from "wet" to "dry" systems with the intermediate steps of the "semi-wet" and "semi-dry" process routes. The first rotary kilns – introduced around 1895 – were long wet kilns.

"Wet" kilns allowed for an easier handling and homogenisation of the raw materials, especially in cases when the raw materials are wet and sticky or exhibit large fluctuations in the chemical composition of the individual raw mix components. With more advanced modern technology however, it is possible to prepare a homogeneous raw meal using the "dry" process, i.e. without addition of water to prepare a raw slurry. The main advantage of a modern dry process over a traditional wet system is the far lower fuel consumption and thus, lower fuel cost.

Today, the selection of the wet process is only feasible under very specific raw material and process conditions.

The four different basic processes (or "whole plant concepts") can be shortly characterised as follows (see also Figures 3.2 to 3.5):

- ***Dry process:*** Dry raw meal is fed to a cyclone preheater or precalciner kiln or, in some cases, to a long dry kiln with internal chain preheater.
- ***Semi-dry process***: Dry raw meal is pelletised with water and fed to a travelling grate preheater prior to the rotary kiln or in some cases, to a long kiln equipped with internal cross preheaters.
- ***Semi-wet process:*** Raw slurry is first dewatered in filter presses. The resulting filter cake is either
    - extruded into pellets and fed to a travelling grate preheater or
    - fed directly to a filter cake drier for (dry) raw meal production prior to a preheater/precalciner kiln.
- ***Wet process:*** The raw slurry is fed either directly to a long rotary kiln equipped with an internal drying/preheating system (conventional wet process) or to a slurry drier prior to a preheater/precalciner kiln (modern wet process).

The four processes are illustrated in the typical flow diagrams of Figures 3.2 to 3.5. Their operating characteristics are summarised in Table 3.4, and a schematic presentation of the production processes is given in Table 3.5. More detailed descriptions are given in the following Chapter 3.5 as well as in Chapter 6.

Figure 3.2 : Production of Cement by the Dry Process

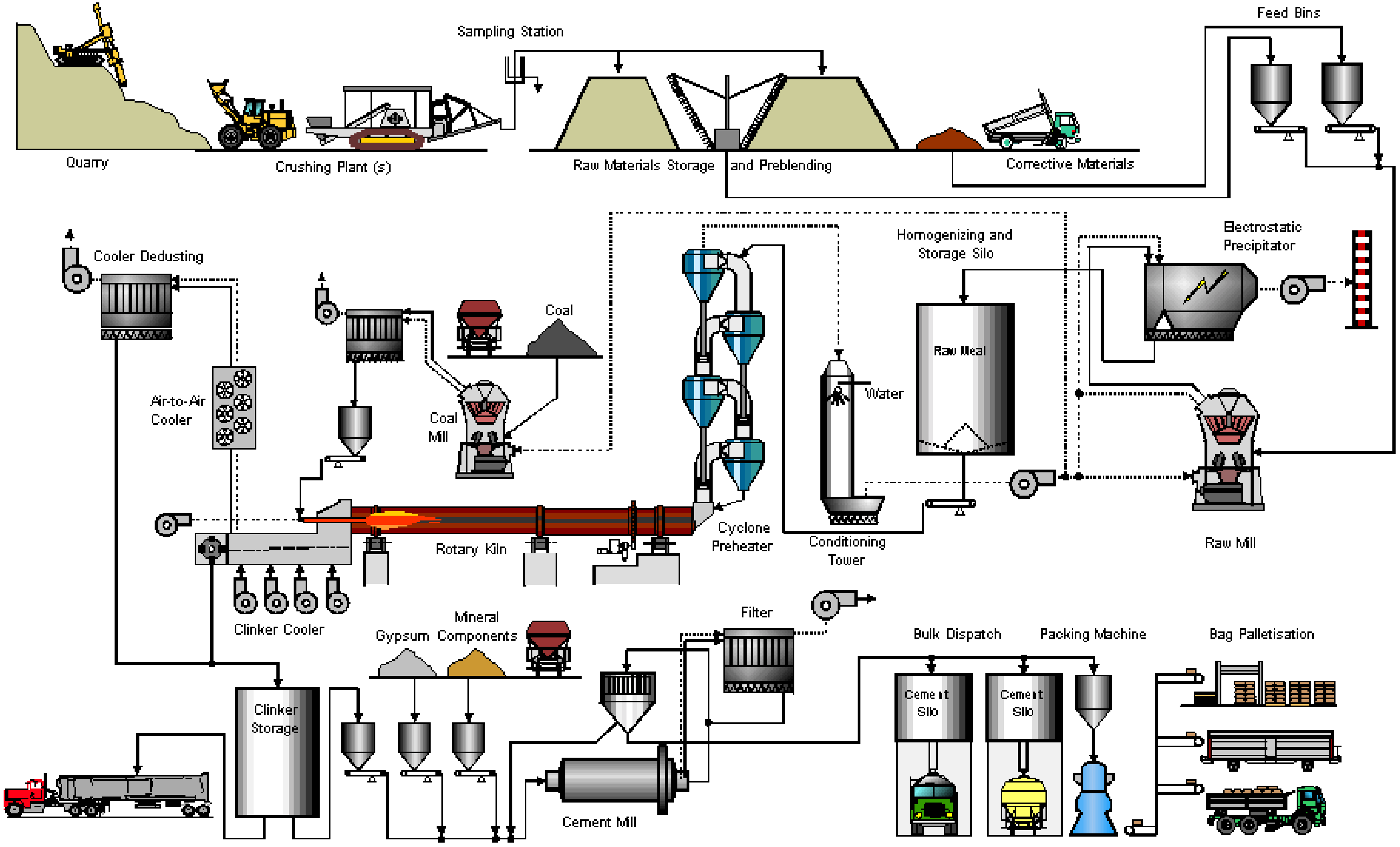


Figure 3.3 : Production of Cement by the Semi-Dry Process

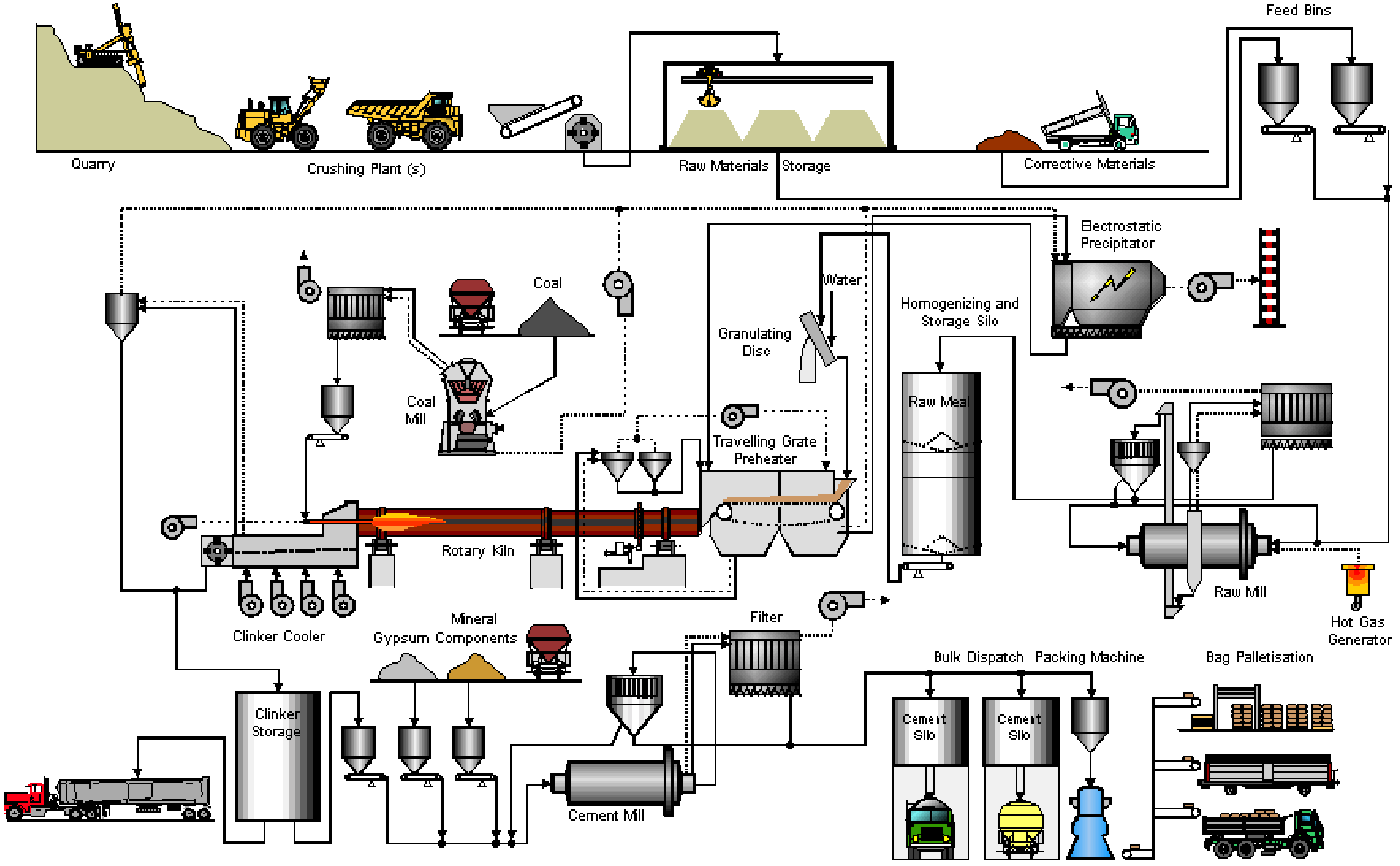


Figure 3.4 : Production of Cement by the Semi-Wet Process

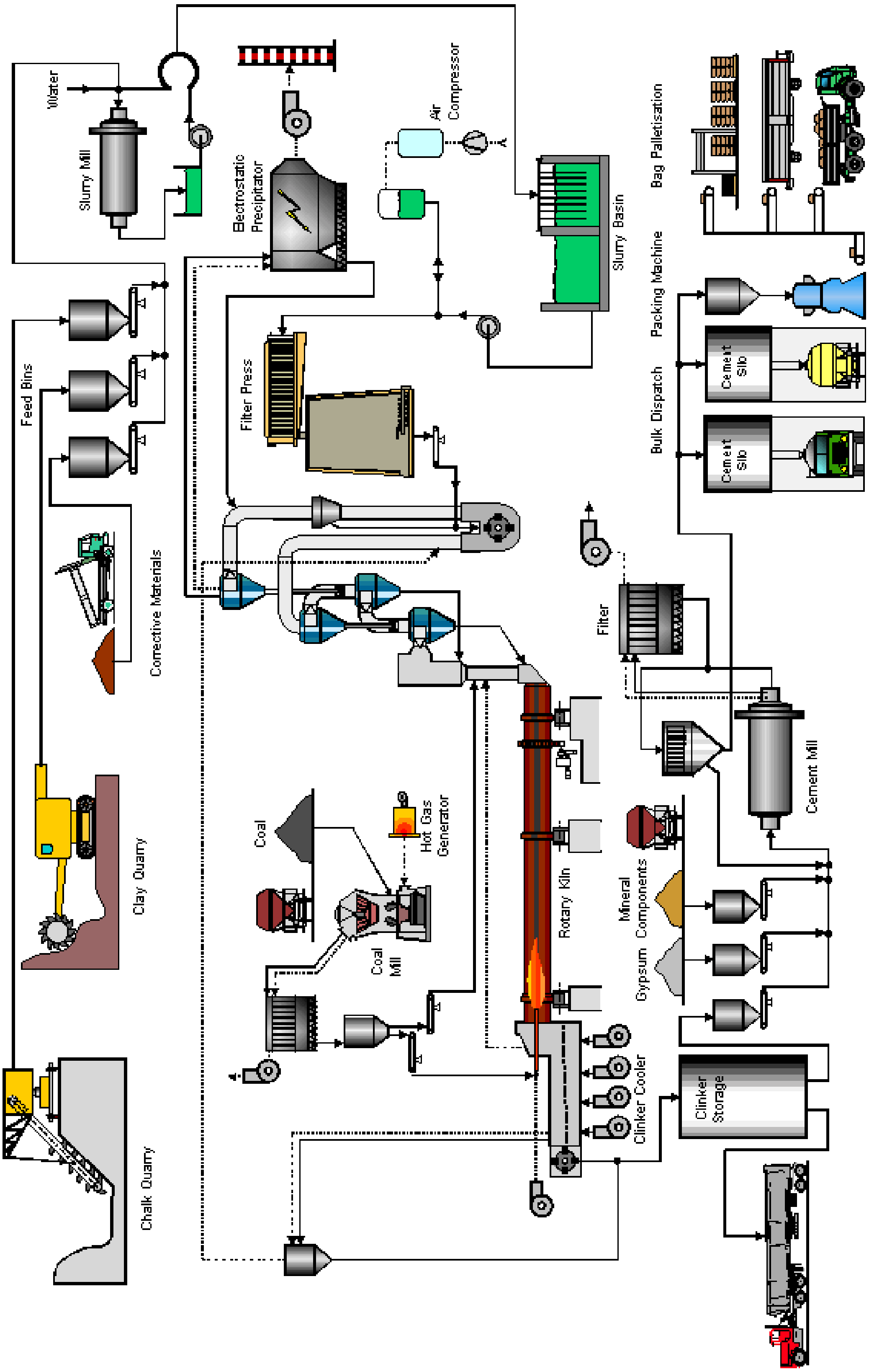


Figure 3.5 : Production of Cement by the Wet Process

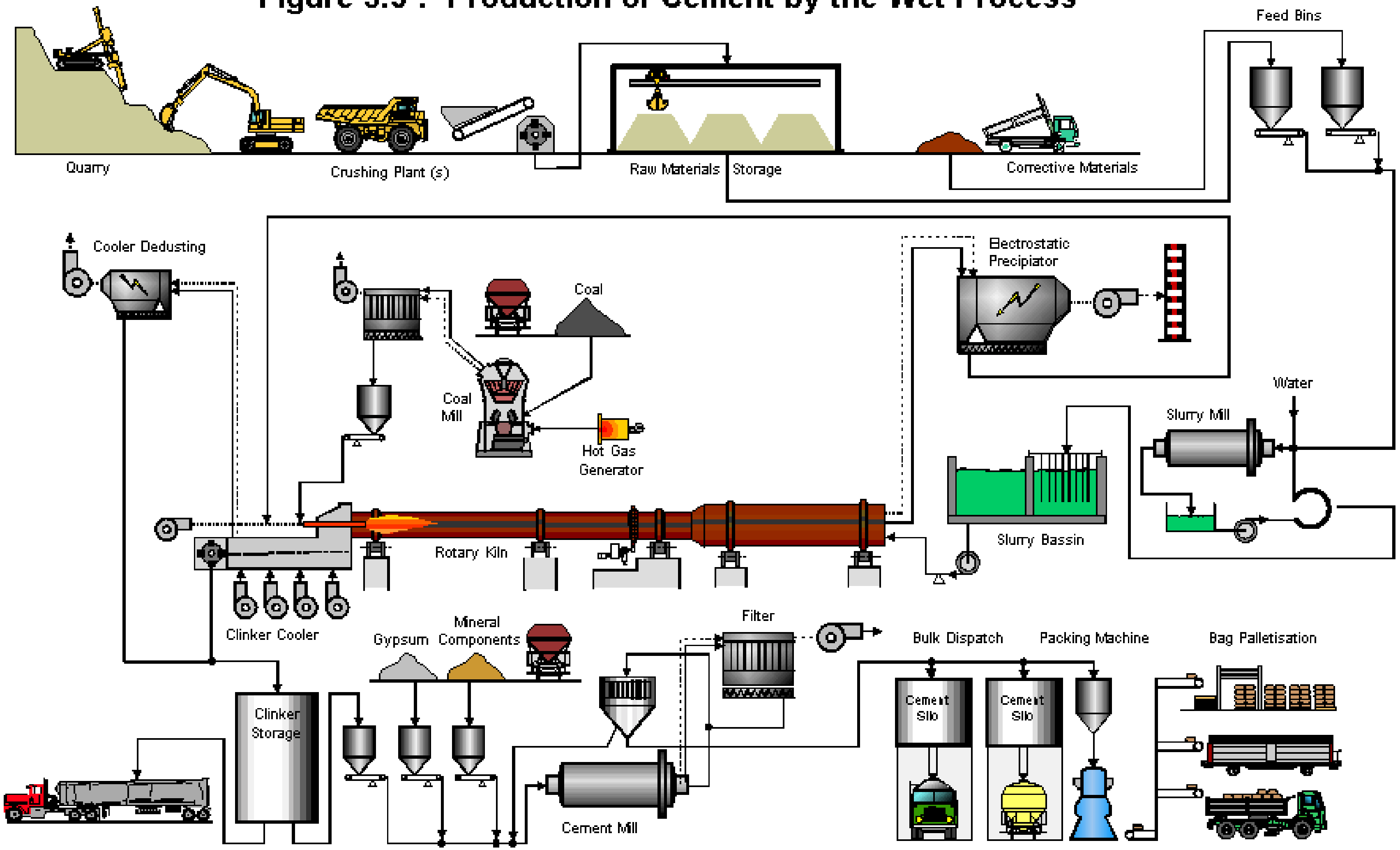


Table 3.4: Operating Characteristics of Kiln Processes

Process Type		Dry			Semi - dry		Semi - wet		Wet	
Kiln Type Lepol = Travelling grate preheater kiln SP = Cyclone preheater kiln PC = Cyclone preheater / precalciner kiln		**Long** **1 stage SP** **2 stage SP**	**4 stage SP**	**4 to 6 stage PC**	**Long**	**Lepol**	**Lepol** **(3 chambers)**	**3 and 4 stage SP and PC with dryer**	**Long**	**2 stage PC with dryer**
Kiln characteristics	Feedstock	← Dry raw meal →			← Pelletised raw meal →		← Filter cake →		← Slurry →	
	Moisture content [%]	← 0.5 – 1.0 →			← 10 – 12 →		← 16 – 21 →		← 28 – 43 →	
	Heat exchange devices	Chains and cyclone preheater	Cyclone preheater	Cyclone preheater	Crosses	Travelling grate preheater	Travelling grate preheater	Cyclone preheater	Chains and crosses	Cyclone preheater
	Kiln capacity [t/d]	300 – 2800	300 – 4000	2000 – 10000	300 – 1500	300 – 2000	300 – 3000	2000 – 5000	300 – 3600	2000 - 5000
	Spec. heat consumption [GJ/t]	3.6 – 4.5	3.1 – 3.5	3.0 – 3.2	3.5 – 3.9	3.2 – 3.6	3.6 – 4.5	3.4 – 3.6	5.0 – 7.5	4.5 – 5.0
Exhaust gas characteristics	Spec. exh. gas quantity at system stack [$Nm^3/kg\ cli_{dry}$]	1.7 – 2.0	1.8 – 2.0 / 2.2 – 2.4 *	1.8 – 1.9 / 2.1 – 2.2 *	1.7 – 1.8	1.9 – 2.1	3.4 – 4.0	2.1 – 2.3	2.2 – 3.2	2.1 – 2.3
	O_2 content at system stack [% vol.]	4 - 5	8 – 9 / 9 – 11 *	8 – 9 / 9 – 11 *	4 – 5	6 - 10	12 – 14	8 – 10	4 – 5	5 – 6
	Temperature at filter inlet (with EP dedusting) [° C]	150	150/100 *	150/100 *	200	100	100	120 – 150	180 – 220	120 - 150
	Dew point [° C]	← 45 – 65 →			← 50 – 60 →		← 55 – 65 →		← 70 – 80 →	

* Direct operation / compound operation

Table 3.5: Schematic Presentation of Cement Production Processes

		Production Processes							
Sub-Processes	**Process Steps**	Dry		Semi-dry		Semi-wet		Wet	
Quarrying	RMat extraction	■	■	■	■	■	■	■	■
	RMat crushing	■	■	■	■	■	■	■	■
	RMat storage	■	■	■	■	■	■	■	■
	RMat prehomogenisation	■	■	■	■	▥	▥	▥	▥
Raw Material Preparation	Raw grinding / drying with ball mills, vertical mills, etc.	■	■	■	■				
	RMeal storage	■	■	■	■				
	RMeal (blending and) homogenisation	■	■	■	■				
	RMeal pelletisation			■	■				
	Slurry grinding with wash mills and ball mills					■	■	■	■
	Slurry blending and storage					■	■	■	■
	Slurry homogenisation					■	■	■	■
	Slurry filtration with filter presses					■	■		
	Filter cake storage					■	■		
	Filter cake nodulisation						■		
Clinker Burning	Long kiln, internal slurry, pellets or nodules drying equipment				■				■
	Separate external slurry, pellets, nodules or filter cake drying equipment			■		■	■	■	
	RMeal preheating	■	■	■	■	■	■	■	■
	RMeal calcination	■	■	■	■	■	■	■	■
	RMeal clinkerisation	■	■	■	■	■	■	■	■
	Clinker cooling	■	■	■	■	■	■	■	■
	Clinker storage	■	■	■	■	■	■	■	■
	Process detail identification *)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Cement Grinding	Cement grinding in ball mills, roller presses, vertical mills, etc.	■	■	■	■	■	■	■	■
	Cement storage	■	■	■	■	■	■	■	■
Cement Dispatch	Bulk loading, bagging, palletising, dispatch on rail, road and waterways	■	■	■	■	■	■	■	■

Process Detail Identification *)

1. 4 stage cyclone preheater kilns, 4 to 6 stage precalciner kilns
2. Long dry kilns, 1 and 2 stage cyclone preheater kilns
3. Grate preheater (Lepol) kilns
4. Long pellet kilns with internal cross systems
5. Cyclone preheater and precalciner kilns with external dryers
6. Grate preheater (Lepol) kilns
7. 2 stage precalciner kilns with external slurry dryers
8. Long wet kilns with chain systems

3.5. PROCESS TECHNOLOGICAL CHARACTERISTICS OF CLINKER PRODUCTION

All processes have in common that the kiln feed is first dried, then calcined by dissociation of carbon dioxide (CO_2) from the $CaCO_3$ in the feed material, and finally sintered to clinker at temperatures between 1,400 and 1,450º C. During this process the feed loses approximately one third of its original dry mass. The hot clinker is cooled by air to 100-200º C in a clinker cooler. The heated air is used as secondary combustion air in the kiln.

3.5.1 THE DRY PROCESS

For dry and semi-dry kiln systems, raw meal is prepared by drying and grinding of the raw material components in tube mills or vertical roller mills, making use of the hot kiln exhaust gases or cooler exhaust air for drying. Prior to being fed to the kiln, the raw meal is homogenised and/or blended either in batch type or in continuously operating homogenising silo systems. For further details see Chapter 6.3 and 6.4.

In ***suspension preheater kilns***, the raw meal is fed to the top of a series of cyclones passing down in stepwise counter-current flow with hot exhaust gases from the rotary kiln thus providing intimate contact and efficient heat exchange between solid particles and hot gas. The cyclones thereby serve as separators between solids and gas.

Prior to entering the rotary kiln, the raw meal is heated up to a temperature of approximately 810-830° C where the calcination (i.e. the release of CO_2 from the carbonates) is already about 30% complete. The exhaust gases leave the preheater at a temperature of 300-360° C and are further utilised for raw material drying in the raw mill.

4-stage preheater kilns are susceptible to blockages and build-ups caused by excessive input of elements such as sulphur, chlorides or alkalis which are easily volatilised in the kiln system. This input has to be carefully controlled. Excessive input may require the installation of a system which allows part of the rotary kiln gases to bypass the preheater. Thereby part of the volatile compounds are extracted together with the gas.

A bypass system extracts a portion (typically 5-15%) of the kiln gases from the riser pipe between the kiln and preheater. This gas has a high dust burden. It is cooled with air, volatile compounds are condensed onto the particulates and the gas then passes through a dust filter.

Modern suspension preheater kilns usually have 4 cyclone stages with a maximum capacity limited to approximately 4000 t/d. In some cases, 2-stage cyclone preheaters or 1-stage preheaters supported by internal chain heat exchangers are still in operation.

A considerable capacity increase can be obtained with ***precalciner kilns*** with a second combustion device between the rotary kiln and the preheater section. In the precalciner, up to 60% of the total fuel of the kiln system can be burnt. At an exit temperature of about 880° C, the hot meal is calcined to a degree of around 90% when entering the rotary kiln.

Kiln systems with 5 to 6 stage cyclone preheater and precalciner are considered standard technology for new plants today, as the extra cyclone stages improve thermal efficiency.

In some cases, the raw meal is fed directly to a ***long dry kiln*** without external preheater. A system of chains in the inlet part of the rotary kiln provides the heat exchange between the hot combustion gases from the hot zone of the kiln and the kiln feed. Long dry kilns have a high heat consumption and high dust cycles requiring separate dedusting cyclones.

3.5.2 THE SEMI-DRY PROCESS

In the semi-dry process, dry raw meal is pelletised with 10-12% of water on an inclined rotating table (“granulating disc”) and fed to a horizontal ***travelling grate preheater*** in front of the rotary kiln **(“Lepol” system)**. The pelletised material is dried, pre-heated and partly calcined on the two-chamber travelling grate making use of the hot exhaust gases from the kiln. A higher degree of calcination can be achieved by burning part of the fuel in the hot chamber of the grate preheater.

The hot exhaust gases from the kiln first pass through a layer of preheated pellets in the hot chamber. After intermediate dedusting in cyclones, the gases are drawn once again through a layer of moist pellets in the drying chamber of the grate. As much of the residual dust is precipitated on the moist pellet bed, the total dust load of the exhaust gases at the preheater outlet is low.

As a drawback of the semi-dry process, kiln exhaust gases cannot be utilised in the raw meal drying and grinding system due to the low temperature level. The maintenance costs of grate preheaters are high. Modern installations rarely use the semi-dry process.

3.5.3 THE SEMI-WET PROCESS

In the semi-wet process the raw slurry is dewatered in filter presses. Typically, modern chamber filtration systems produce filter cakes with a residual moisture content of 16-21%. In the past, filter cakes were further processed in extruders to form pellets which were then fed to grate preheater kilns with three chambers.

With modern cement plants, slurry filtration is applied only where raw materials have a very high natural moisture content, i.e. chalk. Filter cake coming from the filter presses is kept in intermediate storage bins before it is fed to heated crushers or dryers where a dry raw meal is produced which is fed to a modern preheater or precalciner kiln.

With the dryers/crushers operating full time in parallel with the kiln (compound operation), these systems have a very good energy recovery by making full use of the kiln exhaust gases and the cooler exhaust air.

3.5.4 THE WET PROCESS

Conventional wet process kilns are the oldest type of rotary kilns to produce clinker. Wet kiln feed (raw slurry) typically contains 28 to 43% of water which is added to the raw mill (slurry drums, wash mills and/or tube mills). Batch blending and homogenisation is achieved in special slurry silos or slurry basins where compressed air is introduced and the slurry is continuously stirred.

The slurry is pumped into the rotary kiln where the water has to be evaporated in the drying zone at the kiln inlet. The drying zone is designed with chains and crosses to facilitate the heat exchange between the kiln feed and the combustion gases. After having passed the drying zone, the raw material moves down the kiln to be calcined and burnt to clinker in the sintering zone.

Conventional wet kiln technology has a high heat consumption and produces large volumes of combustion gases and water vapour. Wet rotary kilns may reach a total length of up to 240 m compared to short dry kilns of 55 to 65 m length (without the preheater section).

In ***modern wet kiln systems***, the raw slurry is fed to a slurry drier where the water is evaporated prior to the dried raw meal entering a cyclone preheater/precalciner kiln. Modern wet kiln systems have a far lower specific heat consumption compared to conventional wet kilns.

More details and comparative figures for the different kiln processes are given in Chapter 6.6.

3.6. KILN EXHAUST GASES

In all kiln systems, the exhaust gases are finally passed through an air pollution control device for separation of the dust before being released to the atmosphere via stacks. Today, two types of dust separators are commonly used in the cement industry, i.e electrostatic precipitators and bag filters.

Bag filters have been used in the cement industry since well before the development of electrostatic precipitators. Bag filters make use of a fabric filter system, the “bags” which separate the dust particles from the exhaust gas. The dust particles are captured on the bag surface while the gas passes through the bag tissue. Two main types of bag filters are used, i.e. the “reverse gas” filter and the “pulse jet” filter with the main difference being in the cleaning procedure. Bag filter performance is not susceptible to process disturbances or “CO peaks”.

Electrostatic precipitators use electrostatic forces to separate the dust from the exhaust gas. By means of discharge electrodes, the dust particles are negatively charged and can be separated on corresponding collecting electrodes. The particles are then discharged from the collecting electrodes to dust hoppers by electrode rapping. In contrast to bag filters, the design of electrostatic precipitators allows the separate collection of coarse and fine particles. ESPs are susceptible to process changes such as CO peaks. The dedusting efficiency can be increased by making use of more than one electric "field" operating in series.

With a dedusting efficiency of up to 99.99% in modern control devices, it is possible to achieve a dust emission level from the stack below 50 mg per cubic meter of gas.

In the dry process, the kiln exhaust gases have relatively high temperature and low humidity. Therefore, they can be utilised for drying of the raw materials in the raw mill during "compound operation", i.e. when the raw mill is in operation. During "direct operation" (with the raw mill off), the hot exhaust gases have to be cooled down by means of water injection in a conditioning tower to a temperature suitable to the dust collector. With this procedure the gas volume is reduced, too, and the precipitation characteristics of the dust in the filter system are improved.

The dust collected in the filter devices can be fed back to the process, either by reintroducing it to the raw materials preparation system (dry process), by insufflation into the sintering zone (wet kilns), or by feeding the dust to the cement mill (if allowed in the cement standards).

In certain cases where the level of alkali elements is limited in cement clinker ("low alkali" clinker), not all the kiln dust can be returned to the system. Whereas an electrostatic precipitator allows the high alkali part of the dust to be separated and rejected, such a separation cannot be achieved with a bag filter and all the dust would have to be rejected.

The other main sources of dust in the cement manufacturing process which require dedusting are the clinker cooler, the raw mill and the cement mills. Due to its low temperature, exhaust air from cement mills does not require cooling.

Depending on the process stage where it is extracted, the chemical and mineralogical composition of the dust corresponds respectively to that of the raw meal, the clinker or the cement, or their intermediate products.

More details of dust collectors are given in Chapter 7.2.3.

3.7. CLINKER COOLERS

Clinker leaving the rotary kiln at a temperature around 1200-1250° C has to be cooled down rapidly to allow further transport and handling. This process also recovers heat from the clinker back to the kiln by preheating the air used for combustion in the main burner and in any secondary firing. In addition, rapid cooling prevents undesired chemical reactions in the clinker which may negatively affect the quality and the grindability of the clinker.

Three main types of clinker coolers are used (see also Chapter 6.7), i.e.:

- Rotary (tube) coolers
- Planetary (satellite) coolers, and
- Grate coolers

Tube coolers placed underneath the kiln outlet make use of the same principle as the rotary kiln for clinker burning, but for reverse heat exchange with cooling air drawn through the tube in counter-current flow to the hot clinker. This cooler type is rarely used in the cement industry.

In a **planetary (or satellite) cooler**, 9 to 11 tubes are arranged peripherally at the discharge end of the rotary kiln. Hot clinker enters the tubes through inlet ports and passes through the tubes in cross counter-current to the cooling air. Due to their design, planetary coolers are susceptible to comparatively high wear and to thermal shock effects, and – similarly to tube coolers – clinker exit temperatures may still be high without additional cooling by water injection. Planetary coolers are not suited for precalciner kilns as exhaust air cannot be extracted for combustion in the secondary firing.

Grate coolers are preferably used in modern installations. Cooling is achieved by cross-flow air blown through a clinker layer travelling slowly on a reciprocating grate which consists of perforated plates. The whole cooling zone includes a “recuperation zone” and an “aftercooling zone”. From the recuperation zone, preheated air is recovered for combustion of the main burner fuel (“secondary air”) and of the precalciner fuel (“tertiary air”). The hot air from the aftercooling zone can be used for drying of raw materials or coal.

Grate coolers thus provide the most efficient and most flexible heat recovery system for modern dry process kilns.

3.8. FUELS PREPARATION

The physical nature of the fuels used in a cement plant – solid, liquid or gaseous – determines the design of the storage, preparation and firing systems – both for conventional fossil fuels and for alternative fuels from industrial sources. The main fuel input has to be delivered in a form that allows uniform and reliable metering as well as easy and complete combustion. This is usually the case with all pulverised, liquid and gaseous fuels. A limited input (up to 35%) may also be delivered by the addition of coarse materials at specific feed points. For more details see Chapters 6.8 and 6.9.

Coal and petcoke are ground to a fineness similar to raw meal in coal mills (tube mills, vertical roller mills or impact mills). For safety reasons, the whole coal preparation system is designed for protection from fire or explosion. The pulverised fuel may be fed directly to the burner (without intermediate storage and metering system) or – which is common practice today – may be stored in fine coal silos with adequate metering and feeding systems.

Fuel oil is stored in large tanks on site. Handling is facilitated by heating up the oil to a temperature of about 80° C. Metering and combustion are facilitated by additional heating of the oil up to a temperature of 120-140° C, resulting in a reduction of the viscosity.

Natural gas is delivered by national or international distribution systems without on-site storage. Prior to combustion in the kiln, the pressure of the gas has to be reduced to the plant's network pressure in gas transfer stations where also the fuel metering takes place.

Alternative fuels originating from industrial sources may require specific treatment. Gaseous, liquid and pulverised or fine crushed solid fuels can be fed to the kiln system similarly to the fossil fuels mentioned above. Coarsely shredded or even bulky materials can be fed to the preheater/precalciner section or, rarely, to the midkiln section only. For process reasons, the contribution of bulky fuels to the total heat consumption should be limited to about 15 to 30% depending on the kiln system.

Alternative fuels are frequently prepared and blended outside the cement plant by specialised companies in facilities specifically designed for this purpose. The cement plant has to provide the storage and feeding systems only on site. Alternative fuel plants are often designed as "multi-purpose plants" in order to handle a variety of different wastes.

3.9. MINERAL ADDITIONS PREPARATION

Mineral additions used in the manufacture of blended cements require separate installations for storage, preblending, crushing, drying and feeding. Commonly used mineral additions include natural materials such as volcanic rocks, limestone or calcined clay, and materials originating from industrial sources such as granulated blast-furnace slag, pulverised fly ash from power stations, or microsilica.

Pre-drying may be required for materials with a high moisture content, for example, granulated blast-furnace slag. Rotary tube driers or flash driers make use of the kiln exhaust gases or cooler exhaust air or are operated with a separate hot gas source.

Mineral additions may be interground with cement clinker and gypsum in a cement mill or may be ground separately and blended with Portland cement subsequently. Separate grinding and blending is mainly applied in the production of slag cements. For separate grinding of mineral additions, the same installations are used as in cement grinding (see Chapter 3.10).

3.10. CEMENT GRINDING

The design of the cement grinding system selected largely depends on the cement types produced and on the physical characteristics of the individual components such as grindability, moisture content or abrasive behaviour. Accurate proportioning of major and minor components is essential for the quality of the product and for the energy efficiency of the system. The consumption of electrical energy depends on the grindability of the cement constituents and the type of grinding system.

The following mills for ***finish grinding*** are commonly applied (see also Chapter 6.12):

- Tube mills (open or closed circuit)
- Vertical roller mills
- Horizontal roller mills
- Roller presses.

Fineness and particle size distribution of the finished product have a strong influence on the cement quality. In modern grinding installations, fineness is mainly determined by the adjustment of ***separators*** as part of the mill system the oversize particles being returned from the separator to the mill inlet. Grinding systems with dynamic air (“high-efficiency”) separators offer the most flexible solution for plants producing a variety of cement types.

Conventional ***tube (ball) mills*** with open circuit (without separator) are mainly used when producing only one type of cement. Closed circuit tube mills with a separator are more flexible, but – as with open circuit mills – are limited with regard to the moisture content of the mill feed. The consumption of electrical energy in tube mills is generally high compared to the other mill types.

The working principle of ***vertical roller mills*** refers to the action of 2 to 4 “rollers” rotating on a horizontal grinding table or grinding bowl. Vertical roller mills can handle higher moisture contents in the mill feed and are therefore well suited for blended cements with higher rates of (moist) mineral additions or for separate grinding of mineral additions. Vertical mills can also be used for pregrinding in combination with a tube mill.

High pressure ***roller presses*** so far exhibit the lowest energy consumption for the grinding process. However, they still need a comparatively high degree of maintenance, and the particle size distribution of the finished product has to be optimised. Roller presses are mainly used in combination with tube mills, either as a pregrinding unit or in a two-stage grinding process.

A more recent development in cement grinding is the ***horizontal roller mill***. It consists of a rotating horizontal shell and a horizontal roller inside which can be pressed hydraulically onto the shell. The mill feed passes several times between the roller and the shell along the mill due to centrifugal forces and fixed material transfer devices. Only few installations are in operation so far.

3.11. IDENTIFICATION OF ENVIRONMENTAL SIGNIFICANCE

The main environmental impacts in the manufacture of cement are related to the following categories:

- Dust (stack emissions and fugitive sources)
- Gaseous atmospheric emissions (NOx, SO_2, CO_2, VOC, others)
- Other emissions (noise and vibrations, odour, process water, production waste, etc.)
- Resources consumption (energy, raw materials).

The following paragraphs present an overview of the topics mentioned above. Reference is also made to Chapter 7 “Available Techniques for Control of Potential Emissions” for more details.

3.11.1 DUST

Historically, the emission of dust – particularly from kiln stacks – has been the main environmental concern in cement manufacture. ***“Point source” dust emissions*** originate mainly from the raw mills, the kiln system, the clinker cooler, and the cement mills. A general feature of these process steps is that hot exhaust gas or exhaust air is passing through pulverised material resulting in an intimately dispersed mixture of gas and particulates. Primary reduction measures are therefore hardly available. The nature of the particulates generated is linked to the source material itself, i.e. raw materials (partly calcined), clinker or cement.

Dust emissions in the cement industry have been reduced by some 90% in the last 20 years, and state-of-the-art abatement techniques now available (electrostatic precipitators, bag filters) result in stack emissions which are insignificant in a modern and well managed cement plant.

Dust from dispersed sources in the plant area ***(“fugitive dust”)*** may originate mainly from materials storage and handling, i.e. transport systems, stockpiles, crane driving, bagging, etc., and from traffic movement on unpaved roads. Techniques for control and containment of fugitive dust such as dedusting of material transfer points, closed storage installations with proper ventilation, or vacuum cleaning equipment, etc. are described in Chapter 7.7.

As the chemical and mineralogical composition of dust in a cement plant is similar to that of natural rocks, it is commonly considered as a “nuisance” and not as a toxic product in applicable health and safety regulations.

Reduction and control of dust emissions in a modern cement plant requires both investments and adequate management practices but is no longer a technical problem.

3.11.2 GASEOUS ATMOSPHERIC EMISSIONS

Gaseous emissions from the kiln system released to the atmosphere are the primary environmental concern in cement manufacture today. Major gaseous emissions are NO_x and SO_2. Other emissions of less significance are VOCs (volatile organic compounds), CO, ammonia, HCl, and heavy metals. CO_2 as the main greenhouse gas is released in considerable quantities.

NO_x formation is an inevitable consequence of the high temperature combustion process, with a smaller contribution resulting from the chemical composition of the fuels and raw materials. Primary measures of controlling and reducing NO_x formation are described in Chapter 7.3 together with secondary reduction methods which may be required in addition.

Sulphur entering the kiln system via raw materials and fuels is largely captured in the kiln products. However, sulphur contained in raw materials as sulphides (or organic sulphur compounds) is easily volatilised at fairly low temperatures (i.e. 400-600° C) and may lead to considerable ***SO_2 emissions*** in the stack (see also Chapter 4). Primary and secondary SO_2 abatement techniques are covered in Chapter 7.4.

Other substances entering the kiln system which could give rise to undesirable emissions are either effectively destroyed in the high temperature combustion process or almost completely incorporated into the product (see also Chapter 4). Thus, the inherent process conditions prevailing in cement kilns result in emissions being usually at insignificant levels for most of these substances such as VOCs, HCl, HF, NH_3 or heavy metals.

Significant levels of organic compounds in natural raw materials may cause elevated ***hydrocarbon and CO emissions***. The main contribution to the hydrocarbon emissions is from methane. Emissions of chlorinated hydrocarbons such as dioxins and furans are usually well below existing limit values.

Input of other volatile components such as ***mercury*** is carefully controlled and limited to prevent undesired emissions. If kiln exhaust gas temperatures are low enough mercury will to a large extent be condensed onto collected dust in the filter system which is then returned to the process.

Carbon dioxide emissions arise from the calcination of the raw materials and from the combustion of fossil fuels. CO_2 resulting from calcination can be influenced to a very limited extent only. Emissions of CO_2 resulting from fuel combustion have been progressively reduced due to the strong economic incentive for the cement industry to minimise fuel energy consumption.

CO_2 reduction of some 30% in the last 25 years – arising mainly from the adoption of more fuel efficient kiln processes – leaves little scope for further improvement.

Potential is mainly left to the increased utilisation of renewable alternative fuels or other waste derived fuels, and to the production of blended cements with mineral additions substituting clinker.

3.11.3 OTHER EMISSIONS

Heavy machinery and large fans used in the cement manufacture may give rise to emissions of ***noise and vibrations***. Primary and secondary reduction measures are described in Chapters 7.8 and 7.10, respectively.

Odour emissions are seldom a problem with a well operated plant, but may be mainly related to emissions from handling and storage of conventional or alternative fuels. In exceptional cases, nitrogen compounds in the raw materials may lead to ammonia emissions which – even at low concentrations – may give rise to odour. Odour control is dealt with in Chapter 7.9.

Process water in cement manufacturing will usually be completely evaporated or recycled in the process. Filtrate water from filter presses used in the semi-wet process is fairly alkaline and contains suspended solids requiring site-specific treatment and/or disposal options.

Kiln dust collected from the gas cleaning devices is highly alkaline and may contain trace elements such as heavy metals corresponding to the contents in the source materials. Usually, kiln dust is completely returned to the process, but under certain circumstances, part of it has to be rejected and disposed of.

Bypass dust extracted from the kiln system may be highly enriched in alkalis, sulphates and chlorides and – similarly to filter dust – in some cases cannot be completely recycled to the process. For both types of dust, conditioning and safe disposal avoiding contamination of groundwater or soil is a site-specific requirement.

3.11.4 RESOURCES CONSUMPTION

Cement manufacturing is a “high volume process” and correspondingly requires adequate quantities of resources, i.e. raw materials, thermal fuels and electrical power (see also Chapter 4.7).

The following table provides an indication of the consumption of ***raw materials*** used on average for the production of cement. The consumption figures in the last column are calculated for a “medium-sized” plant with a clinker production of 3000 tons per day or 1 million tons per year. Based on average figures for the clinker content in cement in Europe, a clinker production of 1 million tpy corresponds to a cement production of 1.23 million tons per year.

Material (dry basis)	per ton of clinker	per ton of cement	per year and per M tons of clinker
Limestone, marl, clay, shale, others	1.57 t	1.27 t	1,568,000 t
Gypsum, anhydrite		0.05 t	61,000 t
Mineral additions		0.14 t	172,000 t

Cement manufacturing is also an energy intensive process. The specific ***thermal energy*** consumption of a cement kiln varies between 3,000 and 7,500 MJ per ton of clinker, depending on the basic process design of the plant (see also Chapter 3.4, Table 3.4).

Major consumers of ***electrical energy*** in the cement manufacturing process are the mills (cement mills, raw mills, coal mills) and the large fans (predominantly in the kiln system and with the cement mills). The specific electrical energy consumption ranges typically between 90 and 130 kWh per ton of cement.

The continued effort over past years to improve energy efficiency means that there is little room for further improvement. A study by the European Commission in 1993 concluded that the potential further savings which might be made in the EU cement sector amount to about 2.2%.

Although there is little room for further improvement in up-to-date cement plants, efforts continue with regard to equipment design and process technology to further improve the overall energy efficiency. In addition, conservation of natural resources can be achieved through increased substitution of natural raw materials and fossil fuels by industrial by-products and residues in the manufacturing process.

3.12. EMISSION DATA

3.12.1 AVERAGE EMISSION DATA

Representative emission data (long term average values) from European cement kilns in operation are summarised in the following table:

Emission	mg per standard cubic meter [mg/Nm^3]
Dust	20 – 200
NO_x	500 – 2,000
SO_2	10 – 2,500
Total organic carbon (TOC)	10 – 100
CO	500 – 2,000
Fluorides	< 5
Chlorides	< 25
PCDD/F	< 0.1 [ng/Nm^3]
Heavy metals:	
- class 1 (Hg, Cd, Tl)	< 0.1
- class 2 (As, Co, Ni, Se, Te)	< 0.1
- class 3 (Sb, Pb, Cr, Cu, Mn, V, Sn) incl. Zn	< 0.3

Note: The figures given above are representative of the ranges within which kilns normally operate. Due to the age and design of the plant, the nature of the raw materials, etc., individual kilns may operate outside these ranges.

3.12.2 EMISSION LIMITS

Annex 1 provides information on current national emission limits in Europe. In general, emission limits refer to certain “reference conditions” in the dry or wet gas (i.e. 0° C and 1013 mbar), sometimes adjusted to a specified oxygen level. Limit values also refer to averaging periods which may be different from country to country (half-hourly, hourly, daily, annual average). Specific conditions for short term non-compliance (exceedances) also apply.

Compliance with applicable emission limit values has to be demonstrated by **emission monitoring** – either on a continuous or on a periodical basis. Continuous monitoring may be required for dust, NO_x, SO_2 and – in some cases – also for VOC. Periodical spot measurements are required if pollutants cannot be measured continuously or in order to verify and calibrate continuous monitoring equipment.

All these measuring techniques are subject to analytical uncertainties which are described by confidence limits or tolerance intervals. For further details see also Chapter 5.5.

CHAPTER 4

SPECIAL CHARACTERISTICS OF THE CEMENT PRODUCTION PROCESS

4.1 INTRODUCTION

The purpose of this chapter is to provide condensed information on the inherent characteristics of the cement manufacturing process, especially with regard to its environmental impacts and benefits.

The following main characteristics are discussed in sub-Chapters 4.2 to 4.9:

The cement manufacturing process is a high temperature process perfectly suited for the complete destruction of all kinds of organic compounds in the fuels (Chapter 4.2).

- The cement manufacturing process is a closed cycle process where all mineral input is incorporated into the product leaving no residues for disposal (Chapter 4.3).
- The cement manufacturing process represents an integrated multi-stage scrubber system for exhaust gas cleaning (Chapter 4.4).
- Gaseous emissions originating from the cement manufacturing process are to a large extent determined by the characteristics of the available raw materials (Chapter 4.5).
- The cement manufacturing process may give rise to emissions from the input of components which are easily volatilised in the kiln system (Chapter 4.6).
- The cement manufacturing process is a high volume process with continuous operation representing a large potential for the integration of all kinds of materials (Chapter 4.7).
- The environmental impact of the cement manufacturing process is mainly restricted to atmospheric emissions thus not representing an environmental “multi-media” impact process (Chapter 4.8)
- The cement manufacturing process has a large potential for substantial contribution to ecological improvement by making beneficial use of alternative fuels and raw materials (Chapter 4.9).

Finally, Chapter 4 illustrates the substantial role the cement industry can play in national and international waste recycling and valorisation schemes as well as in CO_2 mitigation programmes.

4.2 THE CEMENT MANUFACTURING PROCESS: A HIGH TEMPERATURE PROCESS

Main Combustion Characteristics:

In the burning of cement clinker it is necessary to maintain ***material temperatures*** of up to 1,450° C in order to ensure the sintering reactions required. This is achieved by applying peak ***combustion temperatures*** of about 2,000° C with the main burner flame. The combustion gases from the main burner remain at a temperature above 1,200° C for at least 5-10 seconds.

An excess of oxygen – typically 2-3% – is also required in the combustion gases of the rotary kiln as the clinker needs to be burned under oxidising conditions. These conditions are essential for the formation of the clinker phases and the quality of the finished cement.

The ***retention time*** of the kiln charge in the rotary kiln is 20-30 and up to 60 minutes depending on the length of the kiln. Figure 4.1 illustrates the temperature profiles for the combustion gases and the material for a preheater/precalciner rotary kiln system. While the temperature profiles may be different for the various kiln types, the peak gas and material temperatures described above have to be maintained in any case.

Conditions of Combustion in Cement Kilns:

	Cement kilns
Combustion Temperature	1,800 – 2,000° C (main burner)
Retention Time	5 – 10 s at T > 1,200° C
Oxygen Content	2 – 3%

The burning conditions in kilns with precalciner firing depend on the precalciner design. Gas temperatures from a precalciner burner are typically around 1,100° C**,** and the gas retention time in the precalciner is approximately 3 seconds.

Under the conditions prevailing in a cement kiln – i.e. flame temperatures of up to 2,000° C, material temperatures of up to 1,450° C and gas retention times of up to 10 seconds at temperatures between 1,200 and 2,000° C – all kinds of organic compounds fed to the main burner with the fuels are reliably destroyed.

The combustion process in the main flame of the rotary kiln is therefore complete. No (hydrocarbon type) products of incomplete combustion can be identified in the combustion gases of the main burner at steady-state conditions.

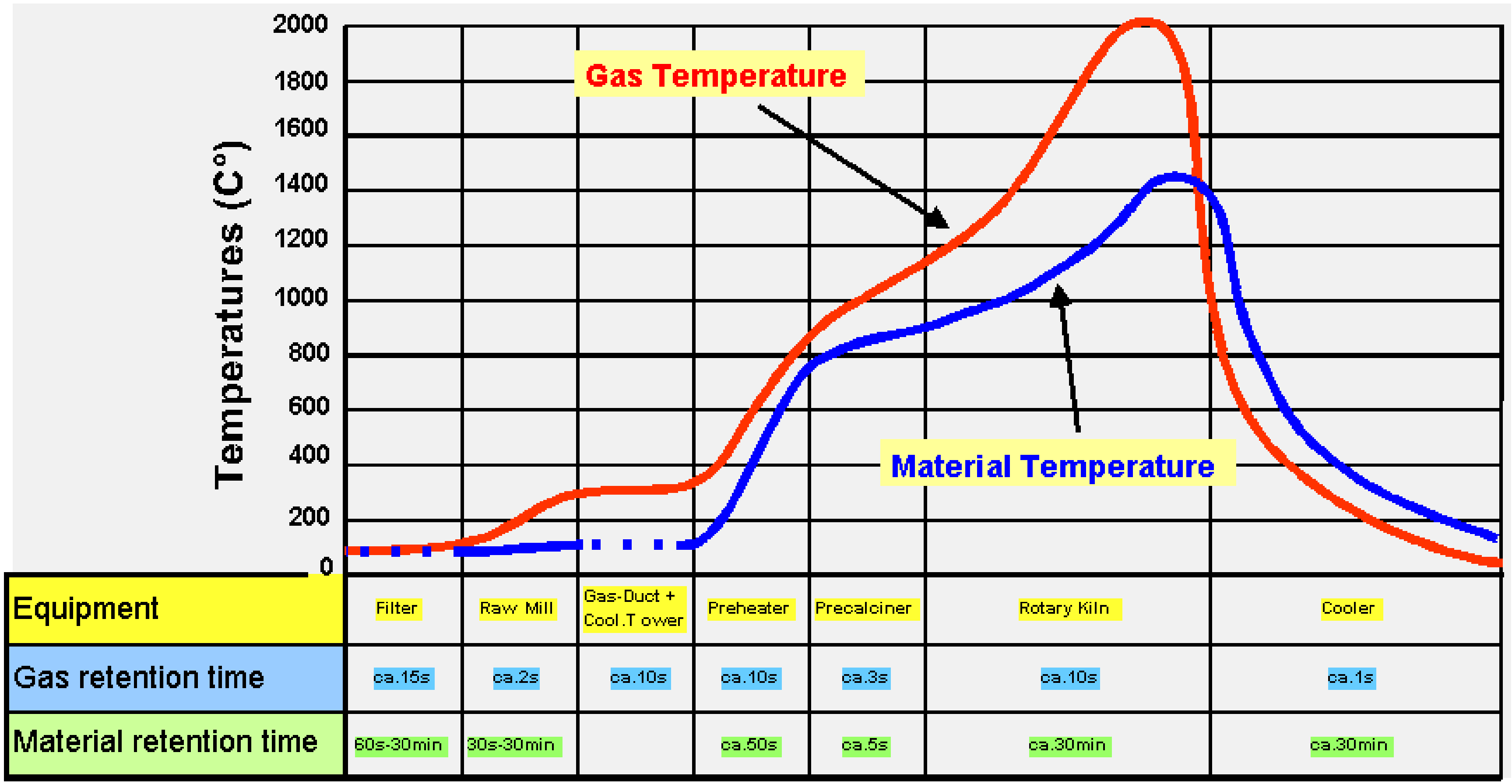
NO_x Formation:

Due to the very high temperatures in the main flame of the rotary kiln, nitrogen oxides are formed by oxidation of molecular nitrogen in the combustion air (***"thermal" NO_x*** [1]). Thermal NO_x formation is strongly dependent on the combustion temperature with a marked increase above 1,400° C. "Hard" burning required by certain raw mixes – i.e. at a higher temperature profile – increases NO_x formation.

---

[1] NO_x: sum of nitrogen oxides. In cement kiln exhaust gases, NO and NO_2 are dominant (> 90% NO, < 10% NO_2).

Figure 4.1 : Gas and Material Profiles in a Cyclone Preheater/Precalciner Kiln System (Compound Operation)



Equipment	Filter	Raw Mill	Gas-Duct + Cool.T ower	Preheater	Precalciner	Rotary Kiln	Cooler
Gas retention time	ca.15s	ca.2s	ca.10s	ca.10s	ca.3s	ca.10s	ca.1s
Material retention time	60s-30min	30s-30min		ca.50s	ca.5s	ca.30min	ca.30min

While thermal NO_x is the dominant contribution to total NO_x generation, a smaller part may also result from nitrogen compounds contained in the fuels which are oxidised in the flame as well ("***fuel*** NO_x"). In the main burner flame, the contribution of fuel NO_x is much lower than that of thermal NO_x.

In the secondary firing of a preheater/precalciner kiln with a flame temperature of not more than 1,200° C, the formation of thermal NO_x is much lower compared to the main burner flame. Therefore, in precalciner kilns where up to 60% of the total fuel can be burnt in the calciner flame, fuel NO_x may be a higher proportion of the reduced total NO_x emissions.

Natural raw materials such as clays or shales may also contain nitrogen compounds. Part of these compounds may be released and oxidised upon heating in the kiln system and may thus in certain cases considerably contribute to the total NO_x emissions (***"raw materials*** NO_x***"***).

Sources of NO_x ***in a Cement Kiln:***

Origin	Mechanism
Thermal NO_x	Oxidation of molecular nitrogen in combustion air at T > 1,200° C
Fuel NO_x	Oxidation of organic nitrogen in fuels
Raw Materials NO_x	Oxidation of (in)organic nitrogen in raw material minerals

NO_x formation is reduced if fuel is burnt in a more "reducing" atmosphere with low oxygen content. Operation under reducing conditions is limited due to process requirements in order to maintain good clinker quality and undisturbed kiln operation.

NO_x emissions in cement kilns (expressed as NO_2) typically vary between 500 and 2,000 mg/Nm^3. Primary and secondary abatement techniques are described in detail in Chapter 7.3.

The formation of nitrogen oxides is an inherent mechanism in a high temperature combustion process such as cement production. It can be influenced to a limited extent only by primary reduction measures.

4.3 THE CEMENT MANUFACTURING PROCESS: ALL INPUT TURNED INTO PRODUCT

During the clinker burning process, all mineral input delivered by the raw materials – be it natural or alternative raw materials sources – is converted into the clinker phases (i.e. calcium silicates, aluminates and ferrites; see Chapter 3.3) at the high temperatures prevailing in the sintering zone of the rotary kiln. Combustion ashes from conventional and alternative fuels are also completely incorporated into the clinker minerals. Therefore cement kiln systems do not generate combustion ashes which require separate disposal.

Consequently, the fuel ashes substitute for part of the (natural) raw materials input. In order to maintain a good clinker quality, the ash composition of the fuels has to be taken into account in the raw mix design.

Trace elements such as ***heavy metals*** are naturally present in low concentrations in the raw materials and fuels used for the manufacture of cement clinker. The behaviour of these metals in the burning process depends largely on their volatility (see also Chapter 4.6):

- **Non-volatile metals** remain completely within the product and leave the kiln system fully incorporated in the mineral structure of the clinker – similarly to the main elements. Most of the common metals are non-volatile.
- **Semi-volatile elements** such as cadmium or lead may in part be volatilised with the high temperature conditions in the sintering zone of the kiln system. They condense on the raw materials in cooler parts of the kiln system and are reintroduced to the hot zone again. A major part of cadmium and lead will be incorporated in clinker, the remaining part will precipitate with the kiln dust and will be collected in the filter systems.
- **Volatile metals** such as mercury and thallium are more easily volatilised and condense on raw material particles at lower temperatures in the kiln system (thallium at appr. 300-350° C, mercury at 120-150° C). Whereas thallium is nearly completely precipitated onto the kiln dust particles, only part of the mercury will be collected with the filter system. Volatile metals are retained in the clinker minerals to a very small extent only.

Being the only metal which can be emitted with the clean gas in gaseous form, the input of mercury with raw materials and fuels has to be carefully controlled.

Kiln dust containing essentially the same minerals as the raw materials and/or clinker (and its intermediate products) is usually returned into the process – either to the kiln system or to the cement mill. In rare cases, it is not possible to recycle kiln dust or bypass dust completely in the process. This residual dust is disposed of on site (or in controlled landfills) or is treated and sold to other industries, i.e. as binder for waste stabilisation or even as fertiliser.

As described above, heavy metals delivered by either conventional raw materials and fuels or by alternative raw materials and fuels from industrial sources will be mainly incorporated in clinker or – to a lesser extent – in kiln dust. The final product in all applications however, is concrete and mortar which acts as a ***"multi-barrier system***" for metals due to the following reasons:

- Chemical and structural incorporation in the clinker minerals;
- Chemical and structural fixation in the hydration products;
- Physical encapsulation in the dense structure of concrete/mortar.

The cement manufacturing process is a closed cycle process where all mineral input – including toxic components such as heavy metals – is safely incorporated into the product leaving almost no residue for disposal.

4.4 THE CEMENT MANUFACTURING PROCESS: A PROCESS WITH INHERENT COMBUSTION GAS CLEANING TECHNOLOGY

In all kiln systems, the finely ground raw material moves in counter-current flow to the hot combustion gases. Thus, it acts perfectly as an integrated multi-stage exhaust gas cleaning system very similar to the operating principle of a circulating fluidised bed absorber. Components resulting from the combustion of the fuels or from the transformation of the raw materials remain in the exhaust gas only until they are absorbed by the fresh raw meal flowing in counter-current.

Wet kilns and long dry kilns provide intimate contact between gas and solid particles mainly at the kiln inlet with its chain system for heat exchange. Semi-dry and semi-wet kilns provide this "***scrubber effect***" mainly in the grate preheater section of the kiln system, and also in heated crushers or dryers when these are used.

Suspension preheater kilns with 4 to 6 cyclone stages are especially well suited to achieve a "multi-stage" scrubber effect especially when operating together with the raw mill (compound operation). At least 5 scrubber stages operate in series at different temperature levels between 100 and 800° C consuming roughly 1 kg of absorbent (i.e. raw meal/hot meal) per Nm^3 of exhaust gas.

Unlike specialised incinerators, the gas cleaning absorbent must not be separately injected to the exhaust gas stream of the clinker kiln as it is inherent in the system. The raw meal with its large specific surface and its high alkalinity provides an excellent medium to retain gas components within the kiln system. For instance, calcined or partly calcined raw meal with its high content of reactive calcium oxide has a high absorption capacity for acid gases such as sulphur dioxide and hydrochloric or hydrofluoric acid, but also for other pollutants such as heavy metals.

The separation of the final stage absorbens – i.e. the raw meal – is achieved in the highly efficient dedusting devices of the kiln system. Thus it is ensured that emissions of metals – possibly with the exception of mercury – together with the clean gas is always kept at very low levels.

The cement kiln system represents an integrated multi-stage scrubber system for exhaust gas cleaning allowing the emission of pollutants such as acid gases or metals to be kept at a minimum.

4.5 THE CEMENT MANUFACTURING PROCESS: ATMOSPHERIC EMISSIONS GOVERNED BY VOLATILE COMPONENTS IN THE RAW MATERIALS

Natural raw materials used for clinker production may contain volatile components in small quantities. These components will be volatilised and partly emitted under the conditions prevailing in the preheater section of a dry process cement kiln or in the drying/preheating zone of a long wet or long dry kiln, i.e. before entering the burning zone of the rotary kiln.

Organic Compounds:

It has been described in Chapter 4.2 that organic matter introduced to the main burner and to the secondary firing will be completely destroyed due to the high temperatures and the long retention time of the combustion gases.

However, natural raw materials such as limestones, marls and shales may also contain up to 0.8% w/w of organic matter (“kerogene”) – depending on the geological conditions of the deposit. A large part of this organic matter may be volatilised in the kiln system even at moderate temperatures between 400 and 600° C.

Kiln tests with raw meals of different origin have demonstrated that approximately 85 to 95% of the organic matter in the raw materials are converted to CO_2 in the presence of 3% excess oxygen in the kiln exhaust gas, and 5 to 15% are oxidised to CO. A small proportion – usually less than 1% – of the total organic carbon (“TOC”) content may be emitted as ***volatile organic compounds*** (“VOC”) such as hydrocarbons.

The emission level of VOC in the stack gas of cement kilns is usually between 10 and 100 mg/Nm^3, with a few excessive cases up to 500 mg/Nm^3. The CO concentration in the clean gas can be as high as 1,000 mg/Nm^3, even exceeding 2,000 mg/Nm^3 in some cases.

The carbon monoxide and hydrocarbon contents measured in the stack gas of cement kiln systems are essentially determined by the content of organic matter in the raw materials, and are therefore not an indicator of incomplete combustion of conventional or alternative fuels.

Sulphur Compounds:

Sulphur compounds enter the kiln system either with the fuels or with the raw materials. Sulphur compounds in raw materials are present mainly as sulphates (for example, calcium sulphate $CaSO_4$) or as sulphides (i.e. pyrite or marcasite FeS_2).

Sulphates in the raw materials are thermally stable up to temperatures of 1,200° C, and will thus enter the sintering zone of the rotary kiln where they are decomposed to produce SO_2. Part of the SO_2 combines with alkalis and is incorporated into the clinker structure. The remaining part of SO_2 is carried back to the cooler zones of the kiln system where it reacts either with calcined calcium oxide or with calcium carbonate thus being reintroduced to the sintering zone again (“***chemical*** $\boldsymbol{SO_2}$ ***absorption”***).

Chemical Reactions with $\boldsymbol{SO_2}$***:***

$Na_2O + SO_2 + \frac{1}{2} O_2 = Na_2SO_4$
$K_2O + SO_2 + \frac{1}{2} O_2 = K_2SO_4$
$CaO + SO_2 = CaSO_3$
$CaCO_3 + SO_2 = CaSO_3 + CO_2$
$CaSO_3 + \frac{1}{2} O_2 = CaSO_4$

Inorganic and organic sulphur compounds introduced with the fuels will be subject to the same internal cycle consisting of thermal decomposition, oxidation to SO_2 and reaction with alkalis or with calcium oxide. With this closed internal cycle, all the sulphur which is introduced via fuels or via raw material sulphates will leave the kiln chemically incorporated in clinker, and will not give rise to gaseous SO_2 emissions.

Sulphides (and also organic sulphur compounds) in raw materials however, are decomposed and oxidised at moderate temperatures of 400 to 600° C to produce SO_2 when the raw materials are heated by the exhaust gases. At these temperatures, not enough calcium oxide is available to react with the SO_2. Therefore, in a dry preheater kiln about 30% of the total sulphide input may leave the preheater section as gaseous SO_2. During direct operation – i.e. with the raw mill off – most of it is emitted to the atmosphere. During compound operation – i.e. with the raw mill on-line – typically between 30 and 90% of that remaining SO_2 is additionally adsorbed to the freshly ground raw meal particles in the raw mill (***“physico-chemical absorption”***).

In grate preheater kilns SO_2 absorption is also good because the gas is passing through the turbulent flow of material from grate to kiln and then passing at low velocities firstly through the bed of material which is partly calcined and then through the moist calcium carbonate in the drying chamber.

In long dry and long wet kilns, the chemical absorption capacity for SO_2 is generally less efficient due to the reduced contact between kiln exhaust gas and raw materials. In these kiln systems, all kinds of sulphur input may partially contribute to SO_2 emissions, and the general emission level may be higher than in dry preheater kilns.

Gaseous emissions such as $\boldsymbol{SO_2}$ ***or VOC are to a large extent determined by the chemical characteristics of the raw materials used, and not by the fuel composition. Emissions are lowest with raw materials low in volatile components.***

4.6 THE CEMENT MANUFACTURING PROCESS: BEHAVIOUR OF VOLATILE COMPONENTS

Volatile components such as ***alkalis, sulphur and chlorine*** introduced with raw materials and fuels may give rise to problems in kiln operation when present in high concentrations. Build-up formation in the preheater cyclones or rings in the rotary kiln inlet zone may lead to reduced kiln availability and productivity. Thus, the input of these volatile components is carefully controlled for economic reasons.

Input control is also required to achieve and maintain the required quality of clinker and cement.

Depending on their volatility, alkalis, sulphur and chlorides evaporate in the sintering zone of the rotary kiln and recondense at cooler parts of the system either on the raw meal particles or on the surrounding walls. With the raw meal, they are reintroduced to the sintering zone again thus establishing a permanent "***internal cycle”*** of volatile “circulating” elements (see Figure 4.2). By reaching an equilibrium between input and output, a major part of the volatile components will finally leave the system incorporated in the clinker.

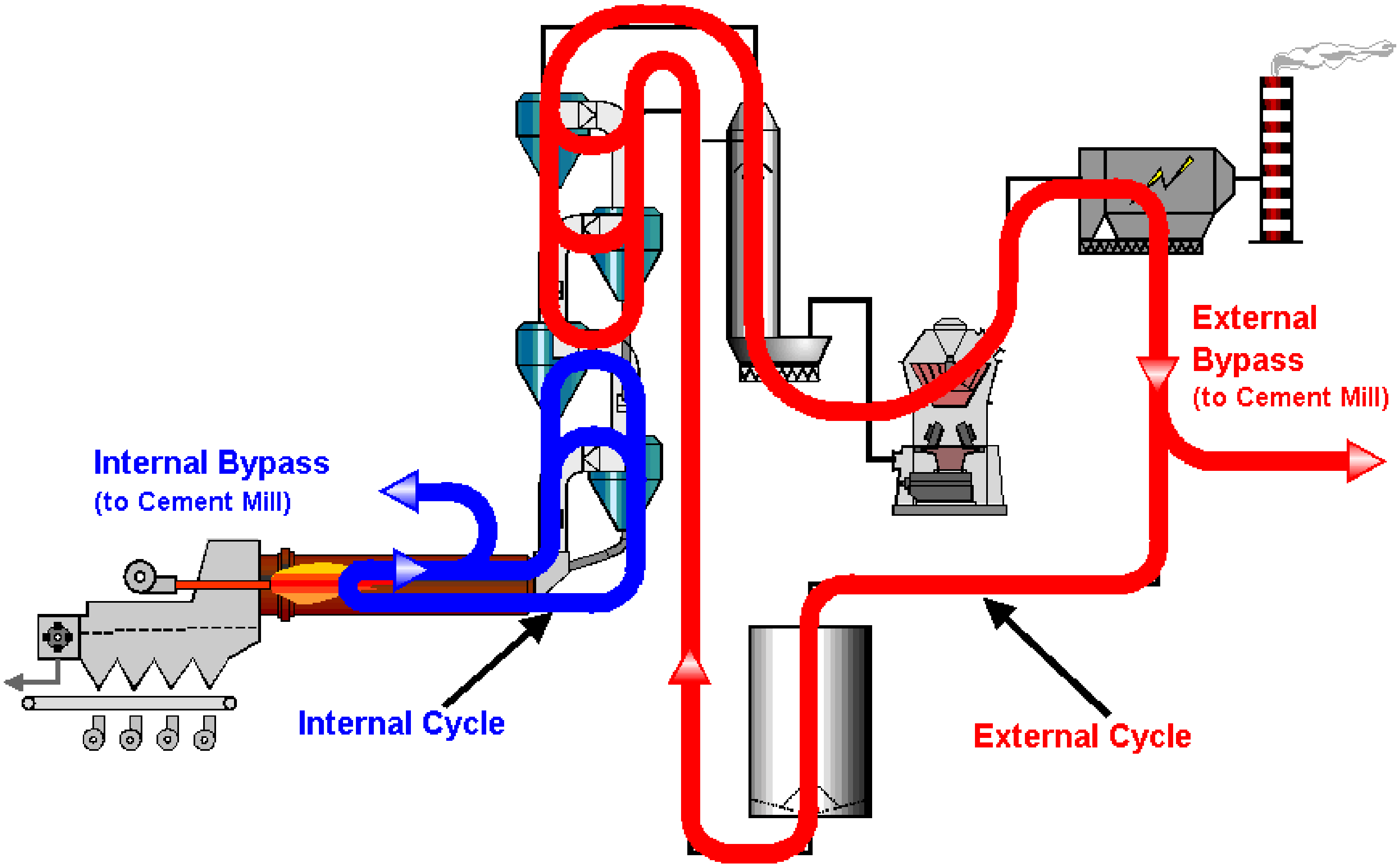
Part of the volatile components however, may form new compounds such as alkali chlorides or alkali sulphates and other intermediate phases such as spurrite which will then contribute to the build-up phenomena mentioned above by producing a “sticky” raw meal adhesive to the walls of the cyclones, the ducts or the kiln tube. A small part only of the circulating elements leaves the kiln with the exhaust gas dust and is precipitated in the dedusting device of the system. The behaviour of sulphidic sulphur in raw materials has been described in Chapter 4.5.

With excessive input of volatile elements, the installation of a kiln gas bypass system may become necessary in order to extract part of the circulating elements from the kiln system. This ***bypass dust*** which is usually highly enriched in alkalis, sulphur or chlorides is cooled down and then passed through a dust collector before being discharged.

Both kiln dust and bypass dust can be completely returned to the process. With wet kilns, the dust is reintroduced to the rotary kiln by either feeding it via specially designed scoops around the periphery of the kiln tube or – more frequently – by insufflating it into the burning zone of the kiln. With dry process kilns, the dust is usually blended into the raw meal for reintroduction, or part of it is fed directly to the cement mill (“***external cycle”,*** see Figure 4.2).

In some cases, for reasons of control of the alkali level in clinker or excessive input, it is not possible to recycle the dust completely to the process again. In these cases, part of the dust is sent to controlled landfills or – with or without further treatment – is sold as binder for waste stabilisation or as fertiliser.

Figure 4.2 : Circulation Phenomena



The behaviour of ***heavy metals*** in the kiln system has been described in detail in Chapter 4.3. The only metal that may be released through the kiln stack with gaseous emissions is mercury. Therefore, the input of mercury with raw materials or fuels is carefully controlled. All the other metals are either incorporated with the clinker or captured with the kiln dust in the dedusting units.

The cement manufacturing process is susceptible to the input of components which are easily volatilised in the kiln system. For simple economic reasons, this input is carefully controlled.

4.7 THE CEMENT MANUFACTURING PROCESS: A HIGH MATERIALS VOLUME PROCESS

The cement manufacturing process is an industrial process where large material volumes are turned into commercial products, i.e. clinker and cement. Figure 4.3 shows specific input and output flows.

Cement kilns operate continuously all through the year – 24 hours a day – with only minor interruptions for maintenance and repair.

A smooth kiln operation is necessary in a cement plant in order to meet production targets and to meet the quality requirements of the products. Consequently, to achieve these goals, all relevant process parameters are permanently monitored and registered including the analytical control of all raw materials, fuels, intermediate and finished products as well as environmental monitoring.

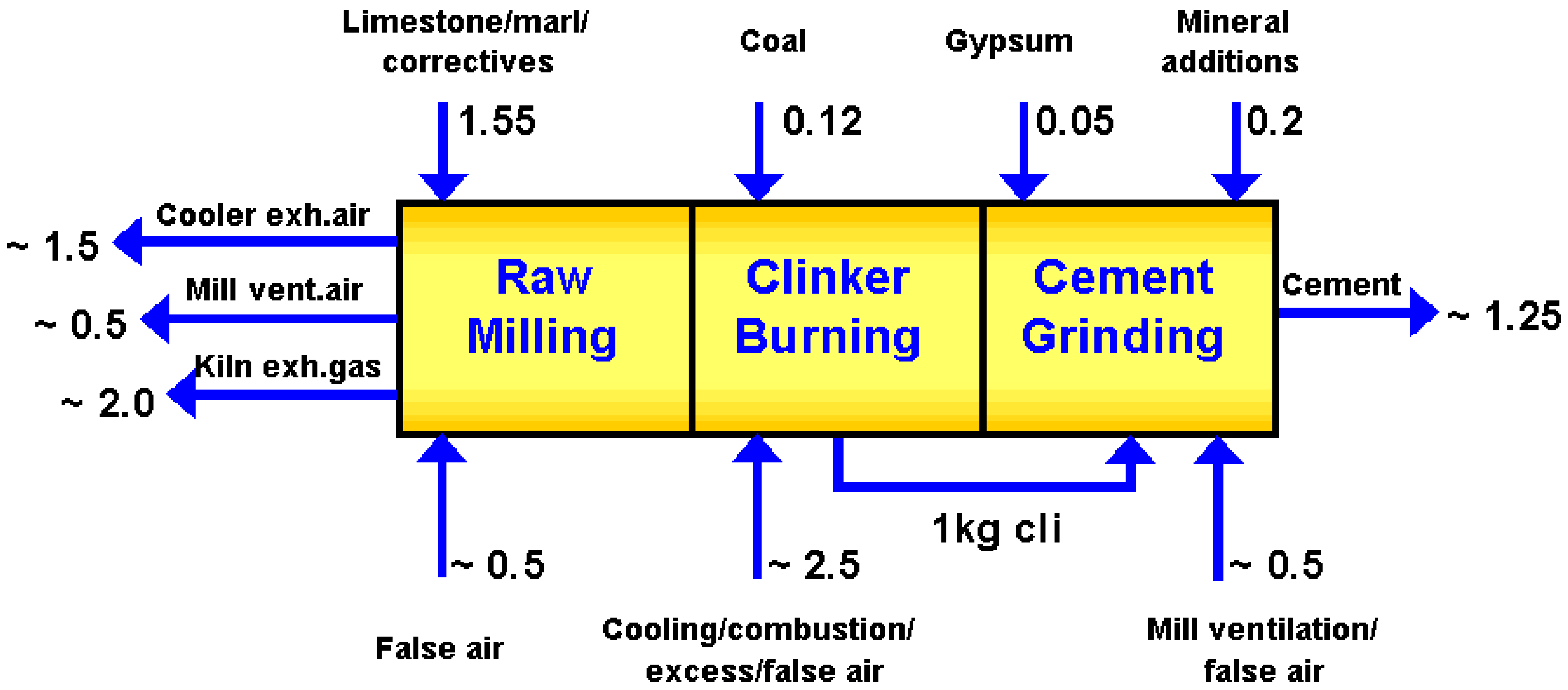
With these prerequisites – i.e. large material flow, continuous operation and comprehensive process and product control -, the cement manufacturing process seems to be perfectly suited for ***co-processing by-products and residues from industrial sources***, both as raw materials and fuels substitutes and as mineral additions.

The selection of appropriate ***feed points*** is essential for environmentally sound co-processing of alternative materials, i.e.:

- **Raw materials:** mineral waste free of organic compounds can be added to the raw meal or raw slurry preparation system. Mineral wastes containing significantly quantities of organic components are introduced via the solid fuels handling system, i.e. directly to the main burner, to the secondary firing or, rarely, to the calcining zone of a long wet kiln (“mid-kiln”).
- **Fuels:** alternative fuels are fed to the main burner, to the secondary firing in the preheater/precalciner section, or to the mid-kiln zone of a long wet kiln.
- **Mineral additions:** mineral additions such as granulated blastfurnace slag, fly ash from thermal power plants or industrial gypsum are fed to the cement mill. In Europe, the type of mineral additions permitted is regulated by the cement standards.

Figure 4.3 : Material Flows in a Cement Plant

Specific flows in kg/ kg cli or Nm3/kg clinker. The values also represent annual flows in million t/a or billion Nm3/a for a 1 million t clinker/a plant



In addition to regulatory requirements, the cement producers have set up self-limitations such as

- To prevent potential abuse of the cement kiln system in waste recovery operations
- To assure the required product quality
- To protect the manufacturing process from operational problems
- To avoid negative impacts to the environment, and
- To ensure workers' health and safety.

The cement manufacturing process is a large materials throughput process with continuous operation and comprehensive operational control. Therefore, it has a large potential for co-processing a variety of materials from industrial sources.

4.8 THE CEMENT MANUFACTURING PROCESS: LIMITED IMPACT ON THE ENVIRONMENT

Particulate and gaseous emissions to the atmosphere are certainly the major environmental impact in the manufacture of clinker and cement, i.e. dust, SO_2, NO_x, VOC in a few cases, and CO_2. In Chapter 4.5 it has been explained that gaseous emissions – except for NO_x – are mainly caused by the chemical characteristics of the raw materials, and not of the fuels.

Other gaseous emissions such as hydrochloric acid or hydrofluoric acid are nearly completely captured by the inherent and efficient alkaline scrubber effect of the cement kiln system, and are far below the regulatory limits (see also Chapter 4.4).

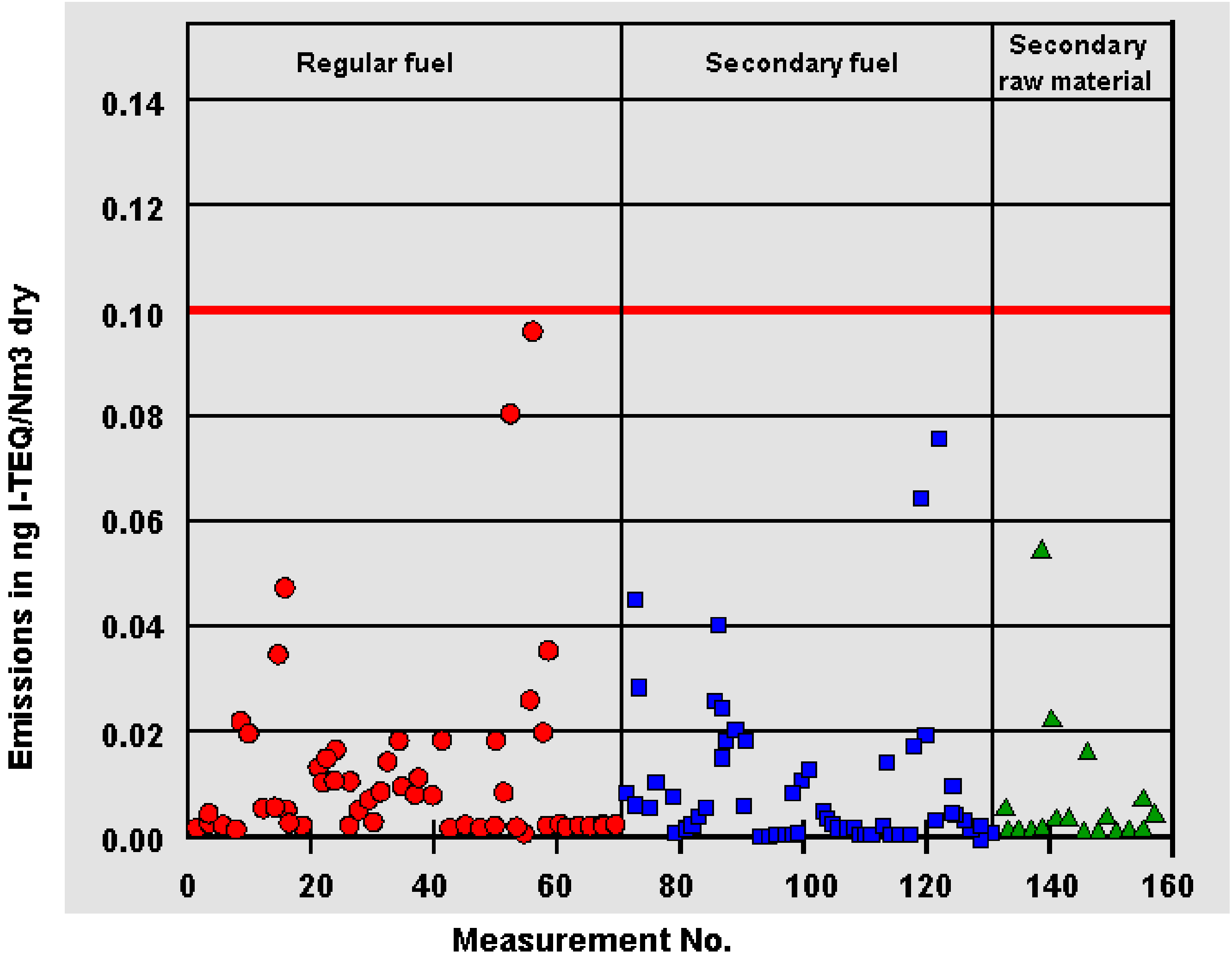
Mercury as the only completely volatile heavy metal in the kiln system is partly captured with the kiln dust in the dedusting device. Careful input control ensures that applicable emission limit values are never exceeded (see Chapter 4.6).

Process conditions in cement kilns – i.e. high combustion temperatures and long retention times – will effectively destroy organic compounds in the fuels (Chapter 4.2). Thus, dioxins and furans introduced with any fuel would not survive. Furthermore, the relatively low temperatures in the filter system of cement kilns (120-150° C) would not support the "de-novo synthesis" of these compounds.

Usually, the level of dioxins and furans emitted is far below the limit value of 0.1 ng/Nm^3 as demonstrated in Figure 4.4 for dry process kilns in Germany. In rare cases, this limit was slightly exceeded with long wet kilns. The mechanism of D/F formation in these cases is not fully clear but is definitely linked to the presence of organic precursors in the raw materials.

In Chapter 4.3 it was outlined that the clinker burning process leaves almost no residues for disposal as all input materials will be incorporated into the product.

Figure 4.4 : Concentration of Dioxin Emissions as a Function of Fuel Types (relative to 10 vol.-% O2)



Source: VDZ

One outlyer at 0.29ng not shown here

Process wastes such as kiln dust can be completely recycled in the process. In only a few cases, part of the kiln dust or bypass dust has to be dumped or is treated and sold for other purposes.

Process water in cement manufacturing – if not evaporated in the kiln system – is recycled into the process. Filtrate water from the filter presses in the semi-wet process is collected and treated by physical and chemical methods before being discharged to open waterways.

Emergencies such as fire, explosions or spillage/leakage are extremely rare in the cement industry. Potential consequences for the environment are minimised by adequate prevention and protection measures such as fire and explosion proof design of machinery and emergency response schemes.

The environmental impact of the cement manufacturing process is mainly limited to atmospheric emissions. Cement manufacturing is not a "multi-media" environmental impact process.

4.9 THE CEMENT MANUFACTURING PROCESS: A LARGE POTENTIAL FOR CONTRIBUTIONS TO ECOLOGICAL IMPROVEMENT

Since the early 70s, and particularly since the mid 80s, alternative – i.e. non-fossil – raw materials and fuels derived mainly from industrial sources have been beneficially utilised in the cement industry for economic reasons. Since that time, it has been demonstrated both in daily operations and in numerous tests that the overall environmental performance of a cement plant is not impaired by this practice in an appropriately managed plant operation.

The utilisation of alternative raw materials, fuels and mineral additions in cement plants has several advantages:

Environmental Benefits:

- ***Conservation of Natural Resources***: Cement kilns make full use of both the calorific and the mineral content of alternative materials. Fossil fuels such as coal or crude oil are substituted by combustible materials which otherwise would often be landfilled or incinerated in specialised facilities.

  The mineral part of alternative fuels (ashes) as well as non-combustible industrial residues or by-products can substitute for part of the natural raw materials (limestones, clay, etc.). All components are effectively incorporated into the product, and – with few exceptions – no residues are left for disposal.

  The use of mineral additions from industrial sources substituting clinker saves both raw material resources and energy resources as the energy intensive clinker production can be reduced.

- ***Air Protection***: Owing to the specific characteristics of the burning process, cement kiln emissions are to a very large extent independent of the fuel characteristics. Combustible waste materials used in cement kilns therefore eliminate corresponding emissions from specialised incinerators and landfills, and do not generate new ones.

- ***Protection of Groundwater and Soil:*** Waste materials diverted from landfills will not generate harmful gaseous emissions or liquid effluents thus reducing the risk of contamination.
- ***Greenhouse Gas Reduction***: With the substitution of fossil fuels by (renewable) alternative fuels, the overall output of thermal CO_2 is reduced (“CO_2 neutrality”). A thermal substitution rate of 40% in a cement plant with an annual production of 1 million tons of clinker reduces the net CO_2 generation by about 100,000 tons.

  Even more important is the substitution of clinker by mineral additions as both thermal CO_2 from fossil fuels and CO_2 from the decarbonation of raw materials is reduced.

  Therefore, the use of alternative fuels, raw materials and mineral additions can contribute significantly to national schemes for the reduction of greenhouse gases.
- ***Power Generation***: With appropriate waste heat utilisation concepts, cement kilns can contribute to the supply of electrical or thermal power thus saving again natural resources and reducing overall CO_2 generation.

Socio-Economic Benefits:

- ***Reduction of Disposal Fees***: Since only moderate investments are needed, cement plants can recover adequate wastes at lower costs than would be required for landfilling or treatment in specialised incinerators. In addition, public investment required for the installation of new specialised incinerators would also be reduced.
- ***Reduction of Land Requirements***: With the integration of cement kilns into regional or national waste management schemes, additional space for landfills can be saved.
- ***Investments in Clean Technologies:*** Substitute materials derived from waste streams usually reduce the production cost in cement manufacturing, thus strengthening the position of the industry particularly with regard to imports from countries with less stringent environmental legislation. It will also facilitate the industry’s development of technologies to further clean up atmospheric emissions.

Thus, for a number of good reasons cement kilns can play an important role within economically and ecologically responsible national waste recycling and valorisation schemes required in “closed cycle economies” of the future.

The cement manufacturing process has a large potential for substantial contributions to ecological improvement by making beneficial use of alternative fuels, raw materials and mineral additions.

CHAPTER 5

FACTORS INFLUENCING BAT SELECTION

5.1 INTRODUCTORY REMARKS

Before describing available techniques for cement production and for control of potential emissions (Chapters 6 and 7), this chapter summarises those features of the IPPC Directive which have particular relevance to the cement industry. It goes on to discuss how the identification of Candidate BATs for the techniques described in Chapters 6 and 7 needs to be influenced by the site specific nature of existing and prospective capital investment and by other factors. As the IPPC Directive requires that a permit shall include emission limit values (ELVs) and monitoring requirements for releases, and states that ELVs have to be based on BAT, observations on these aspects are included.

5.2 IPPC ASPECTS OF DIRECT IMPORTANCE TO THE CEMENT INDUSTRY

This section aims at facilitating understanding of the IPPC Directive and thus the basis of this CEMBUREAU BAT Reference Document.

The essential element of the IPPC Directive is to have – after a certain period of time – all EU industry operating sitewise under new operation permits containing emission limit values for all environmental compartments (integrated approach covering emissions to air, water and soil, energy efficiency and waste minimisation).

These integrated emission limit values have to be set by the locally competent authority with due consideration of:

- ❑ the technical characteristics of the plant;
- ❑ the geographical location;
- ❑ the local environmental conditions;
- ❑ the best available technique (to be taken from the respective Industry BAT Reference Document).

In the following the relevant paragraphs of the IPPC Directive are given in an abbreviated form and in a sequence which is intended to facilitate reading and understanding.

Article 1:

Purpose of the Directive is to:

☐ prevent

☐ reduce

☐ control

pollution of air, water and land arising from the Annex I activities. Thereby a high level of protection of the environment taken as a whole shall be achieved.

Article 2:
(1st part)

Pollution means the direct or indirect man-made introduction of

☐ substances

☐ vibrations

☐ heat

☐ noise

} emissions

into the air, water, la which may be harmful to

☐ human health

☐ quality of the environment

☐ state of material property

☐ amenities

☐ other legitimate uses of the environment

Article 3:

Member states shall take the necessary measures to provide

☐ that the competent authorities ensure

☐ that installations are operated in such a way

☐ that all appropriate preventive measures are taken against pollution

☐ that no significant pollution is caused

☐ that waste is avoided, recovered or adequately disposed of

☐ that energy is used efficiently

☐ that a site of operation is returned to a satisfactory state prior to cessation of activities

Article 4:

No new installation shall be operated without a permit in accordance with this Directive (some exceptions)

Article 21:

The Member State shall comply with the IPPC Directive no later than three years after its entry into force
(10.10.96 (publication date) + 20 days + 3 years 31.10.1999)

Article 5:

Member State competent authorities have to see to it by means of permits .... that existing installations operate in accordance with specified Articles .... of this Directive no later than eight years after the date on which this Directive is brought into effect.

(10.10.96 (publication date) + 20 days + 3 years + 8 years 31.10.2007)
Provisions of specified Articles .... are to be applied as from the date on which this Directive is brought into effect (latest 31.10.99) (This latter paragraph refers particularly to Article 5 (2))

<u>Article 12:</u> The operator has to inform the competent authority of any planned "change in operation". This then might, where appropriate, trigger an update of the operating permit or the operating conditions. (See also Article 2, 2nd part)
The operator has to inform the competent authority of any planned "substantial change" in the operation. This mandatorily triggers the permitting process. (See also Article 2, 2nd part)

<u>Article 2:</u> (2nd part) **"Change in operation"** means a

☐ change in nature

☐ change in functioning

☐ change in extension of the installation

which may have consequences for the environment.
A **"substantial change in operation"** may have in the opinion of the competent authority significant **negative** effects

☐ on human beings

☐ on the environment

<u>Article 9:</u> The permit shall include emission limit values according to Annex III. Of relevance for the cement industry are:

☐ Dust

☐ SO_2 (in some cases)

☐ NO_x

☐ VOC (in some cases)

☐ Metals (in some cases)

Where appropriate, limit values may be supplemented or replaced by

☐ equivalent other parameters

☐ technical measures

These values, parameters, measures ~~shall be based on BAT~~

☐ <u>without prescribing the use of any technique or specific technology</u>

Taking into account

☐ the technical characteristics

☐ the geographical location

☐ the local environmental conditions

In all circumstances the permit shall contain provisions on the

minimisation of long-distance or transboundary pollution.
The permit shall specify emission monitoring requirements, particularly

❑ measurement methodology

❑ measurement frequency

❑ evaluation procedures

❑ obligation for data submission to authorities

The permit shall specify measures other than those relating to normal operating conditions if there is a risk that the environment may be affected by such operating conditions.

Article 2: (3rd part)

"Best available techniques" (BAT) means

❑ the most effective and advanced stage in the development of activities and their methods of operation.

Such BATs are suitable in principle to provide the basis for the setting of emission limit values.

"Best" means

❑ most effective in achieving a high general level of protection of the environment as a whole

"Available" means

❑ developed to a scale which allows implementation under economically and technically viable conditions (These conditions are different for new and existing plants. They also strongly depend on site specific parameters)

❑ reasonably accessible to the operator

❑ taking into account the costs and advantages

"Techniques" means

❑ both technology and plant design construction, maintenance, operation and decommissioning

Determination of BATs includes consideration of costs/benefits and (cement specific) Annex IV items as follows:

1. Use of "low waste" technology
3. Recovery and recycling of own process waste or of waste generated elsewhere
5. Technological advances and changes in scientific knowledge and understanding.
6. Nature, volume, effects of emissions concerned
8. Length of time needed to introduce BAT
9. Process energy efficiency

Article 10: Where environmental quality standards require stricter conditions than those achievable by BAT, additional measures shall be specified in the permit.

Article 13: The competent authorities have to reconsider/update permit conditions

❑ periodically

❑ in case of excessive emissions

❑ in case of substantial BAT changes

❑ in case new provisions (from EU or MS) so dictate

Article 14: The competent authority must be informed of emissions and be afforded plant access.

Article 16: The Commission shall organize an exchange of information between MS and the industries concerned on BAT, emission monitoring and developments in them and shall publish results every three years.

Article 18: The Council (of environmental ministers) will set emission limit values

☐ for Annex I installations and

☐ for Annex III pollutants

for which the need for Community action has been identified by means of the information exchange process (Article 16)
Emission limit values contained in Annex II directives and other Community legislation are fully applicable as minimum ELVs.

5.3 CAPITAL INVESTMENT

A special feature of cement production is that it is very capital intensive. Economies of scale favour large volume production units. The demanding thermal conditions and the abrasive nature of the process materials, together with the essential need for a high degree of reliability and process stability to achieve continuity of production, mean that the equipment has to be very robust. These factors combine, together with the 20% or so of investment allocated to environmental control, to make plants very expensive – but they also ensure that the major machinery has a long life.

Capital costs represent approximately 30% of production cost and the long life of cement plants is crucial to their economic viability. Existing capital has to provide the funds for new investment. If existing equipment is still efficiently operable, its remaining economic value has to be added to the cost of any replacement plant.

This has clear implications on the evaluation of techniques for controlling or abating emissions (or energy consumption). A particular technique may properly be included in a range of Candidate BATs to reduce an emission. But its availability, in terms of economic viability and consideration of the costs and advantages, when account is taken of the economic life of existing equipment which would be replaced by the technique, may exclude the use of the technique in a particular case. Thus the range of Candidate BATs should be broad enough to leave other option(s) open when some techniques are not available.

Another aspect of BAT evaluation in existing plants is that the cost of implementation of a particular technique may vary considerably from one plant to another, depending on existing equipment, space and layout considerations, etc. Capital investment in techniques to reduce emissions has also to make allowance for the cost of capital. From an economic point of view general investment in environmental improvement is non-remunerative. Again the range of BAT options needs to be broad so that availability does not unnecessarily constrict improvement in particular cases.

Economic assessment of equipment and abatement BAT has necessarily to be rather approximate because it is not practicable to accommodate the multiplicity of potential site specific factors. Any general assessment has anyway to be based on a standardised production rate and the specific cost per tonne of output will actually vary with the size of plant.

Investment in environmental improvement is most cost effective when it is allied to other expenditure on modernising and uprating plant. This is because, when new equipment is being installed, there is often only a marginal increase in total cost if the equipment is built to higher environmental standards. Additionally new plant has a longer prospective life over which to depreciate the capital, including the environmental investment.

On occasion it will be justifiable to invest in new plant which is not obviously BAT, although rigorous argument would be needed to support a permit application. For instance, an application might be made to install a new wet process kiln alongside an existing one. Supporting arguments might include:

- ☐ the nature of the raw materials precluding dry processing;
- ☐ investment being minimal because of adequate existing raw plant capacity for the new production;
- ☐ the available raw material reserves having a limited life;
- ☐ the overall emission/tonne of product being reduced with the new plant;
- ☐ without the new kiln the market would have to be supplied by road transport from a distant location.

5.4 CANDIDATE BATS

Chapter 7 evaluates against BAT criteria the main options for choosing between different sub-processes and associated equipment, and between methods of emission control. The sections on control of emissions of fugitive dust, noise, odour, vibrations and releases to surface waters (Chapters 7.7 – 7.11) mainly deal with general design principles, rather than aiming to identify specific BAT options, as these emissions and their abatement techniques are not specific to cement production.

It would be attractive to the industry, and to the formulation of an unambiguous BREF document, if a single BAT, or narrow range of Candidate BATs, could be identified for each choice of equipment or control option. In practical terms such an approach is too restrictive. Therefore the evaluations generally identify a range of options, all or several of which may qualify as Candidate BATs. The reasons why a good proportion of the identified techniques may qualify as Candidate BATs are:

1. There has in the past been progressive refinement in the selection of equipment and sub-processes which means that various non-BAT techniques have already been excluded from plants currently in operation.

2. For some sub-processes, for instance – stacking and reclaiming systems, the overall environmental impact is insignificant and a narrow BAT choice could be anti-competitive (affecting supply prices) and restrict user judgement based on operating experience, layout considerations, etc.

3. BAT evaluation has to take account of existing capital investment, as discussed above. For instance, for many plants it would be economically attractive to reduce cement grinding costs by pre-grinding the clinker in a roller press but existing plant layout may make the option impossible without vast associated expenditure to modify existing storage and handling systems.

4. For some emissions – particularly SO_2 and NO_x which are the most likely to be of environmental significance – there is a range of potential control techniques which may have widely varying costs and benefits. Factors which need to be taken into account when considering abatement options (beside capital and operating costs) include:

   (i) the current emission levels and the degree of abatement considered necessary or desirable;

   (ii) the source of, or reasons for, emissions;

   (iii) the degree of abatement which may be achieved by different techniques – bearing in mind that there is quite limited operating experience of some techniques and operating results already achieved may be quite variable – that is, there are variable levels of confidence;

   (iv) restriction of BAT options will inhibit the development of experience and knowledge leading to refinement and improvement. (For illustration, evaluation of BAT options 40 years ago could have prevented the development of electrostatic precipitators.)

5. For the above reasons a wide choice of techniques should be available for consideration so that the best ones may be selected to suit the circumstances of particular cases. A considerable degree of judgement may be involved in making the correct, or most likely to be correct, decision. The operator is in the best position to make such judgement and to justify the choice made. A narrow range of Candidate BATs would be undesirably prescriptive, with no guarantee of concurrent environmental improvement.

5.5 EMISSION LIMIT VALUES (ELVS)

Emission limit values are expressed as pollutant concentrations in the dry or wet exhaust gas at normal conditions (1013 mbar, 0° C), sometimes adjusted to a specified O_2 level.

ELVs are observed if the average emission concentration over a defined measuring period does not exceed the ELV or observes a predefined tolerance field.

The emissions from a cement plant are strongly influenced by the nature of the materials available in the geographical location in which it is situated.

The emissions are also very dependent on the technical characteristics of the particular installation.

Emission limit values set by national authorities in accordance with the IPPC Directive have to be based on BAT, taking account of the technical characteristics of the installation and its geographical location. This points to the recognition that ELVs need to be set on a site specific basis.

The Directive also requires the permit to contain "suitable release monitoring requirements, specifying measurement methodology and frequency, evaluation procedure,....". The variability over time and the problems of continuous measurement of the main emissions create difficulty in specifying realistic ELVs and specifying measurement methodology. Providing that emissions are not threatening air quality standards, and bearing in mind that the SO_2 and NO_x emissions are dispersed at a high level (where they may, for instance, contribute to transboundary pollution but short term fluctuations are not significant), careful assessment of ELVs and monitoring requirements is needed.

CHAPTER 6

AVAILABLE TECHNIQUES

FOR

CEMENT PRODUCTION

6.1 RAW MATERIALS PREBLENDING AND STORAGE

6.1.1 INTRODUCTORY REMARKS

Depending on climatic conditions and the amount of fines in the raw material coming from the crushing plant, it is usual for the raw material to be kept in covered stores. For a 3000 t/d plant these buildings may hold between 20,000 and 40,000 tons of material.

The raw material fed to a kiln system needs to be as chemically homogeneous as practicable. This is achieved by control of the feed into the raw grinding plant. When the material from the quarry varies in quality, initial preblending can be achieved firstly by stacking the material in a manner which lays the material in rows or layers along the length (or around the circumference) of the store and secondly by cross sectional extraction across the material pile.

When the material from the quarry is fairly homogeneous, simpler stacking and reclaiming systems can be used.

The following section outlines the more common stacking and reclaiming methods in use and gives some detail of the handling equipment. Live stock is the volume of material which is automatically dischargeable from the storage.

6.1.2 RAW MATERIAL STORES (NON-PREBLENDING)

☐ **Strata stacking method:** Mainly applied with longitudinal raw material stores equipped with jib stackers and side, portal or semi-portal scraper reclaimers, resulting in limited blending effect.

☐ **Cone shell stacking method:** Mainly applied for stores (non-blending) with jib stackers and tripper belt stackers in longitudinal stores. Reclaiming is done with claw-wheel reclaimers.

Non-preblending stores are used for single raw material components not requiring blending.

In addition to the above described automatic store systems also the following semi-automatic stores are used:

☐ Longitudinal and circular store with gravity discharge feeders. Live stock depends on number and arrangement of the feeders.

☐ Longitudinal store with front end loader reclaiming.

☐ Travelling overhead crane store

☐ Storage silo with gravity discharge feeders.

6.1.3 PRE-BLENDING STORES

- ❑ **Chevron stacking method:** Applied with jib stackers and tripper belt stackers in longitudinal preblending systems and with jib stackers in circular preblending systems. Reclaiming is done with bridge scraper and bucket wheel reclaimers.
- ❑ **Chevcon stacking method:** Applied with jib stackers in circular preblending system for continuous stacking. Reclaiming is done with bridge scraper, disc and bucket wheel reclaimers.
- ❑ **Windrow stacking method:** Applied mainly with bridge stackers in pit preblending systems stores in connection with sticky material and swivel jib stackers in longitudinal preblending systems. Reclaiming is done with bridge scraper and bucket wheel reclaimers.

Preblending stores are used for improving the chemical consistency of either a single raw mix component or a multiple component raw mix (integrated preblending system).

In case of an integrated preblending store a quality control system is required including either a sampling, sample preparation and an XRF-analyses or an on-line Prompt Gamma Newton Activation analyser.

No.	BAT Evaluation Item	Automatic Raw Material Stores (Non-Preblending)			
		Long. Store with Side Scraper Reclaimer	Longit. or Circ. Store with Claw-Wheel Reclaimer	Longit. Store with Portal Scraper Reclaimer	Circular Store with Portal Scraper Reclaimer
1.	**Consumables:**				
1.1	Wear Parts	Steel wear parts, consumption negligible			
1.2	Air, - ambient - compressed	N.A. N.A.	N.A. N.A.	N.A. N.A.	N.A. N.A.
1.3	Water	N.A.	N.A.	N.A.	N.A.
2.	**Energy Consumption:**				
2.1	Thermal	N.A.	N.A.	N.A.	N.A.
2.2	Electrical	< 0.50 kWh/t			
3.	**Waste Generation:**				
3.1	Solid	N.A.	N.A.	N.A.	N.A.
3.2	Liquid	N.A.	N.A.	N.A.	N.A.
4.	**Emissions:**				
4.1	To air	Fugitive dust if material is dry and store is open or not dust tight			
4.2	To water	Possible in case of open store through wash away by rain water			
4.3	Noise	N.A.	N.A.	N.A.	N.A.
4.4	Odour	N.A.	N.A.	N.A.	N.A.
7.	**Relative Costs:**				
7.1	Investment costs	**100%**	**130%**	**120%**	**80%**
7.2	Operating costs	**Negligible differences**			

General Remarks:

Data to be understood as orders of magnitude.

N.A. means not applicable

No.	BAT Evaluation Item	Automatic Raw Material Preblending Stores		
		Long. Prebl. Store with Bridge Scraper Reclaimer	Long. Prebl. Store with Bucket Wheel Reclaimer	Circ. Prebl. Store with Bridge Scraper Reclaimer
1.	**Consumables:**			
1.1	Wear Parts	Steel wear parts, consumption negligible		
1.2	Air, - ambient - compressed	N.A. N.A.	N.A. N.A.	N.A. N.A.
1.3	Water	N.A.	N.A.	N.A.
2.	**Energy Consumption:**			
2.1	Thermal	N.A.	N.A.	N.A.
2.2	Electrical	< 1.0 kWh/t		
3.	**Waste Generation:**			
3.1	Solid	N.A.	N.A.	N.A.
3.2	Liquid	N.A.	N.A.	N.A.
4.	**Emissions:**			
4.1	To air	Fugitive dust if material is dry and store is open or not dust tight		
4.2	To water	Possible in case of open store through wash away by rain water		
4.3	Noise	N.A.	N.A.	N.A.
4.4	Odour	N.A.	N.A.	N.A.
7.	**Relative Costs:**			
7.1	Investment costs	**100%**	**120%**	**130%**
7.2	Operating costs	**Negligible differences**		

General Remarks:

Data to be understood as orders of magnitude.

6.2 SECONDARY RAW MATERIALS STORAGE AND PREPARATION

Secondary raw materials are stored either separately or together with the primary raw material components as described in Chapter 6.1 and are prepared together with the primary raw material components as is described in Chapter 6.3.

Secondary raw materials used in relatively small quantities may alternatively be stored in silos or bunkers.

Any secondary raw materials with potentially harmful properties must be stored and prepared according to individual specific processes.

6.3 RAW GRINDING

6.3.1 INTRODUCTORY REMARKS

As noted in Chapters 6.3.6 and 6.3.7, the raw materials are either dried and ground to a fine powder when a dry preparation process is being used or, when wet (> 20 - 30%) and sticky materials dictate the use of wet preparation, further water is added and the material is processed into slurry.

Preparation of the raw material is of great importance to the subsequent kiln system both in getting the chemistry of the raw feed correct and also in ensuring that it is sufficiently fine. Therefore the following paragraphs cover the proportioning of the raw materials and methods of separating the ground product from the oversize particles as well as the grinding methods used.

The data in tables hereafter are based on the following assumptions:

Grindability of raw mix components	15.0 kWh/t at 18% R 90 m, (L.T.M.)
Moisture of raw material mix	2 – 10%
Standard electrical energy price	0.04 ECU per kWh

6.2.2 METERING METHOD

The accuracy of metering and proportioning of the mill feed components by weight is of great importance both for achieving the consistency of chemical composition which is essential for steady kiln operation and high quality products and for maintaining a high energy efficiency of the grinding system. The predominant metering and proportioning equipment for raw material feed to mills is the apron feeder followed by belt weigh feeder.

6.2.3 COMMINUTION METHODS

The grinding systems described in the Chapters 6.3.6 and 6.3.7 use one or more of the following comminution methods:

- Comminution by impact forces
- Comminution by compression forces
- Comminution by friction / shear forces
- Comminution by inter-particle contact forces

6.2.4 SEPARATION

The fineness and particle size distribution of the product leaving a raw grinding system are of great importance for the following burning process. The target given for these parameters is achieved by the adjustment of the separator used for classifying the product leaving the grinding mill. For dry classification, air separators are used. The newest generation, rotor cage type separators, have several advantages. These are:

- ❑ Less specific energy consumption of the grinding system (less over-grinding)
- ❑ Increase of system throughput (efficiency of particle separation)
- ❑ More favourable particle size distribution (PSD) and product uniformity

6.2.5 PRODUCT TRANSPORT TO STORAGE

For raw meal transport to storage silos pneumatic and mechanical systems are used. Mechanical conveyors normally have a higher investment cost but a much lower operating cost than pneumatic conveying. A combination of air-slide or screw/chain conveyors with a belt bucket elevator is nowadays the most commonly used conveying system.

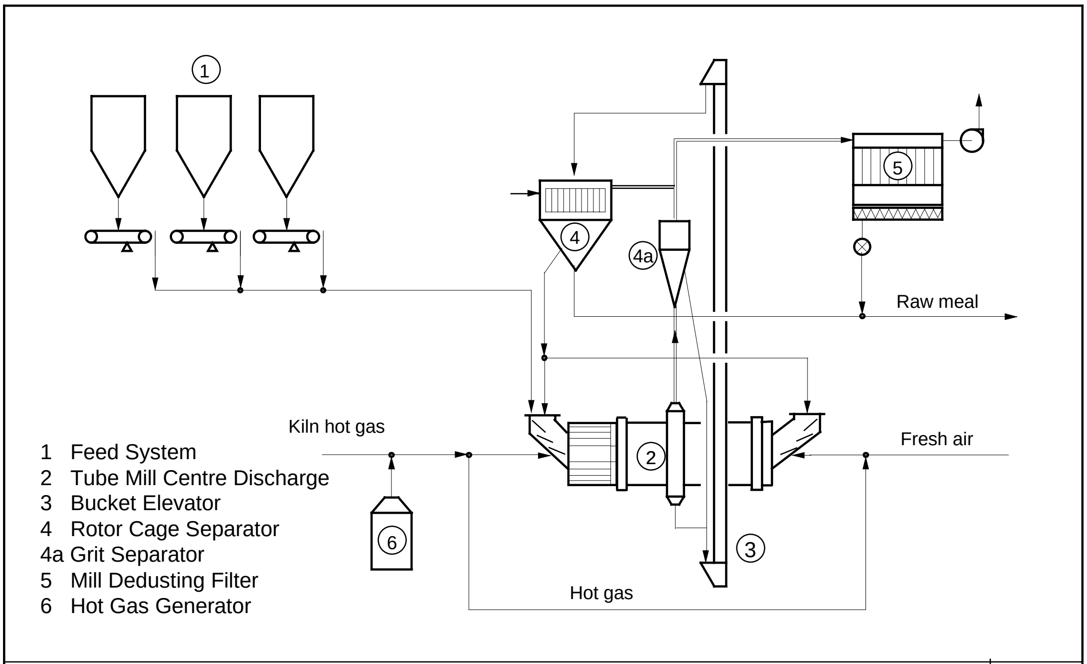
6.2.6 DRY GRINDING

For dry and semi-dry kiln systems, the raw material components are ground and dried to a fine powder, making use mainly of the kiln exhaust gases and cooler exhaust air respectively. For relatively high moisture in raw materials and for start up procedures an auxiliary furnace may be needed to provide additional heat.

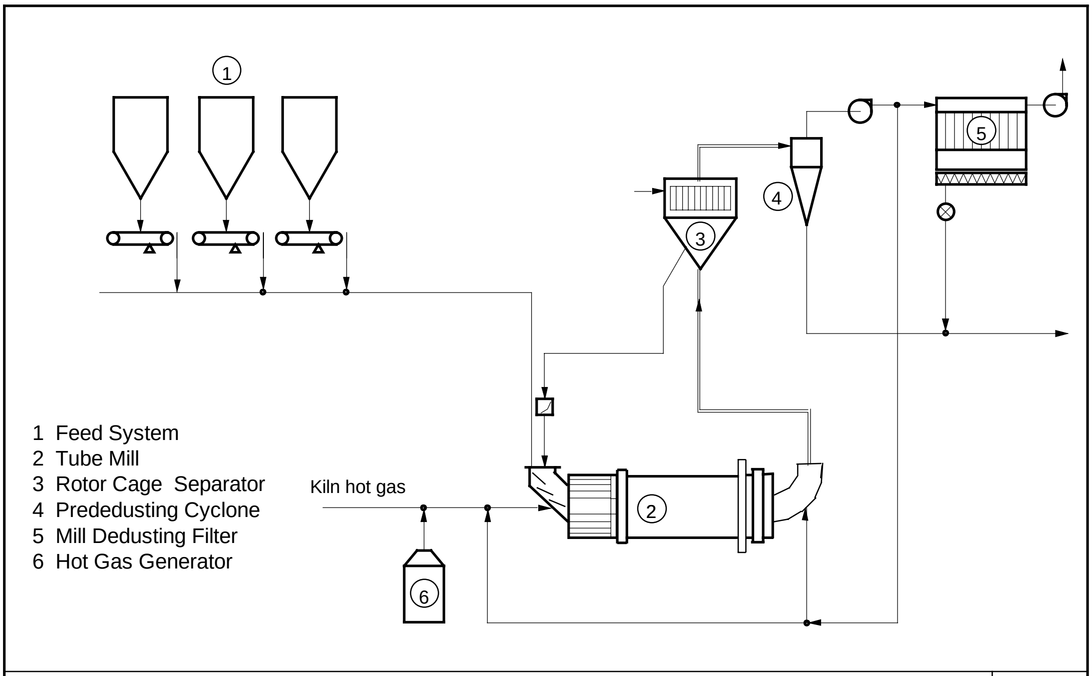
Beside the grinding systems illustrated on pages 3 and 4 other systems are used to a lesser extent. These are:

- ❑ Tube mill, end discharge in closed circuit
    - ♦ Drying capacity limitation of ~6% (using kiln exhaust gases)
    - ♦ Production capacity limitation of ~300 t/h
    - ♦ Electrical energy consumption is medium
- ❑ Autogenous mill
    - ♦ Suitable for materials which are very sticky and of high moisture content
    - ♦ Can be used only as pre-grinding unit, production capacity up to 400 t/h
- ❑ Roller press, with or without crusher drier
    - ♦ Drying capacity without crusher drier is limited to ~5% moisture (using kiln exhaust gases)
    - ♦ Production capacity is limited to ~200 t/h per unit (in a finish mill function)
    - ♦ Only few installations in operation so far

- ❑ Horizontal roller mill
  - ♦ Drying capacity without flash drier is limited to ~5% moisture
  - ♦ Only few installations in operation so far

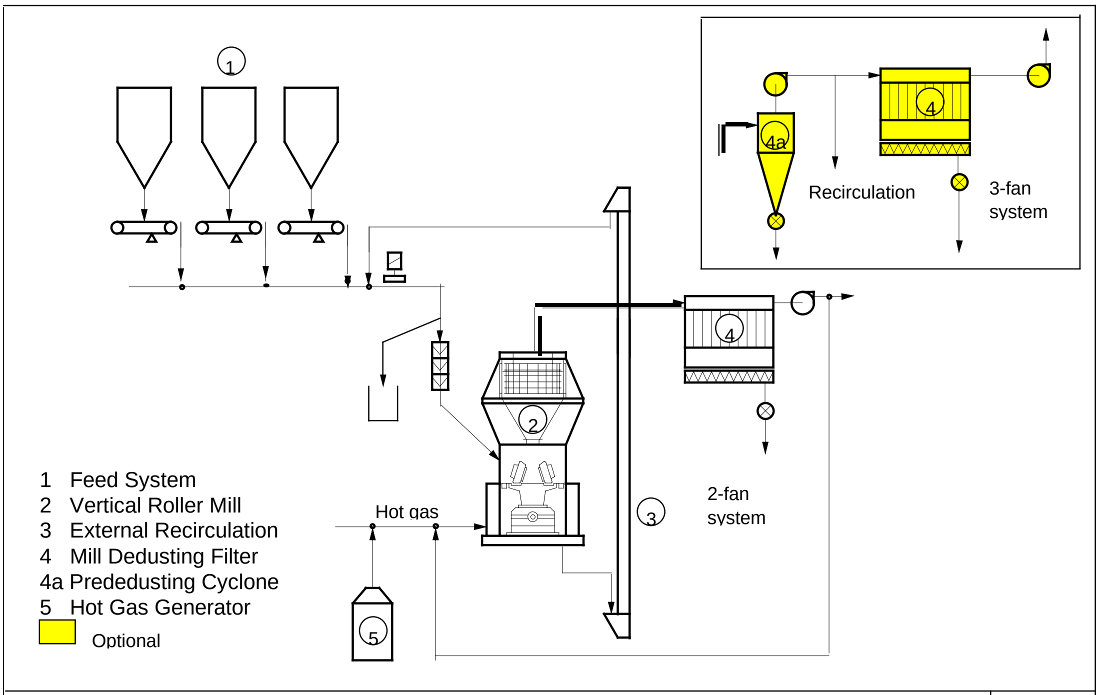


Raw Grinding with Centre Discharge Tube Mill (TMCD) **RG1**



Raw Grinding with Airswept Tube Mill (TMAS) **RG2**

Replacement of grit separators or separators of the old generations in existing systems is usually not economically justifiable.



Raw Grinding with Vertical Roller Mill (VRM) **RG3**

No.	BAT Evaluation Item	Dry Raw Grinding Systems	
		TMCD/TMAS	VRM
1.	**Consumables:**		
1.1	Wear Parts	Mill lining, grinding media	Roller tyres, table liner
1.2	Air, - ambient - compressed	Only if hot gas generator is in use N.A.	
1.3	Water	N.A.	Up to several t/h possible
2.	**Energy Consumption:**		
2.1	Thermal	N.A. if kiln gases and cooler exit air are sufficient for drying raw materials	
2.2	Electrical, - Mill - System, excl. transp.	13.0 - 14.0 kWh/t 17.0 - 20.0 kWh/t	7.0 kWh/t 13.0 - 14.0 kWh/t
3.	**Waste Generation:**		
3.1	Solid	Spent / worn out wear parts	
3.2	Liquid	N.A.	N.A.
4.	**Emissions:**		
4.1	To air	Fugitive dust possible if system is not properly maintained	
4.2	To water	N.A.	N.A.
4.3	Noise	High, ball charge	Low
4.4	Odour	N.A.	N.A.
7.	**Relative Costs:**		
7.1	Investment costs	**100%**	**120%**
7.2	Operating costs	**100%**	**80%**

General Remarks:

Data to be understood as orders of magnitude.

Energy consumption and therefore the relative costs depend very much on the specific type of mill, the mill's temperature as well as the grindability.

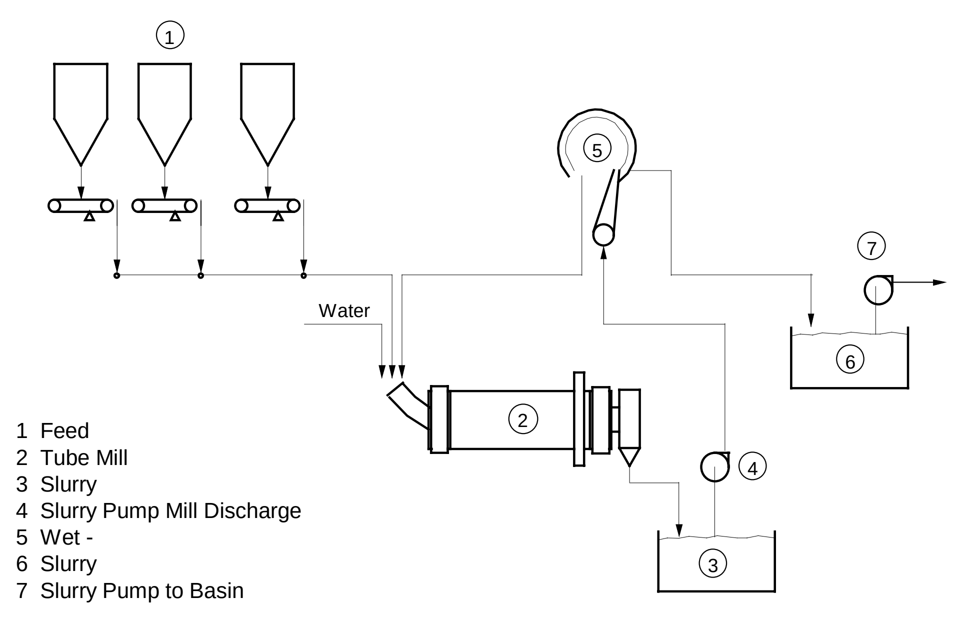
Wet Grinding

Wet grinding is used only in combination with a wet or semi-wet kiln system. The raw material components are ground with the addition of water to form a slurry. To achieve the required slurry fineness i.e. to comply with modern quality demands, mainly closed circuit mill systems have to be considered.

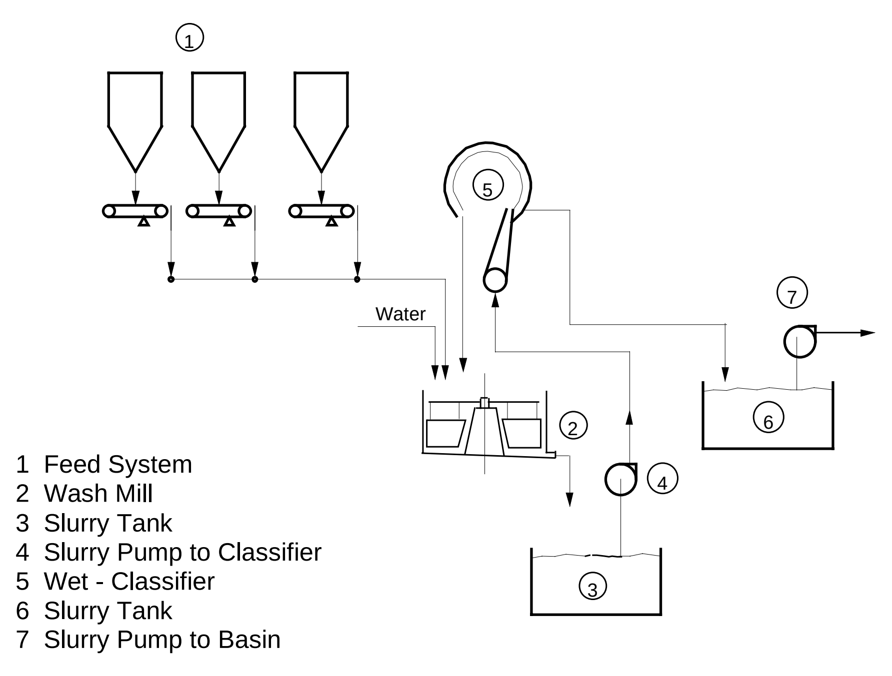
Raw materials such as chalk, marl or clay, which are sticky and of high inherent moisture content, are soft and as a first stage of preparation they may be ground in a wash mill. Water and crushed material are fed to the wash mill and broken down into slurry by shearing and impact forces imparted by the rotating harrows. Where sufficiently fine the material passes through screens in the wall of the wash mill and is pumped to subsequent storage. To achieve the required slurry fineness further grinding in a tube mill is usually required, especially if a secondary raw material such as sand is to be added.

To reduce kiln fuel consumption water addition during the raw material grinding is controlled to the minimum necessary to achieve the required flow and pumpability characteristics of the slurry.

Beside the closed circuit tube mill, the same mill type is used as an open circuit mill.



Wet Raw Grinding with Tube Mill in Closed Circuit (TMCC) **RG7**



Wet Raw Grinding with Wash Mill in Closed Circuit (WM) **RG9**

No.	BAT Evaluation Item	Wet Raw Grinding Systems	
		TMCC	WM
1.	**Consumables:**		
1.1	Wear Parts	Mill lining, grinding media	Lining
1.2	Air, - ambient - compressed	N.A. N.A.	N.A. N.A.
1.3	Water	400 - 600 l/t dry matter	500 - 800 l/t dry matter
2.	**Energy Consumption:**		
2.1	Thermal	N.A.	N.A.
2.2	Electrical, - Mill Motor - System	11.0 kWh/t 13.5 kWh/t	3.0 - 6.0 kWh/t 5.0 - 8.0 kWh/t
3.	**Waste Generation:**		
3.1	Solid	N.A.	N.A.
3.2	Liquid	N.A.	N.A.
4.	**Emissions:**		
4.1	To air	N.A.	N.A.
4.2	To water	N.A.	N.A.
4.3	Noise	High with steel lining, low with rubber lining	Low
4.4	Odour	Low	Low
7.	**Relative Costs:**		
7.1	Investment costs	Negligible differences	
7.2	Operating costs	Negligible differences	

General Remarks: Data to be understood as orders of magnitude

6.4 RAW MEAL / SLURRY BLENDING / HOMOGENISATION AND STORAGE

6.4.1 INTRODUCTORY REMARKS

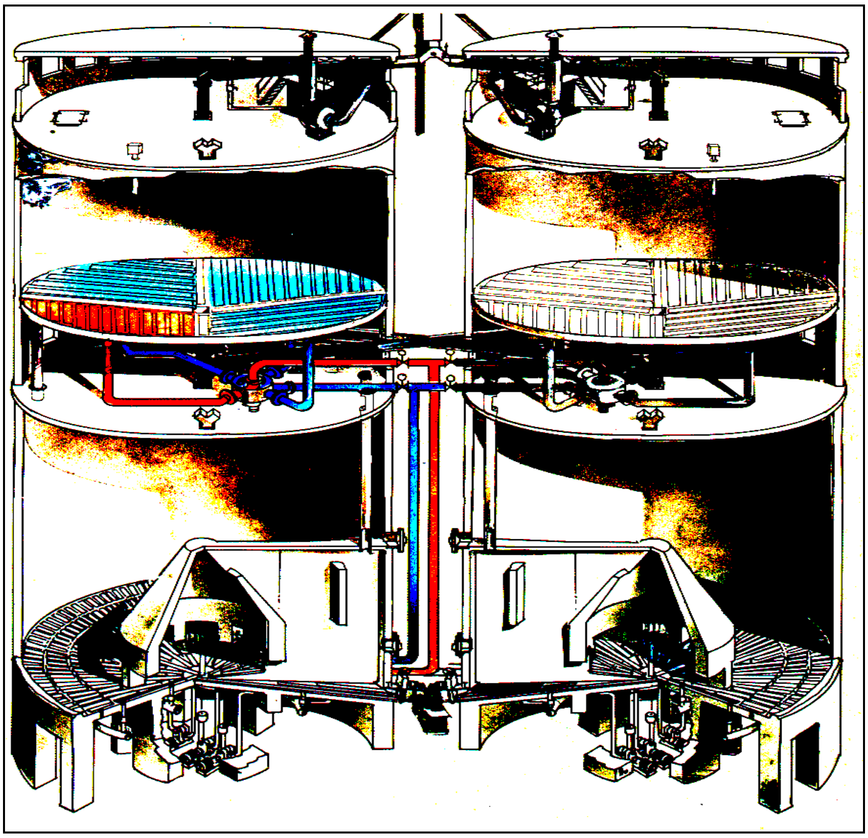
Raw meal or slurry leaving the raw grinding process requires further blending/homogenisation to achieve optimum consistency of the raw mix prior to being fed to any kiln system. For this purpose two principles are applied: raw meal or slurry blending and raw meal or slurry homogenisation.

6.4.2 RAW MEAL BLENDING,/HOMOGENISATION AND STORAGE

6.4.2.1 BATCH TYPE HOMOGENISING SILO SYSTEMS (BHS)

The batch type homogenising system consists always of two homogenising silos and at least of one storage silo. The homogenising silos are usually located on top of the storage silo(s) in order to discharge the homogenised raw mix by gravity to the storage silo(s). The homogenisation is achieved by aerating the silo with medium pressure air for about 2 hours.

The homogenising effect is better than 10 : 1.

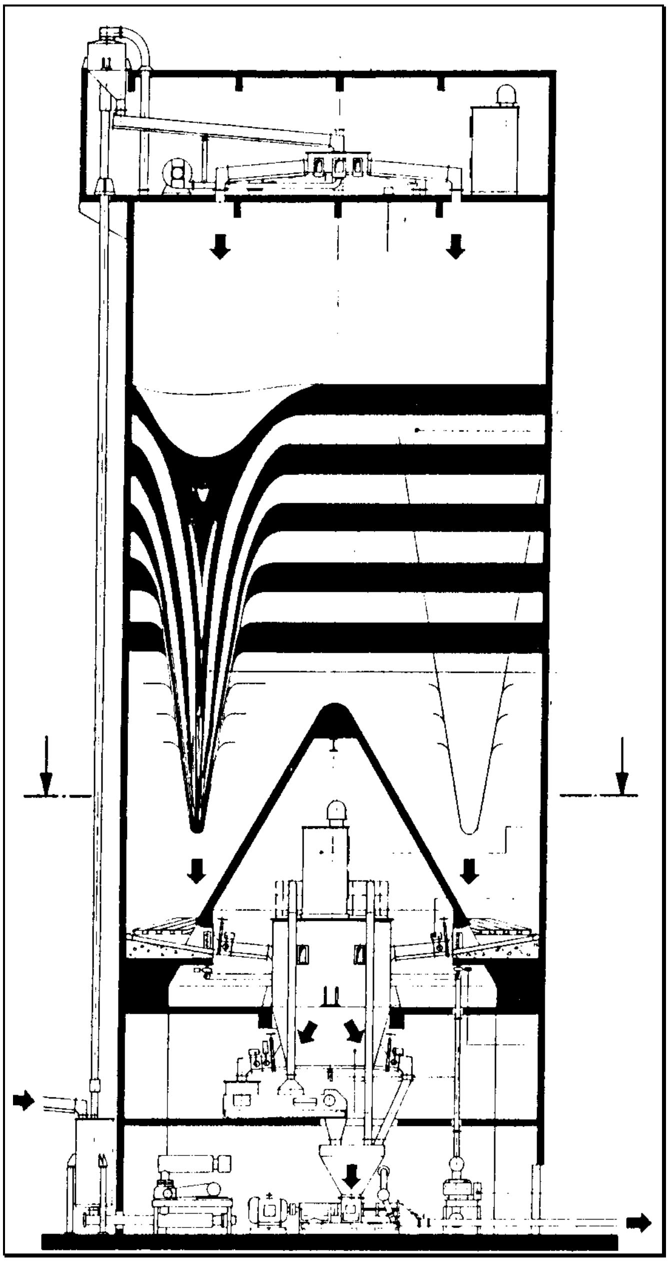


6.4.2.2 CONTINUOUS HOMOGENISING SILO SYSTEM (CHS)

The continuous homogenising system consists of a homogenising silo usually located on top of a storage silo. Silo discharge of the homogenised raw meal is continuous by means of overflow. The homogenising effect is up to 10 : 1.

6.4.2.3 CONTINUOUS BLENDING AND STORAGE SILO (CBS)

The continuous blending silo is simultaneously used for blending of the raw mix as well as for its storage. The blending is effected through sectional formation of discharge funnels. The blending effect is about 5 : 1.

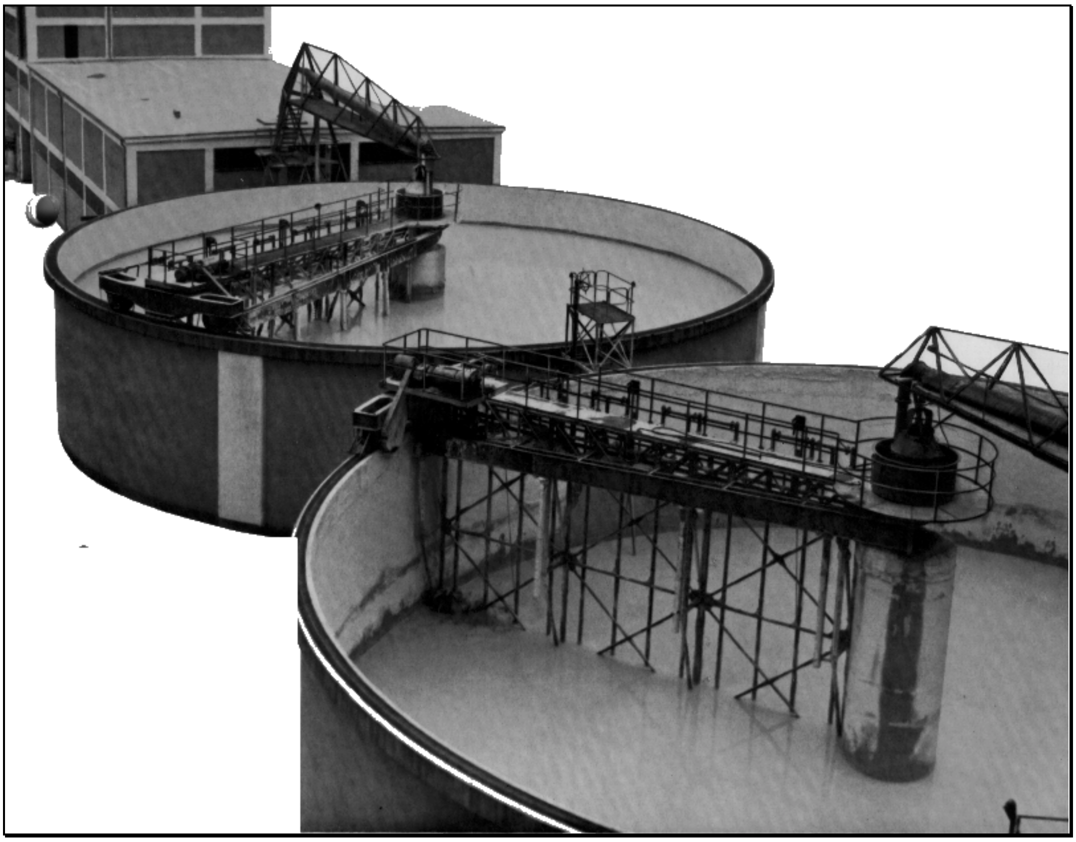


6.4.3 SLURRY BLENDING/HOMOGENISING AND STORAGE IN BASINS OR SILOS (SBHB)

For slurry blending and homogenising the batch system only can be used.

The blending and homogenising effect in the silo takes place by introduction of high quantities of compressed air into the slurry. The air is fed through pipes at least at four points, about 0.5 m above the silo bottom.

The blending and homogenising effect in the basin is effected by several rotating stirrers mounted on a rotating girder. Additionally compressed air is introduced into the slurry at certain intervals. The air is fed through pipes at each stirrer about 0.5 m above the basin bottom.



No.	BAT Evaluation Item	Raw Meal Homogenisation & Storage		Raw Meal Blending	Slurry Blending/Homogen.
		BHS	CHS	CBS	SBHB
1.	**Consumables:**				
1.1	Wear Parts	Negligible			
1.2	Air, - ambient - compressed	N.A. medium	N.A. high	N.A. low	N.A. high
1.3	Water	N.A.	N.A.	N.A.	N.A.
2.	**Energy Consumption:**				
2.1	Thermal	N.A.	N.A.	N.A.	N.A.
2.2	Electrical	0.5 - 0.8 kWh/t	0.8 - 1.2 kWh/t	0.15 - 0.3 kWh/t	0.3 - 0.5 kWh/t
3.	**Waste Generation:**				
3.1	Solid	N.A.	N.A.	N.A.	N.A.
3.2	Liquid	N.A.	N.A.	N.A.	N.A.
4.	**Emissions:**				
4.1	To air	Fugitive dust if silo venting/dedusting system is not properly maintained			N.A.
4.2	To water	N.A.	N.A.	N.A.	N.A.
4.3	Noise	Low, if compressors are equipped with silencers			
4.4	Odour	N.A.	N.A.	N.A.	N.A.
7.	**Relative Costs:**				
7.1	Investment costs	**160%**	**160%**	**100%**	-
7.2	Operating costs	**200–250%**	**300-400%**	**100%**	

General Remarks:

Data to be understood as orders of magnitude

6.5 SEMI-WET SPECIALITIES

6.5.1 INTRODUCTORY REMARKS

The semi-wet process includes slurry filtration and filter cake drying equipment to transform wet processed raw material (slurry) into dry kiln feed material (raw meal).

The purpose of the filtration process thereby is to replace the energy wasting purely thermal dewatering process as applied in wet kilns by much more economical mechanical dewatering with filter presses.

Typically, filtration allows the mechanical removal of 2/3 of the original slurry water content (example: 36% moisture slurry [0.87 kg water/kg cli] is filtered down to a 18% moisture filter cake containing thus 0.34 kg water/kg cli).

Today high pressure filtration equipment (chamber filter presses) is used exclusively whereas in the past suction filtration was also used for slurries that dewatered easily.

With new plants slurry filtration is applied in cases of very high natural raw material moisture content only. Such raw materials (e.g. chalk) often allow for extremely simple raw milling processes.

In an early technology, filter cakes were subject to an extrusion process to form nodules which then were further processed in a (3 chambers) grate preheater kiln.

Today, filter cakes from the intermediate filter cake storage bins are directly fed to special drying equipment (dispersion dryers, vertical dryers). The resulting dry raw meal is then directly supplied to a modern cyclone preheater or precalciner kiln.

6.5.2 SLURRY DEWATERING WITH FILTER PRESSES

Chamber filter presses comprise up to 150 filter plates (forming the filter chambers) with plate dimensions of up to 2 x 2 m or 2.3 m diameter.

Filtration pressures are between 15 and 20 bar, filtration times from 15 to 35 minutes and press charging/discharging times around 10 minutes.

A complete pressure filtration plant comprises components as follows:

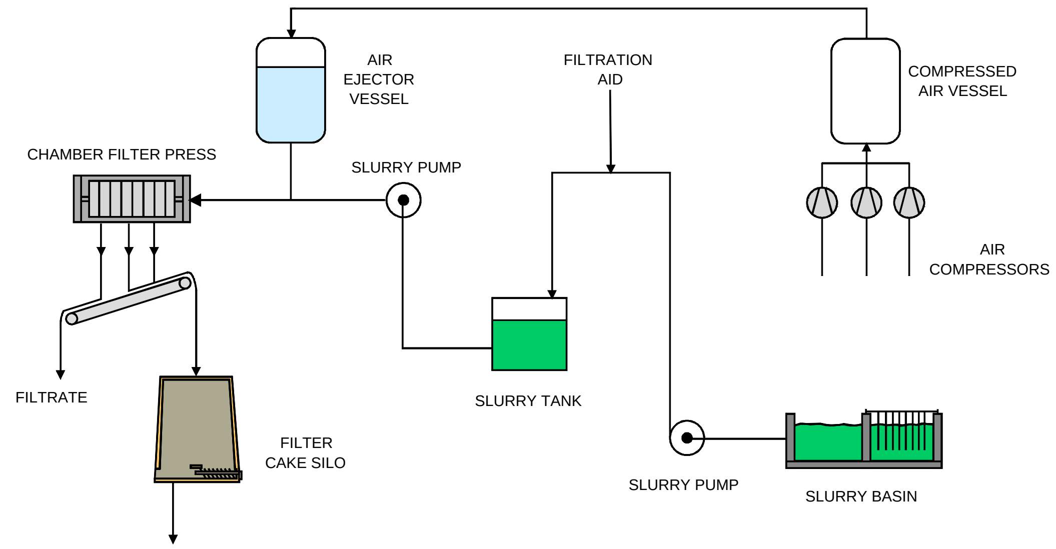


FIGURE 6.5.1 : PRESSURE FILTRATION PLANT FOR CEMENT RAW MATERIAL SLURRIES

No.	BAT Evaluation Item	Comments	Further Remarks
1	**Consumables:**		
1.1	Materials	Filter cloths	Up to 6000 cycles life expectancy
1.2	Air (pressurised)	Yes	For press filling and core blowing
1.3	Filter aid	In most cases	$Ca(OH)_2$
2	**Energy Consumption:**		
2.1	Thermal	None	
2.2	Electrical	5 kWh/t cli	
3	**Waste Generation:**		
3.1	Solids	None	
3.2	Liquids	Filtrate water	Neutralisation / reuse

4	**Emissions:**		
4.1	To air	Low	
4.2	To water	See 3.2	
4.3	Noise	Negligible	
4.4	Odour	Negligible	
5	**Impact on Product Quality**		
5.1	Cement	N.A.	
6	**Experience**		
6.1	Duration	50 years	
6.2	Number of applications	> 10	
7	**Relative Costs:**		
7.1	Investment costs		
7.2	Operating costs		

6.5.3 FILTER CAKE DRYING

Essentially two types of filter cake drying equipment are used:

- Fast Rotating or Dispersion Dryers (Figure 6.5.2)
- Flash Dryer / Crusher Dryer Combinations (Figure 6.5.3)

with the latter being given preference today.

Complete use is made of kiln exhaust gas and clinker cooler exhaust air for filter cake drying. Since the dryer is operating in parallel with the kiln (100% compound operation) such systems reach highest energy utilisation values.

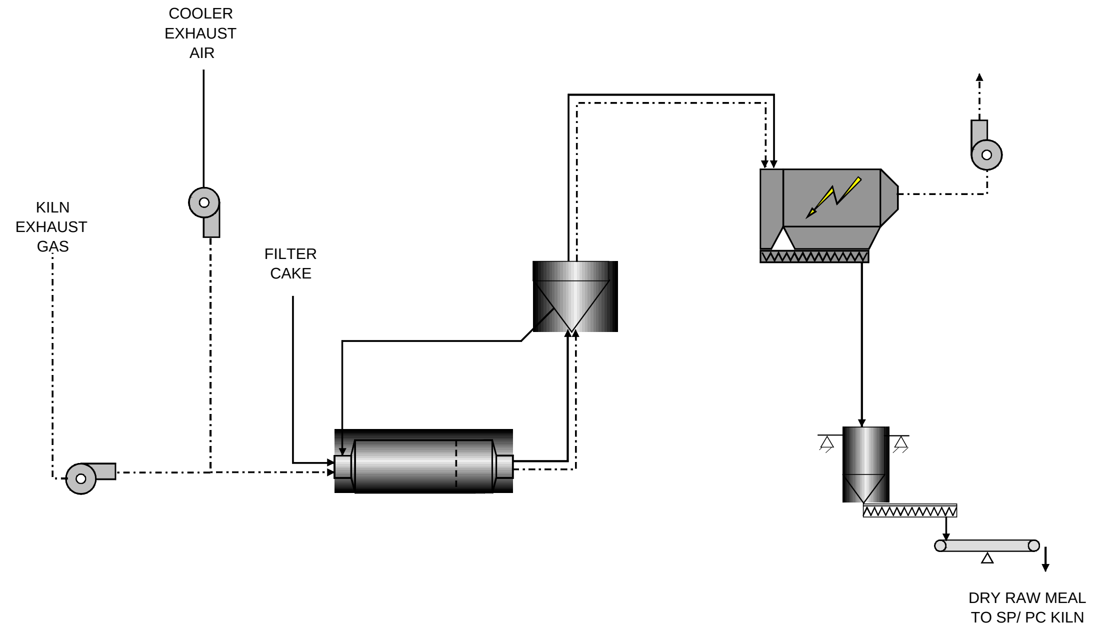


FIGURE 6.5.2 : FAST ROTATING OR DISPERSION DRYER SYSTEM FOR FILTER CAKES

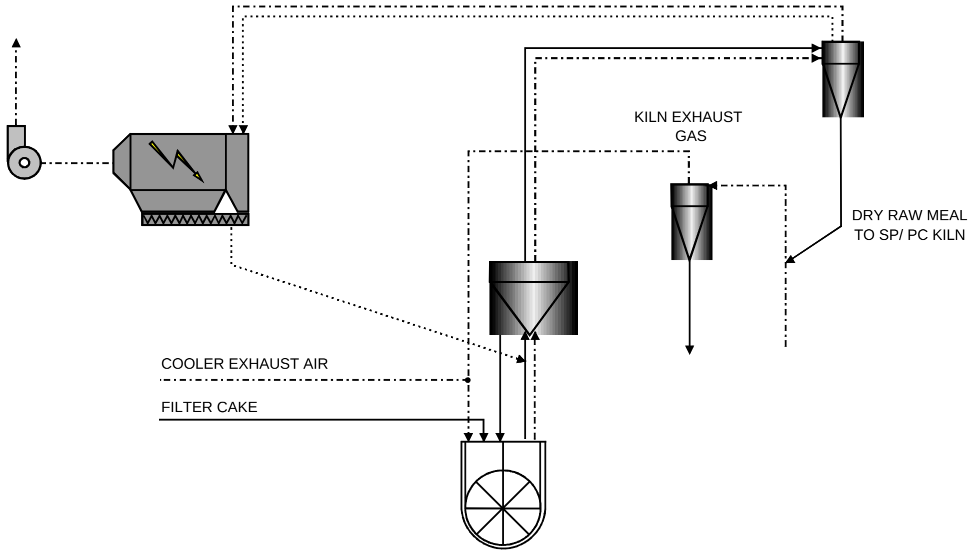


FIGURE 6.5.3 : FLASH DRYER / CRUSHER DRYER COMBINATION FOR FILTER CAKE DRYING

No.	BAT Evaluation Item	Dispersion Dryer	Flash/Crusher Dryer
1	**Consumables:**		
1.1	Materials	Steel wear parts, negligible	
1.2	Air	None	None
1.3	Water	None	None
2	**Energy Consumption:**		
2.1	Thermal	Predominantly waste heat from kiln and cooler	
2.2	Electrical	5 to 6 kWh/t cli	
3	**Waste Generation:**		
3.1	Solids	None	None
3.2	Liquids	None	None
4	**Emissions:**		
4.1	To air	Dryer exhaust gas = Water vapour, kiln exhaust gas, cooler exhaust air	
4.2	To water	None	None
4.3	Noise	Low	Low
4.4	Odour	N.A.	N.A.
5	**Impact on Product Quality**		
5.1	Cement	N.A.	N.A.
6	**Experience**		
6.1	Duration	20 years	10 years
6.2	Number of applications	< 10	< 10
7	**Relative Costs:**		
7.1	Investment costs		
7.2	Operating costs		

6.6 DRYING, PREHEATING, PRECALCINING AND SINTERING PROCESS

6.6.1 INTRODUCTORY REMARKS

Cement clinker is the intermediate product in the manufacture of the hydraulic binding agent Portland cement. By means of a single thermal treatment, a mixture of non-hydraulic naturally occurring minerals – limestone/chalk, quartz, clays and feldspars – is transformed into an intimate mixture of hydraulically active minerals **alite, belite, aluminate** and **ferrite**.

This thermal treatment of heating and cooling which is responsible for this transformation is called **clinkering** and involves peak material temperatures of 1450° C.

The thermal process contains the following major process steps:

☐	20 to 900° C	Removal of all kinds of H_2O, heating up of material
☐	600 to 900° C	Calcination (CO_2 driven out)
☐	800 to 1450° C	Completion of reaction, recrystallisation of alite and belite

Ever since the rotary kiln was introduced around 1895, it became the central part of all modern clinker producing installations. The previously used vertical shaft kiln is still used for production of hydraulic lime, but only in few countries for cement clinker in small scale plants.

The first rotary kilns were long wet kilns, where all of the heat consuming thermal process takes place in a rotary kiln with a length to diameter (L/D) ratio of around 30 to 38, with several support stations.

With the introduction of the dry process, optimisation led to technologies which allowed drying, preheating and calcining to take place in a stationary installation instead of the rotary kiln.

The following sections deal with the most important types of installation suitable for drying, preheating, calcining and sintering the material.

General Remarks

1. All figures and numbers listed in the tables below are typical for normal operation. Real figures of the respective type of installation are expected to be in the range of +/- 15%.

2. Investment costs for installations which are no longer used for new plants are rough estimates in order to be comparable with operating cost of new technology.

3. All cost figures are expressed in % of the corresponding data of a 3000 t/d 5-stage preheater precalciner kiln system which represents the standard solution of the 1990s:

• Clinker production:	3000 t/d
• Kiln type:	5-stage preheater / precalciner kiln with L/D=12
• Heat consumption:	3000 MJ/t cli

4. The following figures are used for variable operating cost:

• Coal cost:	60 ECU/t
• Power cost:	0.04 ECU/kWh

The principle of the rotary kiln, invented by Frederick Ransome in England (patented in 1895), is still the central part for all industrial cement clinker production lines. No other type of equipment has been found to suit the needs of the sintering process better, where the kiln charge is partially liquid and sticky.

The rotary kiln consists of a steel tube with a length to diameter (L/D) ratio between 10 and 38, supported by two to seven or more support stations. The inclination of 2.5 to 4.5% together with a drive to rotate the kiln about its axis at 0.5 to 4.5 revolutions per minute, allows for a slow internal material transport.

In order to withstand the very high peak temperatures (gas: 2000° C, material: 1450° C), the entire rotary kiln is lined with different types of heat resistant bricks (refractories). All long and some short kilns are equipped with internals (chains, crosses, lifters) to improve heat transfer.

Major cost items of kiln operation are consumption of refractories and internals (mainly chains) as well as general maintenance such as alignment of support stations and girth drives. Other critical areas are the seals between the rotary kiln and the stationary installation at both ends.

One common property of all rotary kiln systems is the long retention time in the high temperature zone of gas and material, even surpassing the comparable figures of the typical hazardous waste incinerator. Most hazardous substances are either destroyed (organics) or integrated into the product in concentrations in the range of the earth surface. From a technical point of view, the cement kiln would be an ideal solution to truly close the life cycle of a large variety of problematic industrial waste.

The major environmental impact of cement kiln systems can be summarised as follows:

- ☐ emission of combustion gas, CO_2, vapour, dust, air pollutants and noise;
- ☐ generation of dust (in some cases);
- ☐ consumption primarily of combustibles, but also of power, refractories and steel;
- ☐ environmentally sustainable elimination of a large variety of hazardous waste.

6.6.2 LONG ROTARY KILNS

Long rotary kilns can be fed with slurry, crushed filter cakes, nodules or dry meal and are thus suitable for all process types.

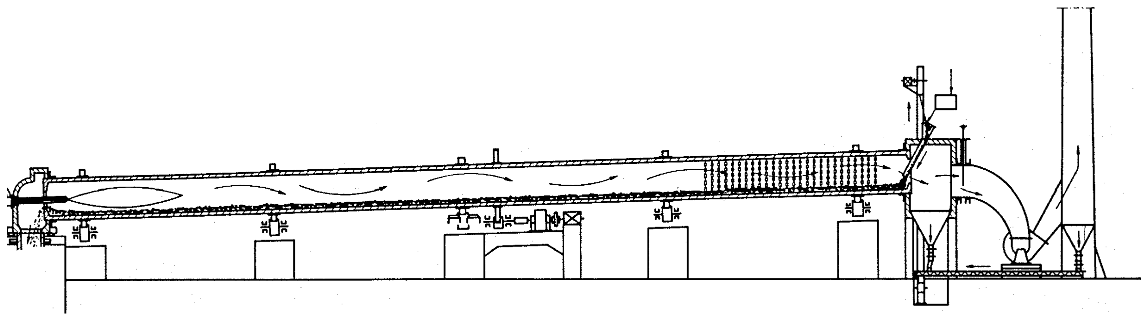
The largest long kilns have L/D of 38, diameter of 7.5 m and length of 230 m. Such huge units produce around 3600 t/d using the wet process (Belgium, US, former Soviet Union).

Long rotary kilns are designed for drying, preheating, calcining and sintering, so that only the feed system and cooler have to be added.

6.6.2.1 LONG WET KILNS WITH CHAINS

Wet process kilns, used since 1895, are the oldest type of rotary kilns for producing cement clinker. Because homogenisation was easier to perform with liquid material, wet raw material preparation was initially applied. Wet kiln feed contains typically 30 to 40% of water which is required to maintain liquid properties of the feed. This water must then be evaporated in the specially designed drying zone at the inlet section of the kiln where a significant portion of the heat from fuel combustion is used.

This technology has high heat consumption with the resulting emission of high quantities of combustion gas and water vapour.



No.	BAT Evaluation Items	Comments	Further Remarks
1	**Consumables**		
1.1	Materials	1000 g/t cli	Chains + refractories
1.2	Air	1600 Nm^3/t cli	For fuel combustion 1)
1.3	Water	0.65 to 0.85 m^3/t cli	For slurry
2	**Energy Consumption**		
2.1	Thermal	Up to 6000 MJ/ t cli	Entire kiln system
2.2	Electrical	2.0 + 5.2 kWh/ t cli	ID fan + kiln drive

3	**Waste Generation**		
3.1	Solids	0 to 300 kg dust/ t cli	0-100% recirculation
3.2	Liquids	None	
4	**Emissions**		
4.1	To air (= exhaust gas)	3000 Nm^3/ t cli	Comb.gas+CO_2+H_2O + air pollutants 1)
4.2	To water	None	
4.3	Noise	Medium	ID fan
4.4	Odour	None	
5	**Impact on Product Quality**		
5.1	Cement	Normal	
6	**Experience**		
6.1	Duration	100 years	
6.2	Number of Applications	>100	
7	**Relative Costs**		
7.1	Investment costs [%]	80	
7.2	Operating costs [%]	205	

1) Stoichiometric combustion air/gas only

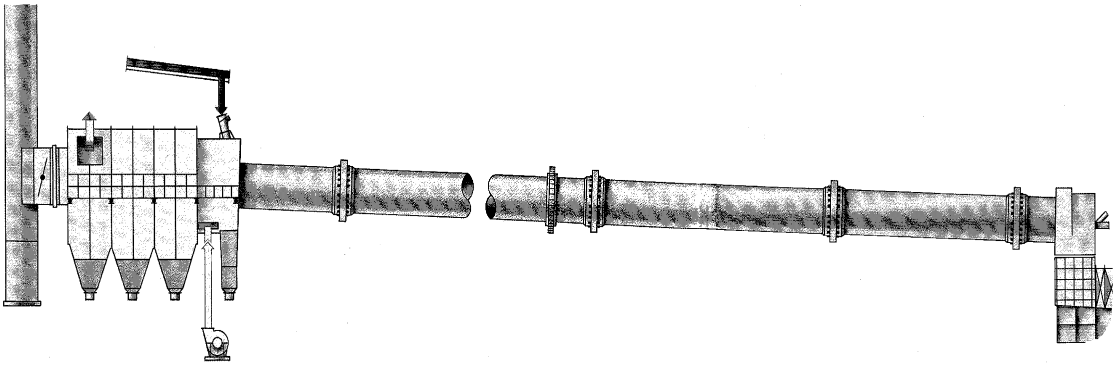
6.6.2.2 LONG DRY KILNS WITH CHAINS (AND CROSSES)

Long dry kilns were developed in the US based on batch type dry homogenising systems for raw material preparation. Due to their simplicity, they became popular and were used for about 50% of the installed capacity. Because of the high fuel consumption, particularly without heat exchanging internals, only few of them have been installed in Europe.

High heat consumption leads also to high kiln exit gas temperature requiring water injection before the ID fan. Therefore numerous long dry kilns have been equipped with dedusting cyclones making them actually into one-stage suspension preheaters.

Unlike with the wet kiln, dust return is technically easy to arrange, but often results in high external dust cycles.

Units of up to 5000 t/d with kiln dimensions of LxD = 7.5x260m were projected, however only up to 2000 t/d kilns were actually built.



No.	BAT Evaluation Items	Comments	Further Remarks
1	**Consumables**		
1.1	Materials	1000 g/t cli	Chains + refract.
1.2	Air	1200 Nm^3/ t cli	For fuel combustion 1)
1.3	Water	<0.1 m^3/ t cli	Water injection
2	**Energy Consumption**		
2.1	Thermal	4500 MJ/ t cli	Kiln w. internals
2.2	Electrical	1.6 + 5.0 kWh/ t cli	ID fan + kiln drive
3	**Waste Generation**		
3.1	Solids	0 to 300 kg/ t cli	0-100% recirculation
3.2	Liquids	None	
4	**Emissions**		
4.1	To air (= exhaust gas)	1600 Nm^3/ t cli	Comb.gas+CO_2+H_2O +air pollutants 1)
4.2	To water	None	
4.3	Noise	Medium	ID fan
4.4	Odour	None	
5	**Impact on Product Quality**		
5.1	Cement	Normal	
6	**Experience**		
6.1	Duration	>50 years	
6.2	Number of Applications	>100	
7	**Relative Costs**		
7.1	Investment costs [%]	80	
7.2	Operating costs [%]	160	

1) Stoichiometric combustion air/gas only

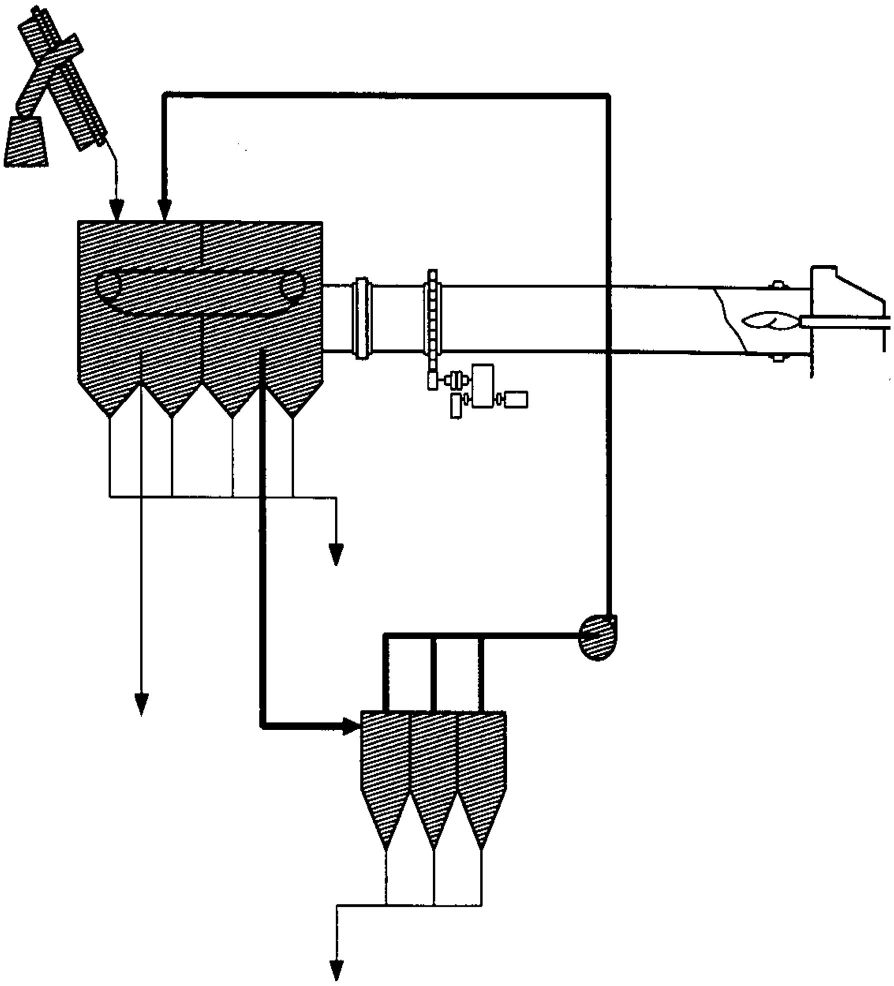
6.6.3 GRATE PREHEATER KILNS

Grate preheater technology, perhaps better known as Lepol kilns, was invented in 1928 and represented the first approach to let part of the clinkering process take place in an innovative piece of equipment allowing the reduction of the rotary kiln to a L/D ratio of 11 to 16.

Nodules made from dry meal on a nodulizer disc (semi-dry process) or from wet slurry filter cakes in an extruder (semi-wet process) are fed onto a horizontal travelling grate where mainly preheating takes place.

In order to achieve optimum thermal efficiency, the semi-wet grate preheaters can be equipped with triple pass gas systems and cooler waste air is used for raw material drying.

Maximum unit size built is 3300 t/d for a semi-wet kiln system.



No.	BAT Evaluation Items	Comments	Further Remarks
1	**Consumables**		
1.1	Materials	300 g/t cli	Refractories
1.2	Air	850/950 Nm^3/ t cli	For fuel combustion 1)
1.3	Water	0.17/0.35 m^3/ t cli	Semi-dry/semi-wet
2	**Energy Consumption**		
2.1	Thermal	3300/3700 MJ/ t cli	Entire kiln system
2.2	Electrical	6.4 kWh/ t cli	Excl. cooler
3	**Waste Generation**		
3.1	Solids	None	
3.2	Liquids	None	
4	**Emissions**		
4.1	To air (= exhaust gas)	2200/3500 Nm^3/ tcli	Comb.gas+CO_2+H_2O+air pollutants 1)
4.2	To water	None	
4.3	Noise	Medium	ID fan
4.4	Odour	None	
5	**Impact on Product Quality**		
5.1	Cement	Normal	
6	**Experience**		
6.1	Duration	>40 years	
6.2	Number of Applications	>100	
7	**Relative Costs**		
7.1	Investment costs [%]	100	
7.2	Operating costs [%]	105/120	Semi-dry / semi-wet

1) Stoichiometric combustion air/gas only

6.6.4 SUSPENSION PREHEATER KILNS

A significant development was the invention of the suspension preheater in the early 1930s. Preheating and even partial calcination of the dry raw meal takes place by maintaining the meal in suspension with hot gas from the rotary kiln. Considerably larger contact surface allows almost complete heat exchange, at least theoretically. Following different philosophies, a variety of solutions were initially installed by the cement kiln suppliers.

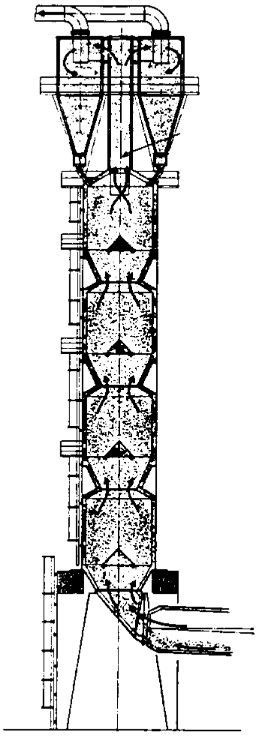
6.6.4.1 SHAFT PREHEATER KILNS

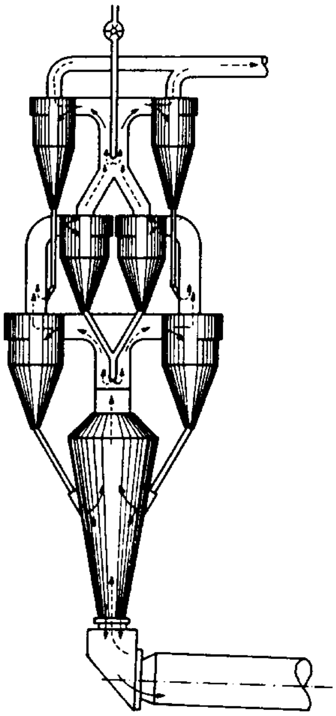
Shaft preheaters were built in numerous cases when suspension preheater technology was introduced. Due to its theoretically superior heat exchange (according to the counter current principle), several suppliers applied that technology. However, due to the difficulty of even distribution of meal to gas, actual performance was far worse than expected, and the technology using only shaft stages was eventually abandoned in favour of hybrid systems with cyclone stages or pure multi-stage cyclone preheaters.

Other than the pure shaft preheaters, which were usually equipped with dedusting cyclones, there was also a variety of hybrids with both shaft and cyclone stages. Many of those hybrids are still in operation, however most of them have been converted to pure cyclone preheaters.

A shaft stage is considerably less sensitive to build-up problems than a cyclone stage, which can be beneficial for the bottom stage in cases where excessive quantities of circulating elements (chlorides, sulfur, alkalis) are present. Hybrid preheaters with a bottom shaft stage are still available for new plants.

Typical capacities of shaft preheater kilns were up to 1500 t/d, whereas hybrid systems can produce 3000 t/d and more.





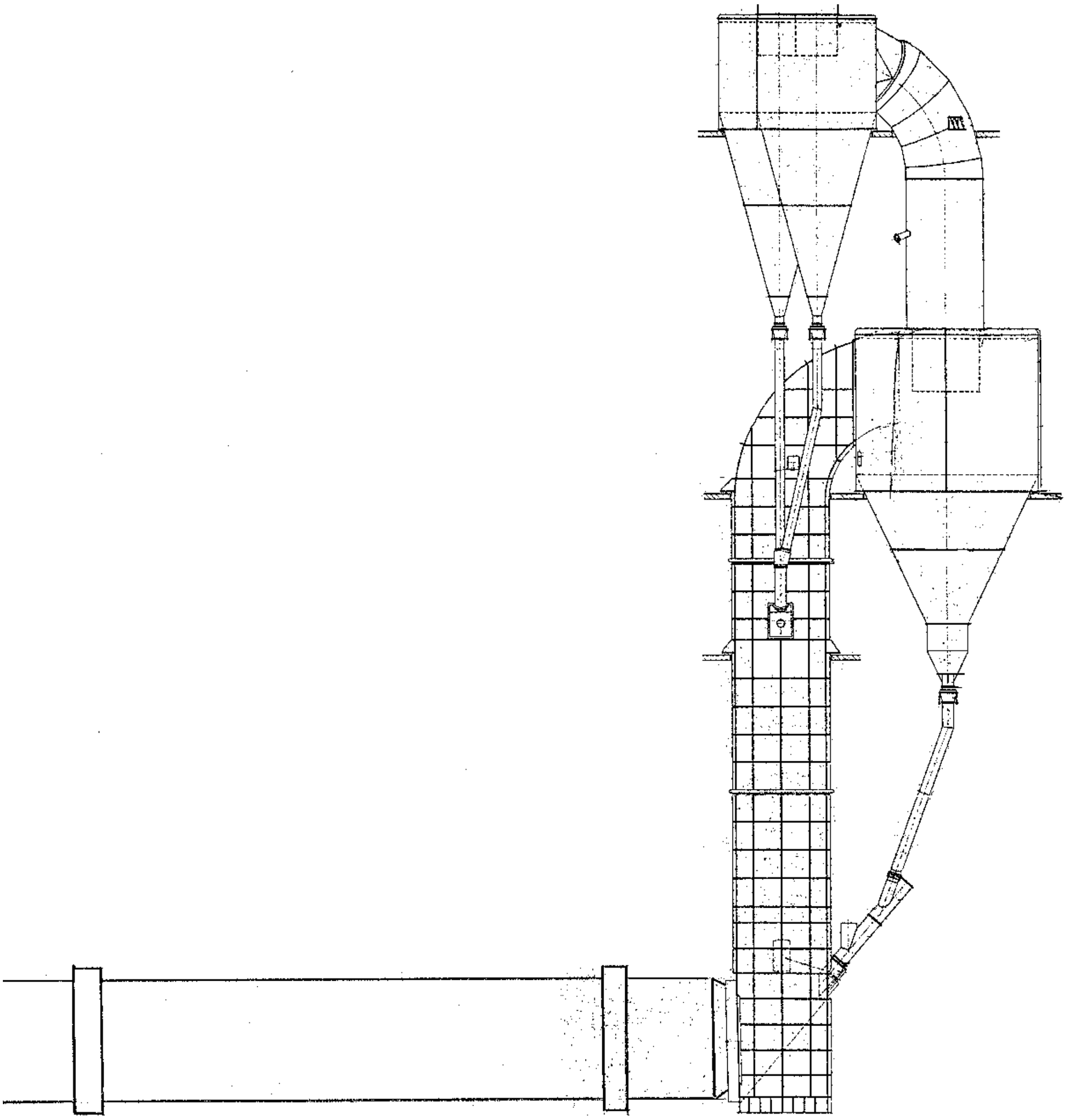
No.	BAT Evaluation Items	Comments	Further Remarks
1	**Consumables**		
1.1	Materials	700 g/t cli	Refractories
1.2	Air	820 Nm^3/ t cli	For fuel combustion
1.3	Water	None	
2	**Energy Consumption**		
2.1	Thermal	3500 to 4000 MJ/ t cli	Entire kiln system
2.2	Electrical	7.0 to 6.4 kWh/ t cli	ID fan + kiln drive
3	**Waste Generation**		
3.1	Solids	None	
3.2	Liquids	None	
4	**Emissions**		
4.1	To air (= exhaust gas)	1400-1600 Nm^3/ tcli	Comb.gas+CO_2+air pollutants 1)
4.2	To water	None	
4.3	Noise	Medium	ID fan
4.4	Odour	None	
5	**Impact on Product Quality**		
5.1	Cement	Normal	
6	**Experience**		
6.1	Duration	>40 years	
6.2	Number of Applications	>10	
7	**Relative Costs**		
7.1	Investment cost [%]	115	
7.2	Variable op. cost [%]	125 to 135	

1) Stoichiometric combustion air/gas only

6.6.4.2 2 STAGE CYCLONE PREHEATER KILNS

The cyclone preheater with 2 stages was often applied to convert wet kilns to dry process, or for new plants with high inputs of circulating elements (sulfur, chloride, alkalis) before kiln gas bypass technology was developed.

The 450 to 500° C hot exhaust gas must be cooled with air before entering the kiln ID fan and can then be used for raw material drying.



No.	BAT Evaluation Items	Comments	Further Remarks
1	**Consumables**		
1.1	Materials	1000 g/t cli	Refractories
1.2	Air	950 Nm^3/ t cli	For fuel combustion1)
1.3	Water	None	
2	**Energy Consumption**		
2.1	Thermal	3700 MJ/ t cli	Entire kiln system
2.2	Electrical	8.0 kWh/ t cli	ID fan + kiln drive

3	**Waste Generation**		
3.1	Solids	None	
3.2	Liquids	None	
4	**Emissions**		
4.1	To air (= exhaust gas)	1500 Nm^3/ tcli	Comb.gas+CO_2+air pollutants 1)
4.2	To water	None	
4.3	Noise	Medium	ID fan
4.4	Odour	None	
4.5	NO_x reduction [%]	None	
5	**Impact on Product Quality**		
5.1	Cement	Normal	
6	**Experience**		
6.1	Duration	>40 years	
6.2	Number of Applications	>10	
7	**Relative Costs**		
7.1	Investment cost [%]	100	
7.2	Variable op. cost [%]	135	

1) Stoichiometric combustion air/gas only

6.6.5 FOUR STAGE CYCLONE PREHEATER KILNS

The four stage cyclone preheater kiln system was standard technology in the 1970s. Many plants were built in the 1000 to 3000 t/d range, some of them equipped with planetary coolers.

The exhaust gas with a temperature of around 330° C is normally used for raw material drying.

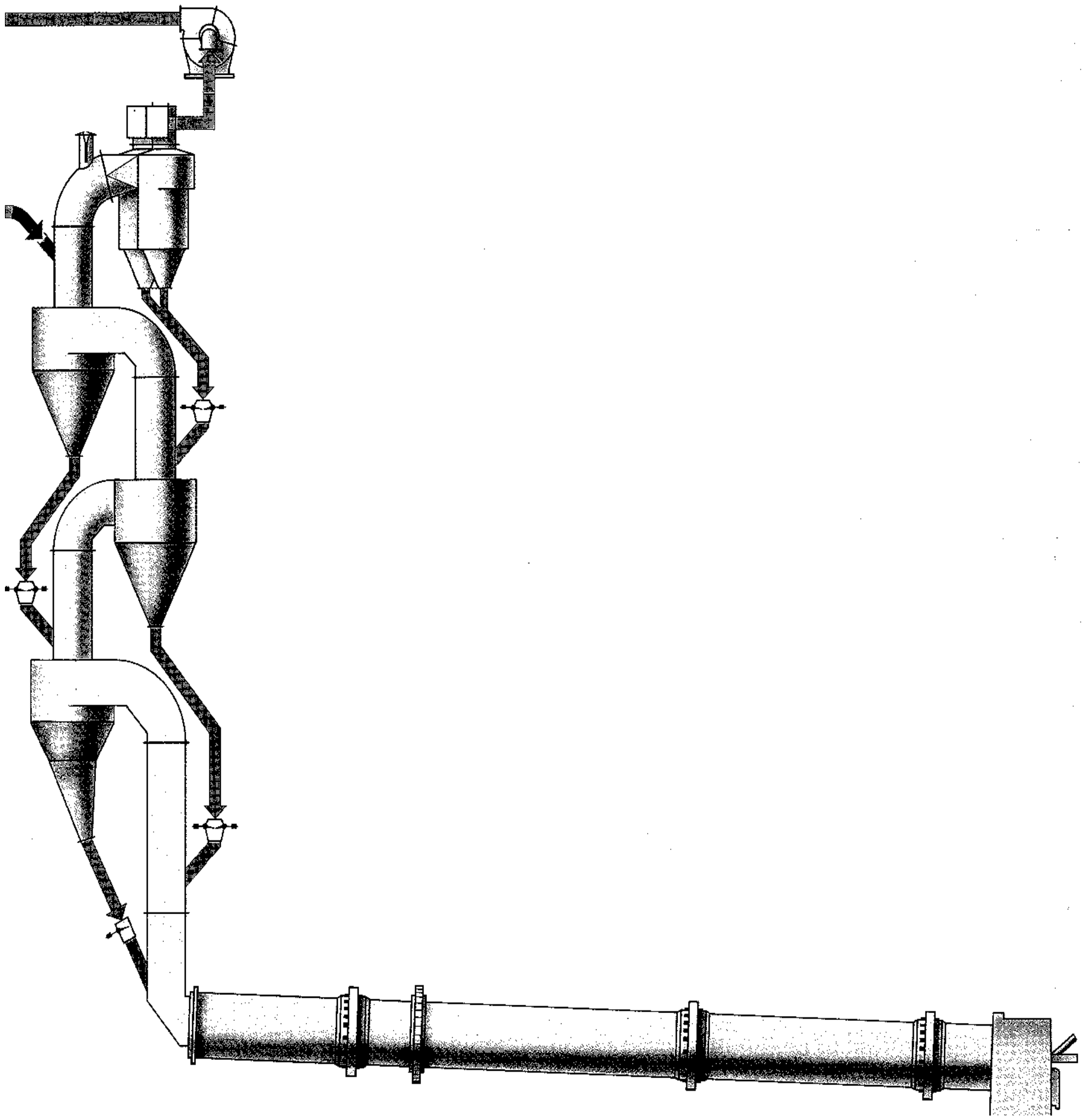
Pressure drop across the preheater is about the same as for a modern 5-stage preheater with precalciner because of the older cyclone design used in earlier years.

When the meal enters the rotary kiln, calcination is already about 30% completed.

In earlier years, insurmountable problems were encountered with four stage preheaters where excessive inputs of circulating elements (chlorides, sulfur, alkalies) from feed and/or fuel occurred. Highly enriched cycles of those elements lead to build-ups in cyclone and duct walls frequently causing blockages and kiln stops of several days duration. Only the kiln gas bypass solved the problem later on, however at cost of higher heat and material consumption as well as the need for dust disposal.

Almost all four stage suspension preheaters have a rotary kiln with three supports, which has been the standard concept after about 1970. Sizes from 3.5 to 6 m diameter have been built with L/D ratios being in the range of 13 to 16.

Mechanically simpler than the long wet and dry kilns, it is probably the most widely applied kiln type today.



No.	BAT Evaluation Items	Comments	Further Remarks
1	**Consumables**		
1.1	Materials	400 g/t cli	Refractories
1.2	Air	820 Nm^3/ t cli	For fuel combustion 1)
1.3	Water	None	
2	**Energy Consumption**		
2.1	Thermal	3150 MJ/ t cli	Entire kiln system
2.2	Electrical	6.5 kWh/ t cli	ID fan + kiln drive
3	**Waste Generation**		
3.1	Solids	None	Exception: bypass dust
3.2	Liquids	None	
4	**Emissions**		
4.1	To air (= exhaust gas)	1350 Nm^3/ tcli	Comb.gas+CO_2+ air pollutants 1)
4.2	To water	None	
4.3	Noise	Medium	ID fan
4.4	Odour	None	
5	**Impact on Product Quality**		
5.1	Cement	Normal	
6	**Experience**		
6.1	Duration	>40 years	
6.2	Number of Applications	>100	
7	**Relative Costs**		
7.1	Investment costs [%]	115	
7.2	Operating costs [%]	110	

1) Stoichiometric combustion air/gas only

6.6.6 4 TO 6 STAGE CYCLONE PREHEATERS WITH PRECALCINER KILNS

Kiln systems with 5 cyclone preheater stages and precalciner (PC) are considered standard technology for ordinary new plants.

The size of a new plant is primarily determined by predicted market developments, but also by economy of scale. Typical unit capacity for new plants in Europe today is 3000 to 5000 t/d. Technically, larger units with up to 15,000 t/d are possible, and three 10,000 t/d kilns are currently in operation in fast growing Asian markets.

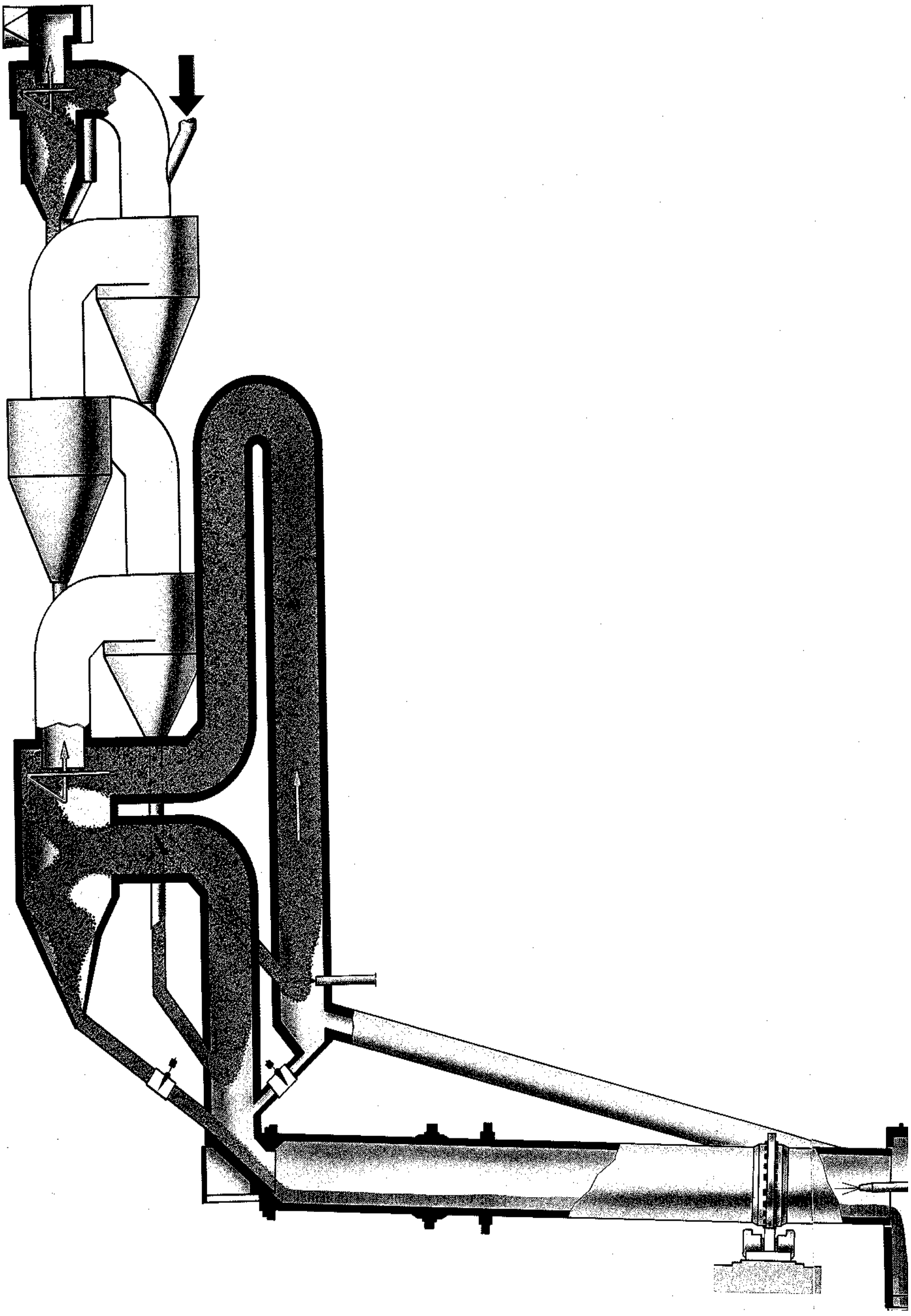
A 5-stage preheater-precalciner kiln with 3000 t/d is used as basis for the relative performance figures (see Section 6.6.1).

Earlier precalciner systems had only 4 preheater stages with accordingly higher exhaust gas temperature and fuel consumption.

Where natural raw material moisture is low, 6 stage preheaters can be the preferred choice, particularly in combination with bag filter dedusting.

Where excessive inputs of circulating elements exist, a kiln gas bypass is required to maintain continuous kiln operation. However, due to the different gas flow characteristics, a bypass has a much higher efficiency than a straight preheater kiln.

In spite of the fact that the meal enters the kiln 75 to 95% calcined, most precalciner kilns are still equipped with a rotary kiln with a calcining zone, i.e. with a L/D of 13 to 16 like the straight preheater. Largest preheater/precalciner kilns with three supports are in operation for 10,000 t/d in Thailand with DxL of 6.0 x 96 to 100m.



No.	BAT Evaluation Items	Comments	Further Remarks
1	**Consumables**		
1.1	Materials	300-400 g/t cli	Refractories
1.2	Air	750-830 Nm^3/ t cli	For fuel combustion 1)
1.3	Water	None	
2	**Energy Consumption**		
2.1	Thermal	2900-3200 MJ/ t cli	Entire kiln system
2.2	Electrical	6.0 kWh/ t cli	ID fan + kiln drive
3	**Waste Generation**		
3.1	Solids	None	Exception: bypass dust
3.2	Liquids	None	
4	**Emissions**		
4.1	To air (= exhaust gas)		Comb.gas+CO_2+air pollutants 1)
4.2	To water	None	
4.3	Noise	Medium	ID fan
4.4	Odour	None	
5	**Impact on Product Quality**		
5.1	Cement	Normal	
6	**Experience**		
6.1	Duration	>20 years	
6.2	Number of Applications	>100	
7	**Relative Costs**		
7.1	Investment costs [%]	95 - 105	
7.2	Operating costs [%]	100 - 105	

1) Stoichiometric combustion air/gas only

6.7 CLINKER COOLERS

6.7.1 INTRODUCTORY REMARKS

The clinker cooler is an integral part of the kiln system and has a decisive influence on performance and economy of the pyroprocessing plant, and has the following tasks:

- ☐ recuperate maximum heat from the hot (1450° C) clinker back to the process;
- ☐ reduce the clinker temperature to a level suitable for the subsequent equipment.

Heat recuperation is done by preheating the air used for combustion in the main and secondary firing as close to the thermodynamic limit as possible.

Due to the high temperature, extreme abrasiveness and wide range of granulometry of the clinker, this task is not easy to fulfil.

Typical problems with clinker coolers are thermal expansion, wear, wrong air flows and poor availability which work against the above requirements.

General Remarks

1. All figures and numbers listed in the tables below are typical for normal operation. Real figures of the respective type of installation are expected to be in the range of +/- 15%.

2. Investment costs for installations which are no longer used for new plants are rough estimates in order to be comparable with operating cost of new technology.

3. All cost figures are expressed in % of the corresponding data of a modern grate cooler which represents the standard solution of the 1990s.

4. The following figures are used for variable operating cost:

• Coal cost:	60 ECU/t
• Power cost:	0.04 ECU/kWh

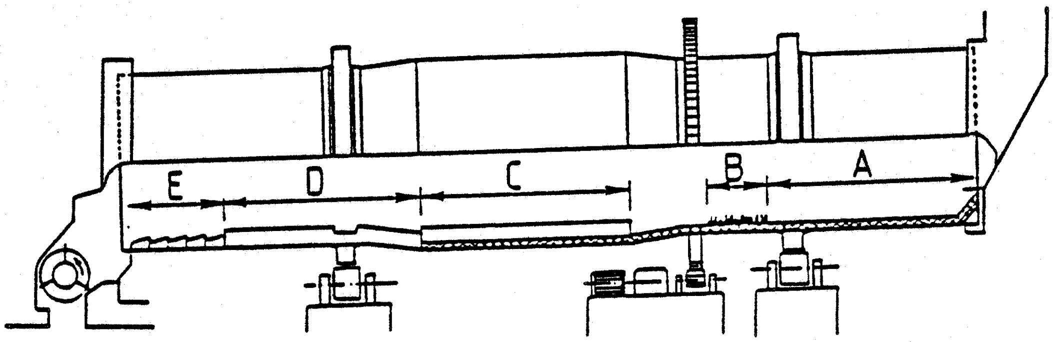
6.7.2 ROTARY COOLERS

6.7.2.1 TUBE COOLERS

The tube cooler uses the same principle as the rotary kiln, but for reversed heat exchange.

Arranged at the outlet of the kiln, often in reverse arrangement, i.e. underneath the kiln, a second rotary tube with its own drive is installed. After kiln discharge, the clinker passes a transition hood before it enters the cooler, which is equipped with lifters to disperse the product into the air flow. Cooling air flow is determined by the air required for fuel combustion.

Other than the speed, only the internals can influence the performance of the cooler. Optimisation of lifters must consider heat exchange (dispersion pattern) versus dust cycle back to the kiln.



No.	BAT Evaluation Items	Comments	Further Remarks
1	**Consumables**		
1.1	Materials	Internals	Steel, refractory
1.2	Air	None	= air for combustion
1.3	Water	None	Optional: H_2O for enhanced cooling (0-60 l/t cli)
2	**Energy Consumption**		
2.1	Thermal	None	
2.2	Electrical	4.0 kWh/t cli	
3	**Waste Generation**		
3.1	Solids	Internals	Recyclable steel, refractories
3.2	Liquids	None	Water spray: H_2O
4	**Emissions**		
4.1	To air	None	Dust, if seal leaks
4.2	To water	None	
4.3	Noise	High	
4.4	Odour	None	
5	**Impact on Product Quality**		
5.1	Cement	Normal	

6	**Experience**		
6.1	Duration	>100 years	
6.2	Number of Applications	> 50	
7	**Relative Costs**		
7.1	Investment costs [%]	70	
7.2	Operating costs [%]	130	

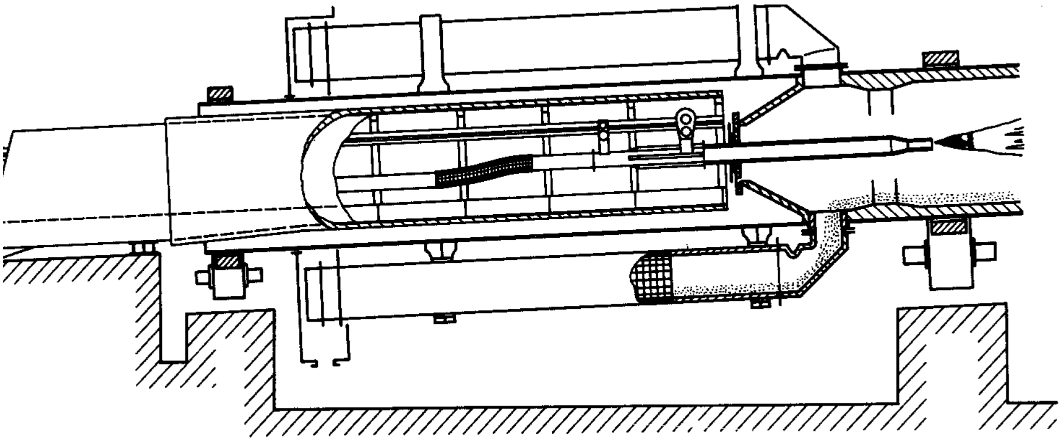
6.7.2.2 PLANETARY COOLERS

The planetary (or satellite) cooler is a special type of rotary cooler. Several cooler tubes, typically 9 to 11, are attached to the rotary kiln at the discharge end. The hot clinker enters through openings in the kiln shell around its circumference at each point where a cooler tube is attached.

The cooling air quantity is determined by the air required for fuel combustion and enters each tube from the discharge end, allowing for a counter flow type heat exchange. As for the tube cooler, internals for lifting and dispersing the clinker are essential. No variable operating parameter exists.

Due to high wear and thermal shock, but also because of dust cycles, high clinker exit temperatures and less than optimum heat recuperation are not unusual. Clinker exit temperature can only be further reduced by water injection into the cooler tubes or onto the shell.

Because it is practically impossible to extract tertiary air, the planetary cooler is not suitable for precalcination. Secondary firing with up to 25% fuel in the kiln riser area is possible, however (formerly called AT-precalciners).



No.	BAT Evaluation Items	Comments	Further Remarks
1	**Consumables**		
1.1	Materials	Internals	Steel, refractory
1.2	Air	None	= air for combustion
1.3	Water	None	Optional: H_2O for enhanced cooling (0-40 l/t cli)
2	**Energy Consumption**		
2.1	Thermal	None	
2.2	Electrical	1.5 kWh/t cli	
3	**Waste Generation**		
3.1	Solids	Recyclable steel, refractories	
3.2	Liquids	None	Water spray: H_2O
4	**Emissions**		
4.1	To air	None	Dust, if flange joints not tight
4.2	To water	None	
4.3	Noise	High	
4.4	Odour	None	
5	**Impact on Product Quality**		
5.1	Cement	Normal	
6	**Experience**		
6.1	Duration	>50 years	
6.2	Number of Applications	> 50	
7	**Relative Costs**		
7.1	Investment costs [%]	105	
7.2	Operating costs [%]	95	

6.7.3 GRATE COOLERS

Cooling in grate coolers is of the cross flow type and takes place by air penetrating from bottom to top a layer of clinker (clinker bed) laying on a grate, which is permeable to air.

Two ways of transporting the clinker are applied: travelling grate and reciprocating grate (steps with pushing edges).

Since the hot air from the aftercooling zone is not used for combustion, it is available for drying purposes, e.g. raw materials, cement additives or coal. If not used for drying, this cooler waste air must be properly dedusted.

Remark:

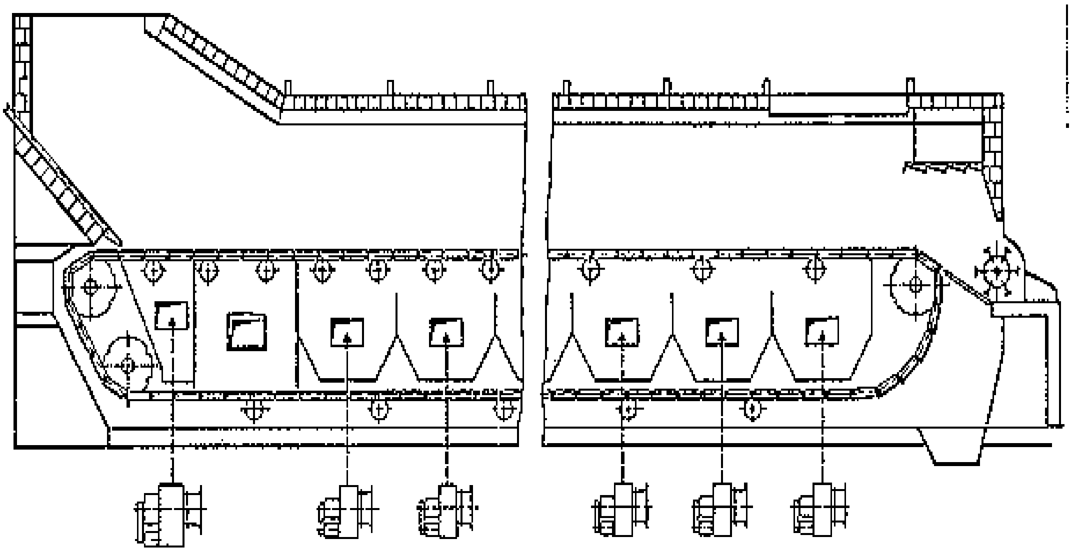
Costs for dedusting are not included in the tables below!

6.7.3.1 TRAVELLING GRATE COOLERS

Clinker transport with this cooler type is by a travelling grate, which has the same design features as the preheater grate (Lepol). Cooling air is pressurised by fans discharging into compartments underneath the grate.

Advantages of this design are undisturbed clinker layer (no steps) and the possibility of exchanging plates without a kiln stop.

Due to mechanical complexity and poor recuperation because of limited bed thickness (caused by difficult sealing between grate and walls), this design was abandoned around 1980.



No.	BAT Evaluation Items	Comments	Further Remarks
1	**Consumables**		
1.1	Materials	Grate plates, refra	Steel, refractory
1.2	Air	<2000 Nm^3/t cli	For aftercooling
1.3	Water	yes	Water cooled inlet chute
2	**Energy Consumption**		
2.1	Thermal	None	
2.2	Electrical	5 kWh/t cli	

3	**Waste Generation**		
3.1	Solids	Refra, cast steel	Recycled
3.2	Liquids	None	
4	**Emissions**		
4.1	To air (= exhaust air)	< 2000 Nm^3/t cli*	
4.2	To water	None	
4.3	Noise	Medium	Fans
4.4	Odour	None	
5	**Impact on Product Quality**		
5.1	Cement	Normal	
6	**Experience**		
6.1	Duration	>50 years	
6.2	Number of Applications	>50	
7	**Relative Costs**		
7.1	Investment costs [%]	110	
7.2	Operating costs [%]	125	

* depending on kiln system

6.7.3.2 RECIPROCATING GRATE COOLERS (CONVENTIONAL)

Material transport in the reciprocating grate cooler takes place by stepwise pushing of the clinker bed by the front edges of each plate row. Relative movement of front edges is generated by hydraulic or mechanical (crankshaft) drives connected to up to every second row. Only the clinker travels from feed end to discharge end, but not the grate.

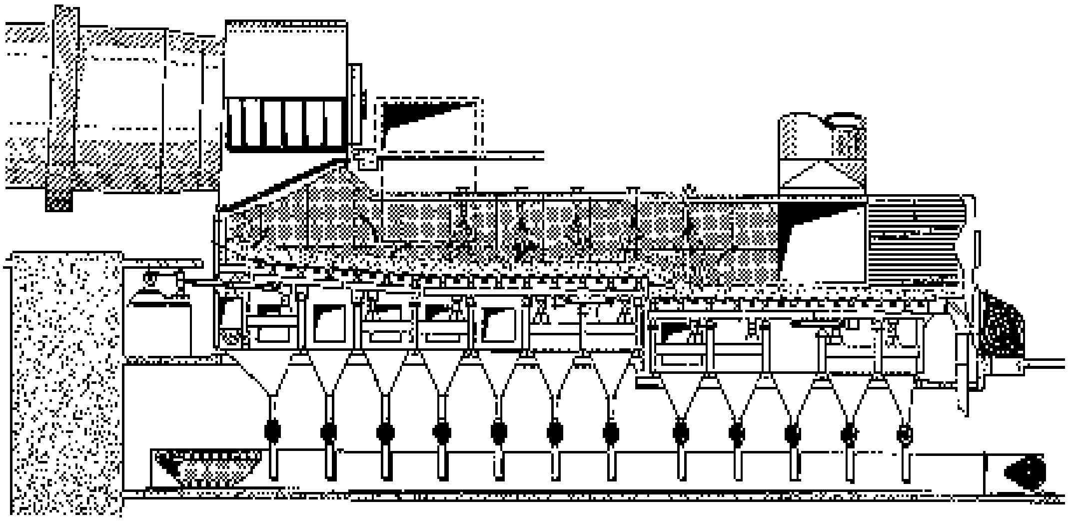
The grate plates are made from heat resistant cast steel and are typically 300 mm wide and have holes for the air to pass through them.

Cooling air is insufflated from fans at 300 – 1000 mmWG via separate undergrate compartments which are required to maintain the pressure profile. Two cooling zones can be distinguished:

- ❑ the recuperation zone, from which the hot cooling air is used for combustion of the main burner fuel (= secondary air) and the precalciner fuel (= tertiary air);
- ❑ the aftercooling zone, where additional cooling air cools the clinker safely to lower temperatures.

The largest units in operation have about 280 m² active surface and cool 10,000 t/d of clinker.

Typical problems with these coolers are segregation and uneven clinker distribution leading to air-clinker imbalance, fluidization of fine clinker (red river) and also build-ups (snowmen) and worse than ideal life of plates.



No.	BAT Evaluation Items	Comments	Further Remarks
1	**Consumables**		
1.1	Materials	Grate plates, refra	Steel, refractory
1.2	Air	<2000 Nm^3/t cli	For aftercooling
1.3	Water	No	Optional: H_2O injection for waste air temp. control (upset)
2	**Energy Consumption**		
2.1	Thermal	None	
2.2	Electrical	5 kWh/t cli	
3	**Waste Generation**		
3.1	Solids	Recyclable steel +refractories	
3.2	Liquids	None	
4	**Emissions**		
4.1	To air (= exhaust air)	< 2000 Nm^3/t cli*	Clean gas, dust
4.2	To water	None	
4.3	Noise	Medium	Grate, fans
4.4	Odour	None	
5	**Impact on Product Quality**		
5.1	Cement	Normal	
6	**Experience**		
6.1	Duration	>40 years	
6.2	Number of Applications	>100	

7	**Relative Costs**		
7.1	Investment costs [%]	95	
7.2	Operating costs [%]	115	

* depending on kiln system

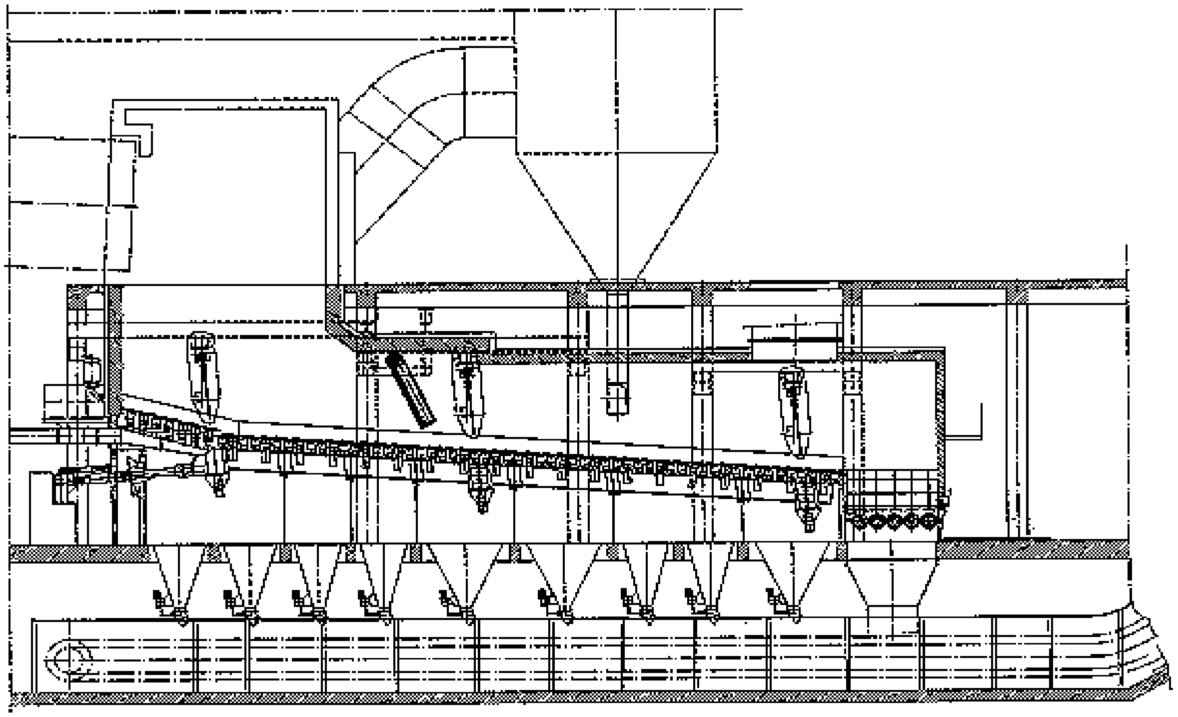
6.7.3.3 RECIPROCATING GRATE COOLERS (MODERN)

Introduction and development of modern technology grate coolers started around 1983.

The design aimed to eliminate the problems with conventional coolers thus taking a step closer to optimum heat exchange and also to more compact coolers using less cooling air and smaller dedusting systems.

Key features of modern cooler technology are, depending on supplier:

☐ modern plates with high pressure drop, permeable for air but not for clinker;
☐ forced plate aeration via ducts and beams;
☐ individually adjustable zones of aeration;
☐ fixed inlet;
☐ fewer and wider grates;
☐ roller crusher;
☐ heat shields.



No.	BAT Evaluation Items	Comments	Further Remarks
1	**Consumables**		
1.1	Materials	Grate plates, refra	Steel, refractory
1.2	Air	800 to 1700 Nm^3/t cli	Aftercooling, seal air
1.3	Water	No	Water injection for temp. control (upset)
2	**Energy Consumption**		
2.1	Thermal	None	
2.2	Electrical	4.0 to 8.0 kWh/t cli	
3	**Waste Generation**		
3.1	Solids	Refra, cast steel	Recycled
3.2	Liquids	None	
4	**Emissions**		
4.1	To air (= exhaust air)	800 - 1700 Nm^3/t cli*	
4.2	To water	None	
4.3	Noise	Low	Fans
4.4	Odour	None	
5	**Impact on Product Quality**		
5.1	Cement	Normal	
6	**Experience**		
6.1	Duration	>10 years	
6.2	Number of Applications	>50	
7	**Relative Costs**		
7.1	Investment costs [%]	100	
7.2	Operating costs [%]	100	

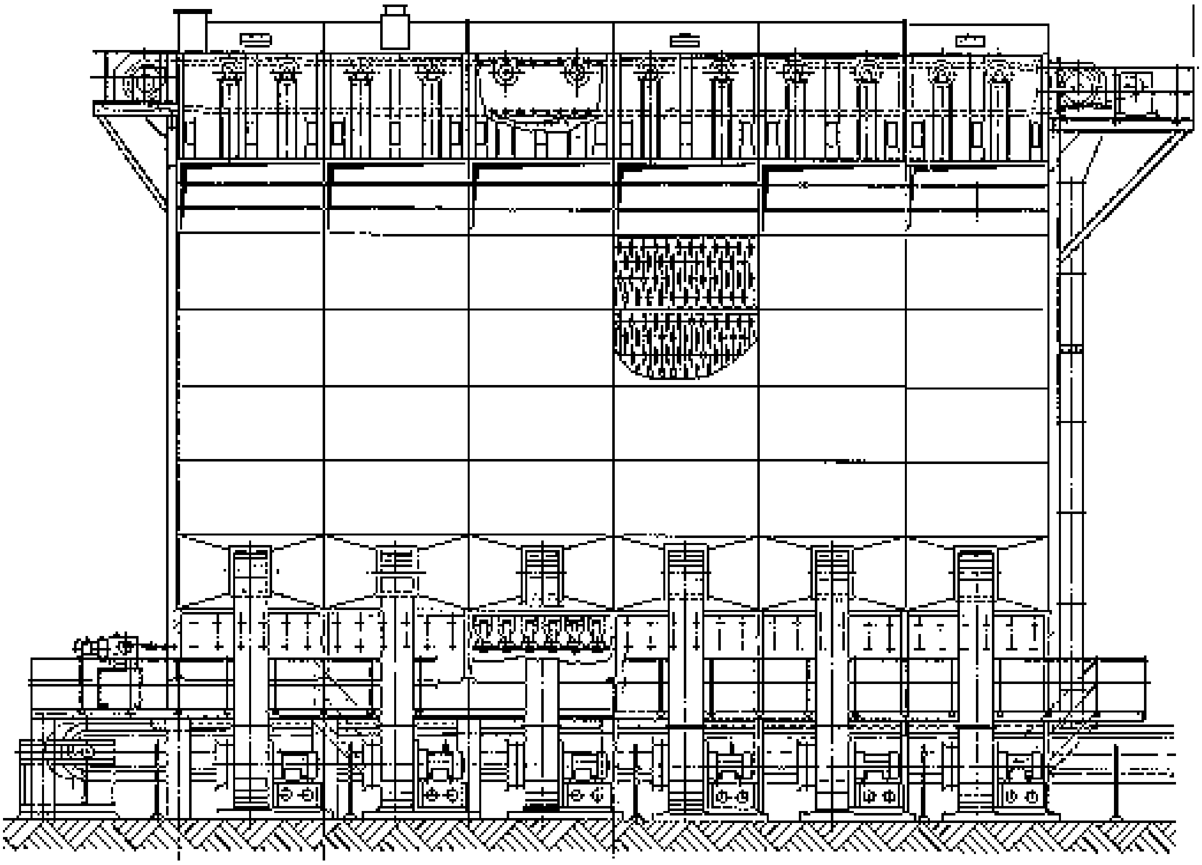
* depending on kiln system

6.7.4 VERTICAL COOLERS

6.7.4.1 GRAVITY COOLERS

A dust free aftercooler called Gravity Cooler or G-cooler has been developed. Installed after a planetary cooler (plant upgrade e.g.) or short grate recuperator cooler, the cooling air never gets in contact with the clinker.

Heat exchange takes place between the clinker and the air which flows transversely through steel tubes passing through the clinker bed. The clinker descends slowly over the tubes as it passes through the cooler chamber.



No.	BAT Evaluation Items	Comments	Further Remarks
1	**Consumables**		
1.1	Materials	None	
1.2	Air	None	Aftercooler only
1.3	Water	None	
2	**Energy Consumption**		
2.1	Thermal	None	
2.2	Electrical	2.5 kWh/t cli	Excl. recuperator
3	**Waste Generation**		
3.1	Solids	None	
3.2	Liquids	None	

4	**Emissions**		
4.1	To air	None	
4.2	To water	None	
4.3	Noise	Low	Cooling fans
4.4	Odour	None	
5	**Impact on Product Quality**		
5.1	Cement	Normal	
6	**Experience**		
6.1	Duration	>20 years	
6.2	Number of Applications	>10	
7	**Relative Costs**		
7.1	Investment costs [%]	30	Aftercooler only
7.2	Operating costs [%]	30	

6.8 CONVENTIONAL FUELS STORAGE, PREPARATION AND FIRING

6.8.1 INTRODUCTORY REMARKS

Three different types of conventional or fossil fuels are used in cement kiln firing in decreasing order of importance:

- ☐ pulverized coal and petcoke;
- ☐ (heavy) fuel oil;
- ☐ natural gas.

Conventional fuels are today increasingly substituted by non-conventional, non-fossil (gaseous, liquid, pulverized, coarse crushed) alternative (or secondary) fuels for resource efficiency and economical reasons.

In order to keep heat losses at minimum, cement kilns are operated at lowest reasonable excess oxygen factors. This requires highly uniform and reliable fuel metering as well as the fuel being present in a form which allows for easy and complete combustion (fuel preparation process and fuel storage).

These conditions are fulfilled by all pulverized, liquid and gaseous fuels, be it conventional or alternative fuels. The main fuel input (65 – 85%) has therefore to be of this type whereas the remaining 15 – 35% may be fed in coarse crushed or lumpy form.

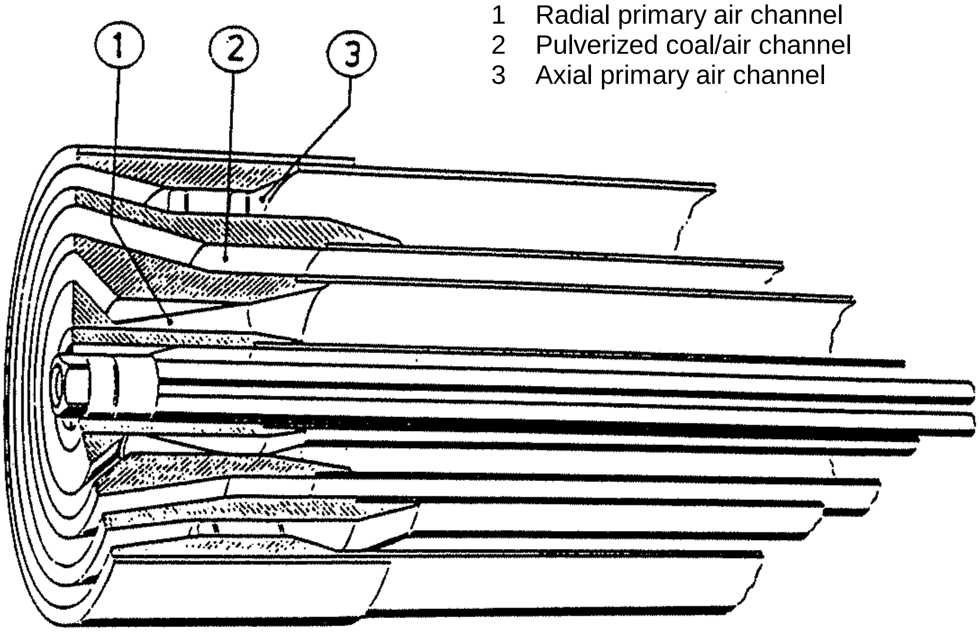
Fuel feed points to the kiln system are:

- ☐ via the main burner at the rotary kiln outlet end;
- ☐ via a feed chute at the transition chamber at the rotary kiln inlet end (for lump fuel);
- ☐ via fuel burners to the riser pipe;
- ☐ via precalciner burners to the precalciner;
- ☐ via a feed chute to the precalciner (for lump fuel);
- ☐ via a mid-kiln valve to long wet and dry kilns (for lump fuel).

The fuel introduced via the main burner to the hot zone of the rotary kiln therein produces the main flame with flame temperatures around 2000° C. For process optimisation reasons the flame has to be adjustable within limits.

The flame is shaped and adjusted by the so called primary air (10 – 15% of total combustion air) through interaction of the outer axial air ring channel as well as of the conical inner air ring channel of the (main) burner.

An example of such a burner is given in Figure 6.8.1 hereunder.



1 Radial primary air channel
2 Pulverized coal/air channel
3 Axial primary air channel

6.8.2 COAL AND PETCOKE FIRING

Raw Coal Storage

Raw coal and petcoke are stored similarly to raw materials (see Chapter 6.1) in (covered) storage halls.

In the case of (strategic) long term stocks, outside storage in large, compacted stockpiles is used. To prevent rainwater and wind erosion such stockpiles may be seeded with grass.

Fine Coal Storage

Pulverized coal and petcoke is exclusively stored in silos. For safety reasons (explosions triggered by smouldering fires and static electricity spark-overs) these silos have to be of the mass flow extraction type and have to be equipped with standard safety devices.

Coal Preparation

Coal and petcoke are pulverized to about raw meal fineness in grinding plants comprising equipment similar to raw grinding plants (see Chapter 6.3). Special features have to be incorporated to protect the equipment from fires and explosions.

Three main types of coal milling and grinding systems are used:

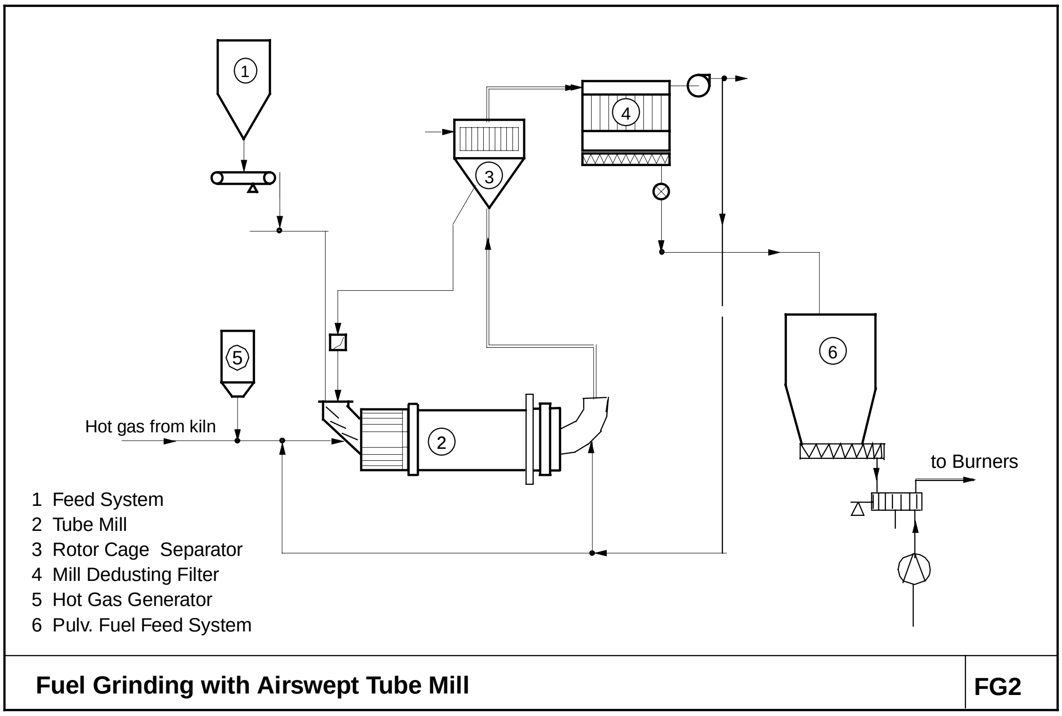


Figure 6.8.2: Tube Mill, Airswept (TMAS)

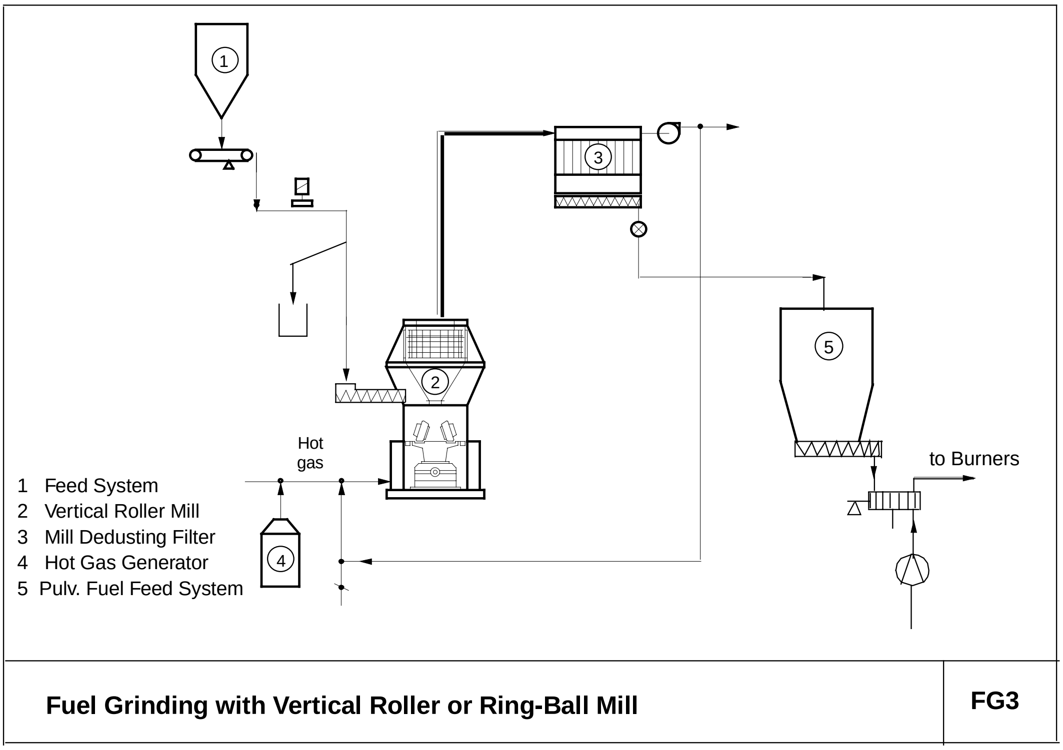


Figure 6.8.3: Vertical Roller or Ring-Ball Mill (VRM/VRBM)

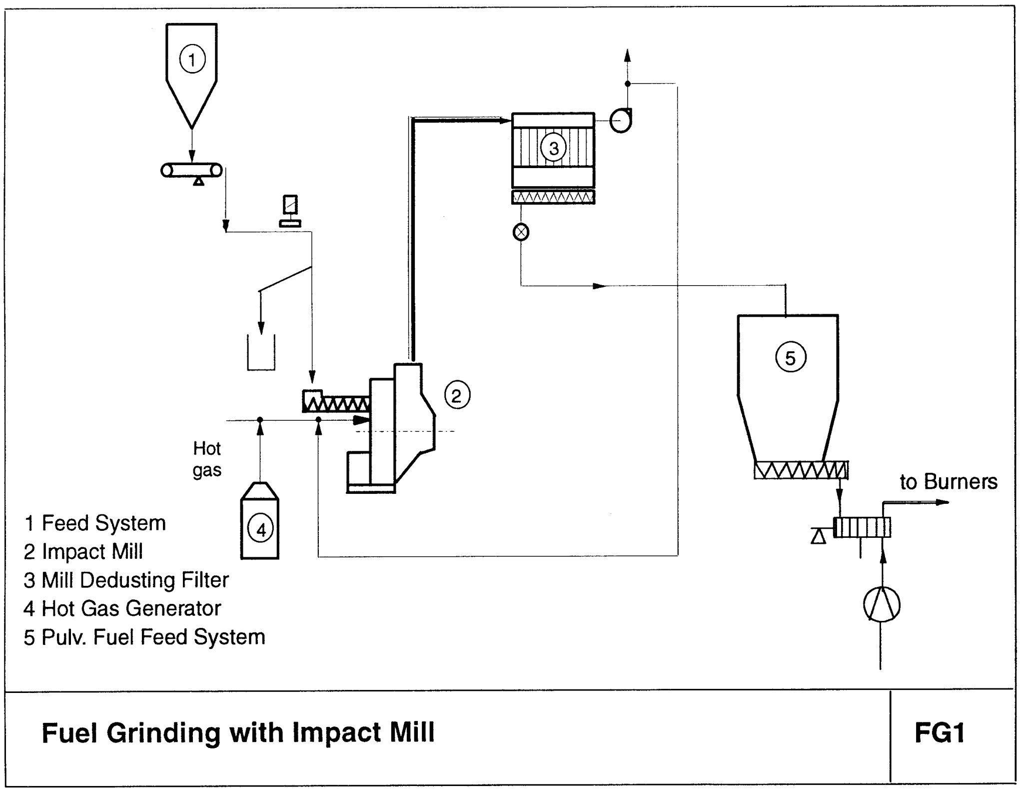


Figure 6.8.4: Impact Mill (IM)

The data in the table below are based on the following assumptions:

Grindability of Coal/Petcoke Mix	24.0 kWh/t at 10% R 90 µm (Lab Tube Mill, 50 HG)
Moisture of Raw Coal/Petcoke Mix	5 – 10%
Standard Electrical Energy Price	0.04 ECU per kWh

BAT Evaluation Coal / Petcoke Grinding Systems:

No.	**BAT Evaluation Item**	**Solid Fuel Grinding Systems 1)**		
		TMAS	**VRM/VRBM**	**IM**
1	**Consumables:**			
1.1	Wear Parts	Mill lining, grinding media	Roller tyre, balls, table liner	Hammer, disc, rod, lining
1.2	Air, - ambient - compressed	N.A. Pneumatic conveying of product to burners		
1.3	Water	N.A.	N.A.	N.A.
2	**Energy Consumption:**			
2.1	Thermal	N.A. if kiln gas or cooler exhaust air is available for drying		
2.2	Electrical, - Mill Motor - System	22.0 kWh/t 27.0-29.0 kWh/t	12.0 kWh/t 18.0-20.0 kWh/t	- 50 - 60 kWh/t
3	**Waste Generation:**			
3.1	Solid	Wear parts as from 1.1		
3.2	Liquid	N.A.	N.A.	N.A.
4	**Emissions:**			
4.1	To air	Fugitive dust if system is not properly maintained		
4.2	To water	N.A.	N.A.	N.A.
4.3	Noise	High	Low	Low
4.4	Odour	Low	Low	Low
5	**Impact on Product Quality**			
5.1	Cement	None		
6	**Experience**			
6.1	Duration	100 years	50 years	80 years
6.2	Number of applications	> 100	> 100	> 100
7	**Relative Costs:**			
7.1	Investment costs	100%	120%	80%
7.2	Operating costs	100%	80%	200%

1) Historically coal/petcoke firing plants have been either indirect firing plants (all plants shown above) or direct firing plants.

Direct firing plants operate without fine coal storage and fine coal metering, i.e. the pulverized fuel is directly blown into the kiln with the mill sweeping air acting as carrier and as (flame shaping) primary air. Since direct firing plants (among other drawbacks) induce additional kiln system heat losses of 200-250 MJ/t cli (plus 6 to 8% on modern kiln systems) they are today seldom installed.

6.8.3 FUEL OIL FIRING

Fuel Oil Storage

Fuel oil is stored in vertical uninsulated steel tanks equipped with heatable suction points to maintain the oil locally at pumpable temperature (50 to 60° C).

Fuel Oil Preparation

In order to facilitate metering and combustion the fuel is brought to 120 to 140° C resulting in a viscosity reduction to 10 to 20 cSt.

Additionally the pressure is increased to 20 to 40 bars.

Fuel Oil Firing

At adequate viscosity and pressure the fuel oil is discharged via an atomizer nozzle into the kiln in order to form e.g. the main flame. As with coal firing flames, shaping is mainly accomplished via multi-primary air channel burners with the oil atomizer head at central location.

6.8.4 NATURAL GAS FIRING

Natural Gas Storage

There is no gas storage equipment in a cement plant. The international high pressure gas distribution network acts as a gas storage facility.

Natural Gas Preparation

Prior to combustion the gas pressure has to be brought from the pipeline pressure of 30 to 80 bar down to plant network pressure of 3 to 10 bar and then further to the burner supply pressure of around 1 bar (overpressure).

The first pressure reduction step is accomplished in the gas transfer station where also consumption metering takes place. To avoid freezing of the equipment due to the Joule-Thompson effect the natural gas is preheated prior to passing through the pressure reduction value.

Alternatively, the pressure reduction can be accomplished by passing the gas through a gas turbine connected to a power generator. Thus some of the energy required for gas compression can be recuperated.

Natural Gas Firing

Kiln burners for natural gas, too, are designed according to the multi-channel principle, the gas thereby replacing the primary air.

6.9 ALTERNATIVE FUELS STORAGE, PREPARATION AND FIRING

6.9.1 INTRODUCTORY REMARKS (SEE ALSO CHAPTER 6.8.1)

Alternative fuels can be subdivided into five classes:

- ☐ **Gaseous alternative fuels**

  Examples: Coke oven gases, refinery waste gas, pyrolysis gas, landfill gas, etc.

- ☐ **Liquid alternative fuels**

  Examples: Low chlorine spent solvents, lubricating as well as vegetable oils and fats, distillation residues, hydraulic oils, insulating oils, etc.

- ☐ **Pulverized, granulated or fine crushed solid alternative fuels**

  Examples: Ground waste wood, sawdust, planer shavings, dried sewage sludge, granulated plastic, animal flours, agricultural residues, residues from food production, fine crushed tyres, etc.

- ☐ **Coarse crushed solid alternative fuels**

  Examples: Crushed tyres, rubber/plastic waste, waste wood, reagglomerated organic matter, etc.

- ☐ **Lump alternative fuels**

  Examples: Whole tyres, plastic bales, material in bags and drums, etc.

Gaseous, liquid, and finely pulverized alternative fuels can be fed to the kiln system via any of the feed points mentioned in Chapter 6.8.1. Coarse crushed and lump fuels can (with some exceptions) be fed to the transition chamber or to the mid-kiln valve only.

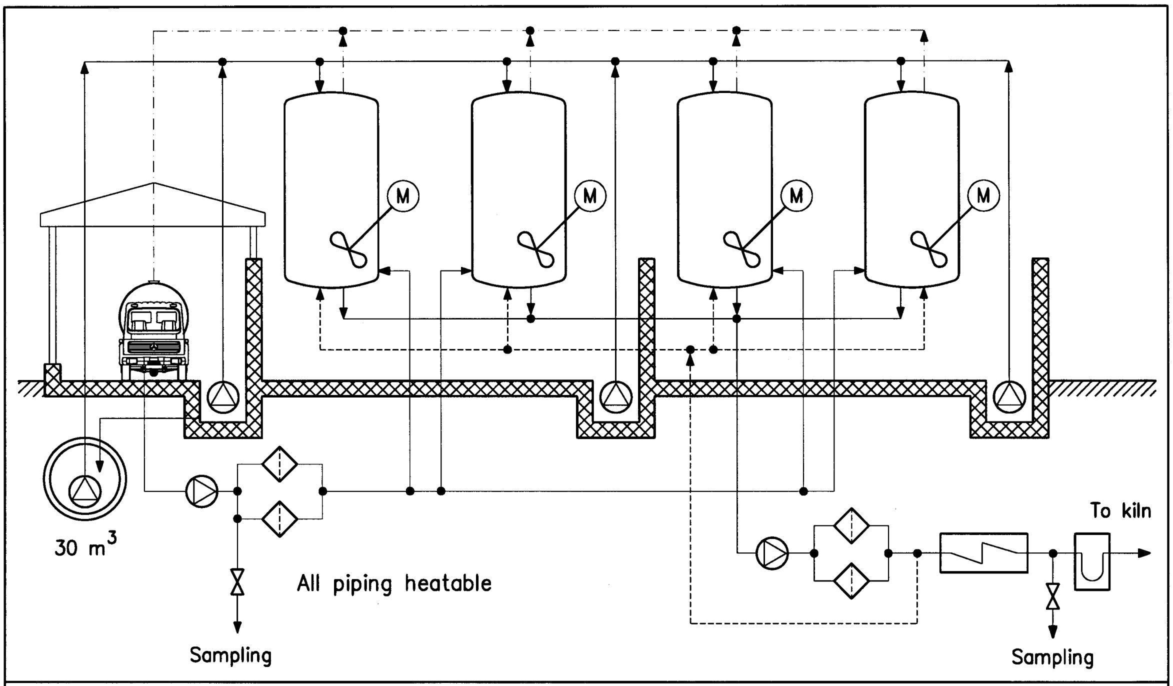
Alternative fuels preparation is usually performed outside the cement plant by the supplier or by specialist organizations. The preparation processes are therefore not dealt with here.

So alternative fuels only need to be stored at the cement plant and then proportioned for feeding them to the cement kiln.

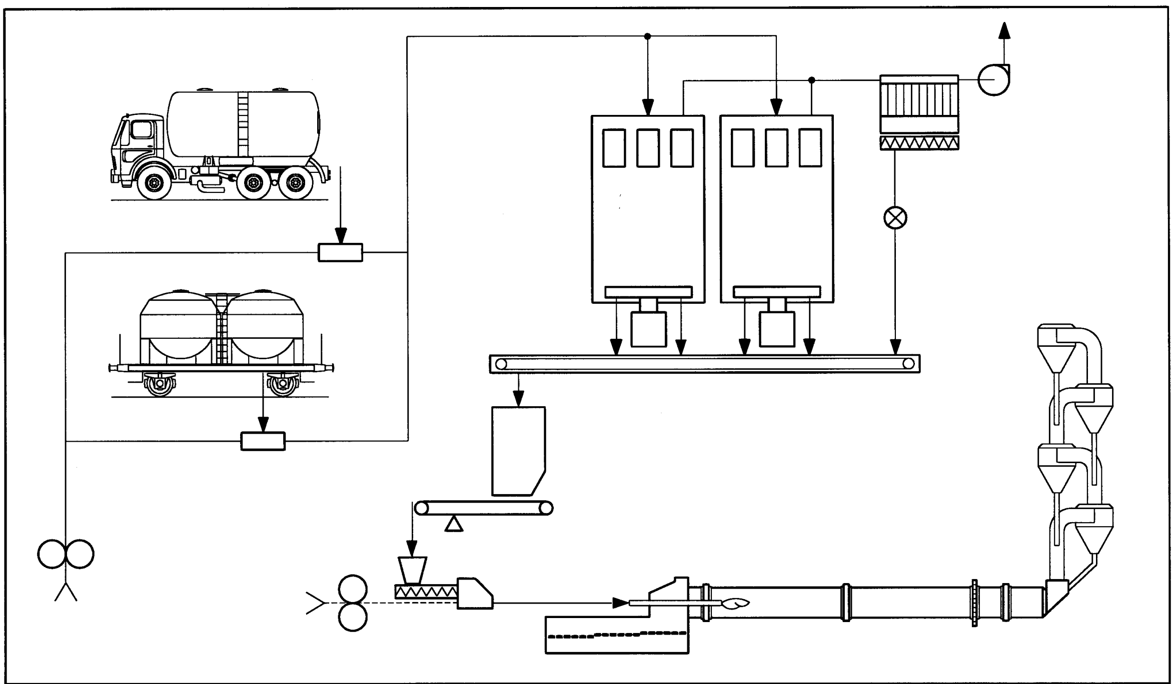
Since alternative fuel supplies tend to be variable in rapidly developing “waste” material markets it is recommended to design alternative fuel plants as multi-purpose plants from the very beginning.

Examples for such plants are shown in the following diagrams.

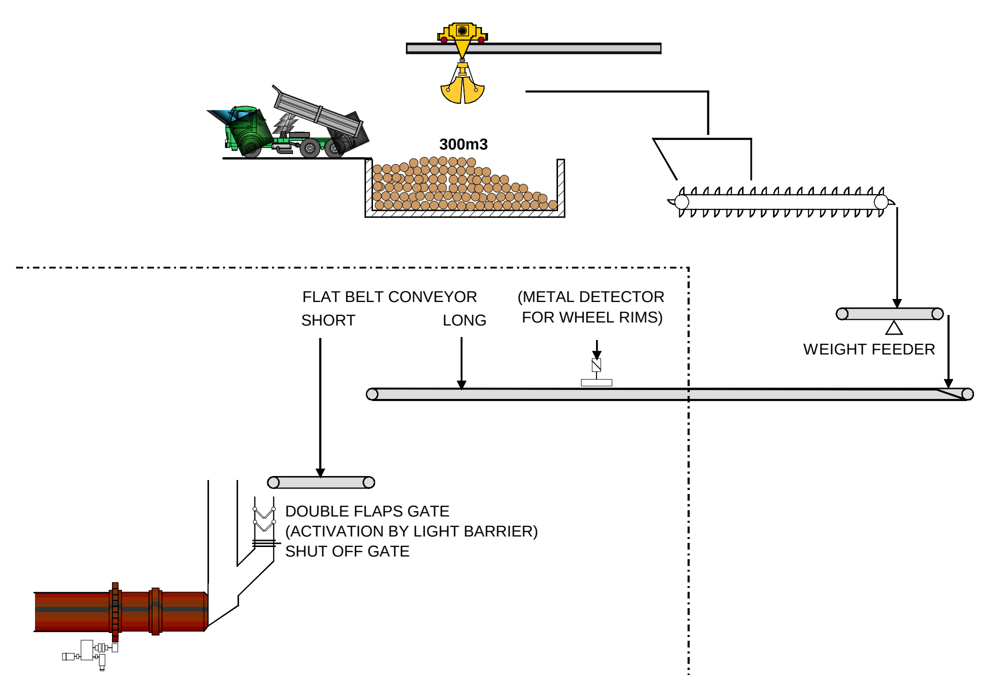
Alternative Fuels Multi Purpose Plants



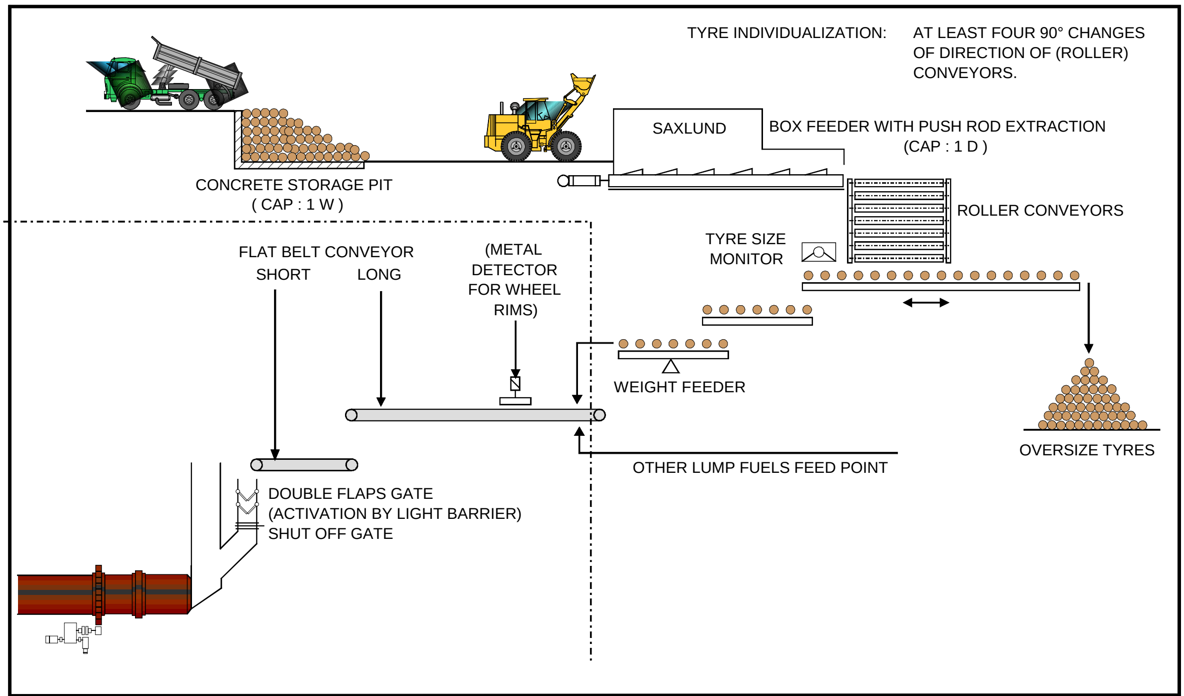
Liquid Alternative Fuels Multi–Purpose Plant



Powdery and Granulated Alternative Fuels Multi–Purpose Plant



LUMP ALTERNATIVE FUEL MULTI-PURPOSE PLANT
CRUSHED MATERIAL HANDLING AND LUMP FUEL KILN FEED



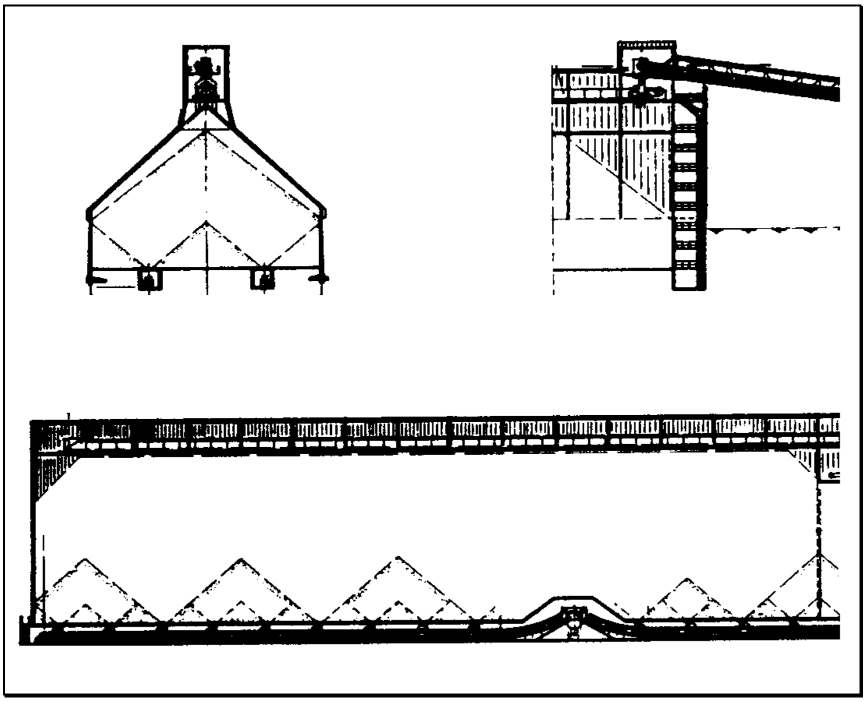
LUMP ALTERNATIVE FUEL MULTI-PURPOSE PLANT
WASTE TYRE HANDLING AND LUMP FUEL KILN FEED

6.10 CLINKER STORAGE

6.10.1 INTRODUCTORY REMARKS

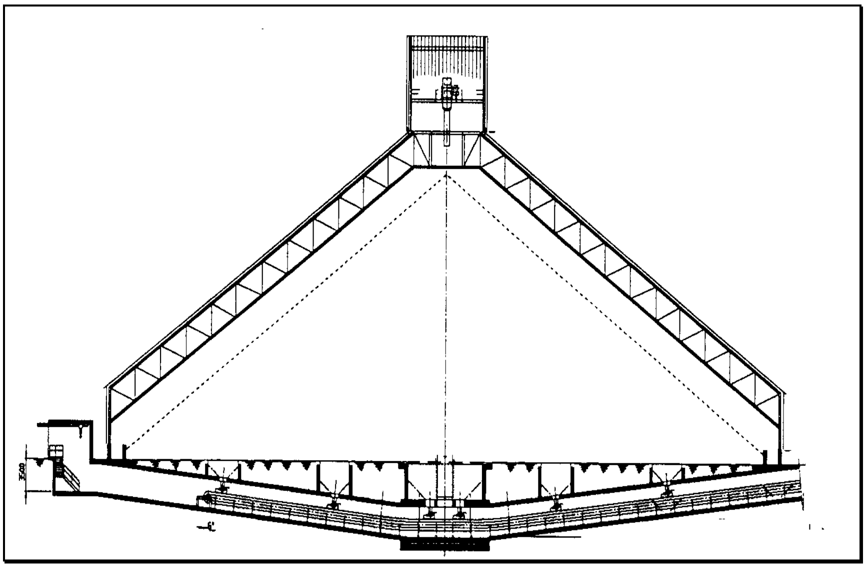
The investment cost comparison of clinker storage systems as indicated below can change when the storage capacity of the system is either very small or extremely big as commonly practised (seasonable market demands, etc.).

6.10.2 LONGITUDINAL STORE WITH GRAVITY DISCHARGE (LSGD)



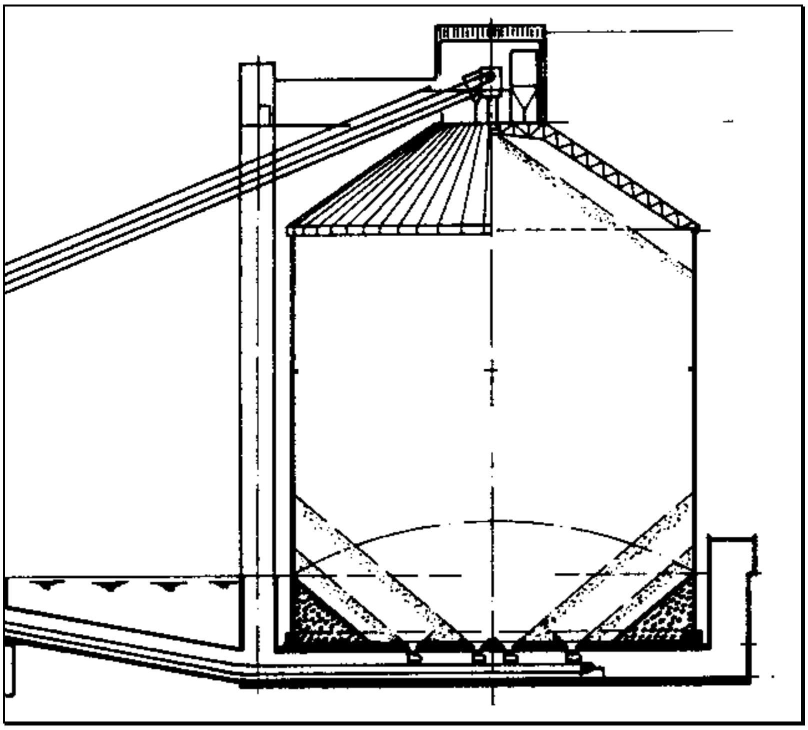
- Limited live stock

6.10.3 Circular Store with Gravity Discharge (CSGD)



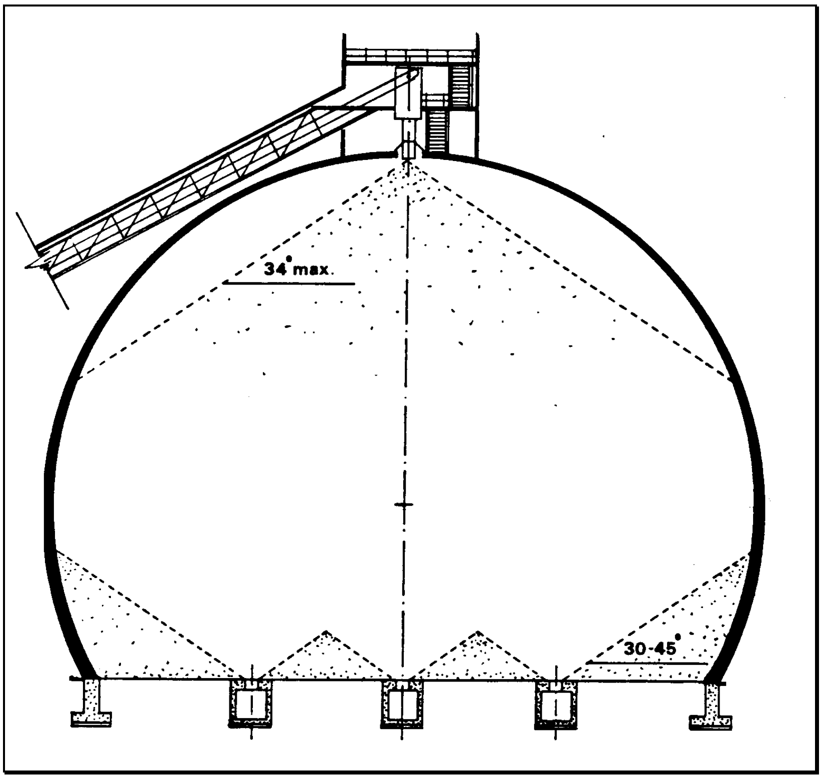
- Limited live stock

6.10.4 Clinker Storage Silo (CSS)



- High live stock
- Problems with ground vibrations can occur during clinker withdrawal from the silo at certain silo levels.

6.10.5 CLINKER STORAGE DOME (CSD)



- Limited live stock

No.	BAT Evaluation Item	Clinker Storage Systems			
		LSGD	CSGD	CSS	CSD
1.	**Consumables:**				
1.1	Wear Parts	Negligible			
1.2	Air, - ambient - compressed	N.A. N.A.	N.A. N.A.	N.A. N.A.	N.A. N.A.
1.3	Water	N.A.	N.A.	N.A.	N.A.
2.	**Energy Consumption:**				
2.1	Thermal	N.A.	N.A.	N.A.	N.A.
2.2	Electrical	< 0.70 kWh/t			
3.	**Waste Generation:**				
3.1	Solid	N.A.	N.A.	N.A.	N.A.
3.2	Liquid	N.A.	N.A.	N.A.	N.A.
3.3	Energy	N.A.	N.A.	N.A.	N.A.
4.	**Emissions:**				
4.1	To air	Fugitive dust if venting system is not properly maintained or storage is not dust tight			
4.2	To water	N.A.	N.A.	N.A.	N.A.
4.3	Noise	N.A.	N.A.	N.A.	N.A.
4.4	Odour	N.A.	N.A.	N.A.	N.A.
7.	**Relative Costs:**				
7.1	Investment costs	**120%**	**100%**	**100%**	**80-90%**
7.2	Operating costs	**Negligible differences**			

General Remarks:

Data to be understood as orders of magnitude.

6.11 MINERAL ADDITIONS STORAGE AND PREPARATION

6.11.1 MINERAL ADDITIONS STORAGE

For the mineral additions storage the same techniques are applied as for the raw material storage and preblending. If a mineral additive is very inhomogeneous preblending might be required.

6.11.2 MINERAL ADDITIONS PREPARATION

6.11.2.1 INTRODUCTION

For metering and comminution methods, separators and product transport to storage, refer to Chapter 6, 6.3.2 to 6.3.5.

The grinding of mineral additions is mostly done by inter-grinding with the clinker and gypsum. The decision criteria for separate grinding of the mineral additives are basically the following:

- ☐ percentage of mineral additives in the final product and in the total of the cement production;
- ☐ whether an idle mill system is available or not;
- ☐ high difference in the grindability between clinker and the mineral additives;
- ☐ moisture content of the mineral additives.

6.11.2.2 INTER-GRINDING SYSTEMS

Any of the grinding systems outlined in Chapter 6.3.6 can be used for inter-grinding mineral additives with clinker and gypsum, however most systems are limited with regard to the moisture content of the feed mixture.

The systems are generally limited to a moisture content in the feed mixture of max. 2% and 4% respectively with a hot gas source (hot gas generator). For higher moisture contents the systems require a pre-drying of the mineral additives in a drier. An exception is the vertical roller system which is capable of handling moisture contents up to 20%, but requires also a hot gas source.

6.11.2.3 SEPARATE GRINDING

For separate grinding of mineral additives the systems under Chapter 6.3.6 can be used, however the same applies for the systems with regard to the moisture content of the additives mixture and a pre-drying may be required.

6.11.2.4 PRE-DRYING OF MINERAL ADDITIVES

If pre-drying of mineral additives is required the following drier systems can be employed using either kiln exhaust gases and/or cooler exhaust air or an independent hot gas source (hot gas generator):

- ☐ rotary tube drier, in co-current and counter current;
- ☐ flash drier, in co-current;
- ☐ quick drier, in co-current.

6.12 CEMENT GRINDING

6.12.1 INTRODUCTORY REMARKS

Due to the variety of cement types required by the market the predominant grinding systems are those equipped with a dynamic air separator of the newest generation.

Besides the grinding systems illustrated below other systems are used. These are:

- tube mill, end discharge in open circuit
    - mainly used when producing only one type of cement
- tube mill, end discharge in closed circuit with mechanical air separator or cyclone air separator of older generations

The data in tables hereafter are based on the following assumptions:

❑ Grindability of cement component mix	36.0 kWh/t at 3,500 Blaine (lab tube mill)
❑ Moisture of cement component mix	1 – 4%
❑ Standard electrical energy price	0.04 ECU per kWh

6.12.2 METERING METHOD

The accuracy and reliability of metering and proportioning of the mill feed components by weight is of great importance for maintaining a high energy efficiency of a grinding system. The predominant metering and proportioning equipment for the material feed to mills is the belt weigh feeder.

6.12.3 COMMINUTION METHODS

The grinding systems described in the Chapter 6.12.6 use the same comminution methods as described in Chapter 6.3.3.

6.12.4 SEPARATOR

The fineness and particle size distribution of the product leaving a cement grinding system is of great importance for the cement quality. The target given for these parameters is achieved by the adjustment of the separator. The separators of the newest generation, rotor cage type separator (high efficiency separator), have several advantages over the previous separator generations, such as:

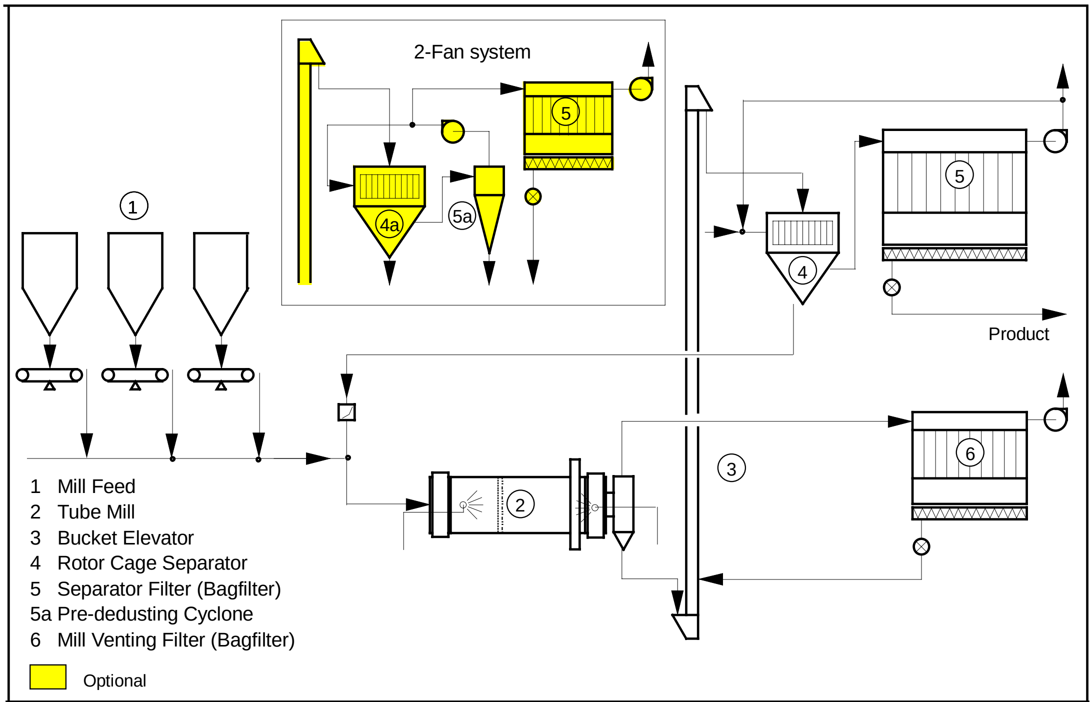
- less specific energy consumption of the system (less overgrinding);
- increase of system throughput (efficiency);
- possibility of product cooling;
- higher flexibility for adjustments in product fineness;
- more favourable particle size distribution and better product uniformity.

6.12.5 PRODUCT TRANSPORT TO STORAGE

For cement transport to storage silos pneumatic and mechanical conveying systems can be used. The latter normally have a higher investment cost but a much lower operating cost than pneumatic transport. A combination of air-slide or screw/chain conveyors with a chain bucket elevator is nowadays the most commonly used conveying system.

6.12.6 FINISH GRINDING SYSTEMS

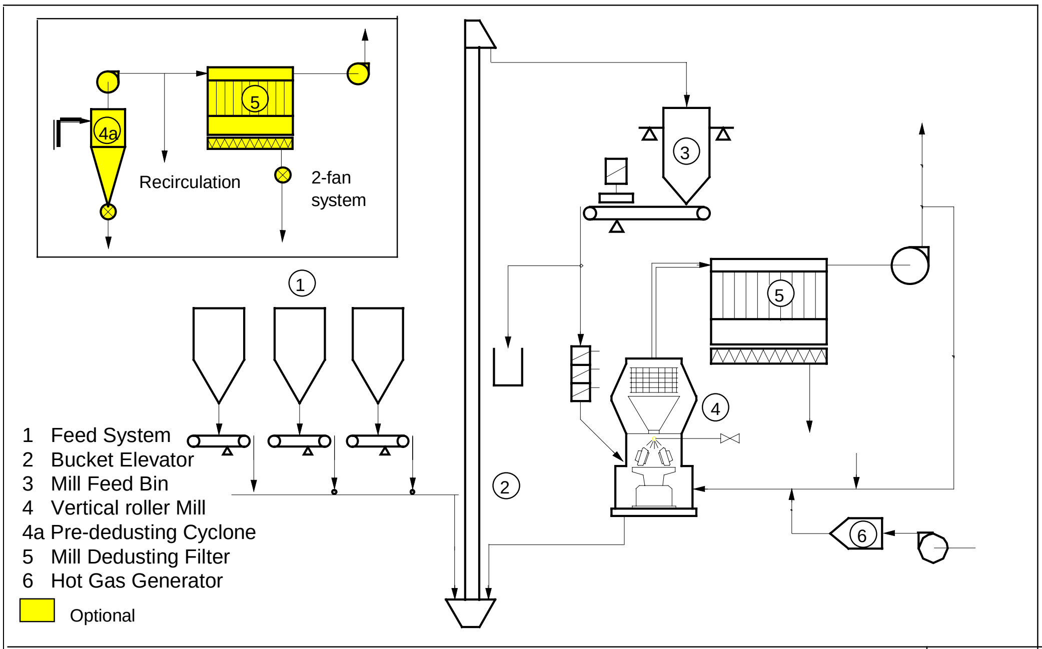
6.12.6.1 TUBE MILL, CLOSED CIRCUIT (TMCC)



Cement Grinding with Tube Mill in Closed Circuit **CG2**

- Mineral addition is rather limited, if not dry or predried.

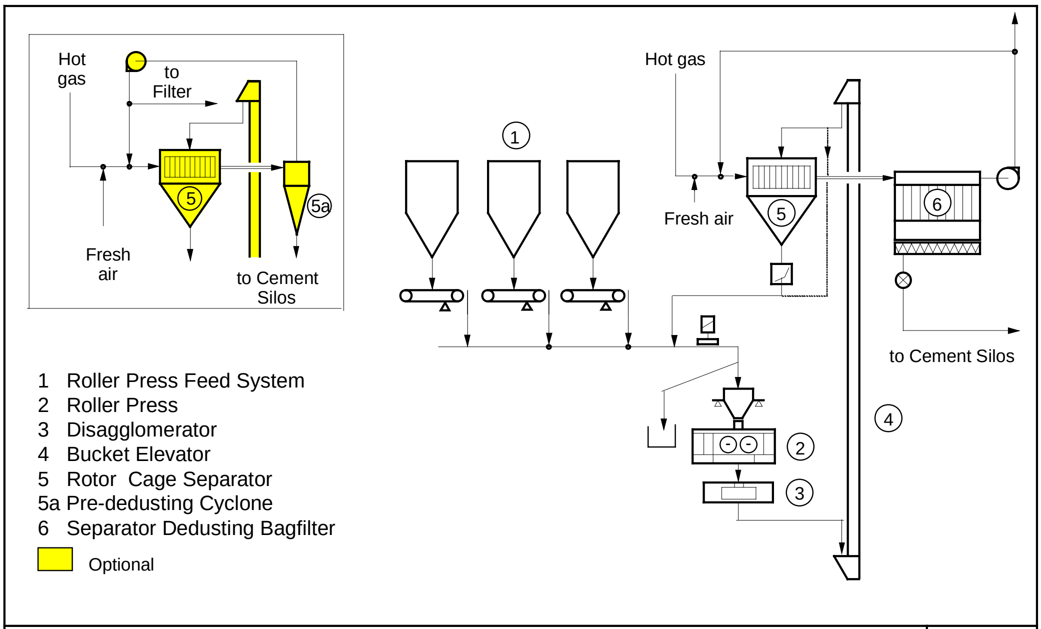
6.12.7 Vertical Roller Mill (VRM)



Cement Grinding with Vertical Roller Mill **CG3**

- Best suited for high mineral additions due to its drying capacity
- Best suited for separate grinding of mineral additions.

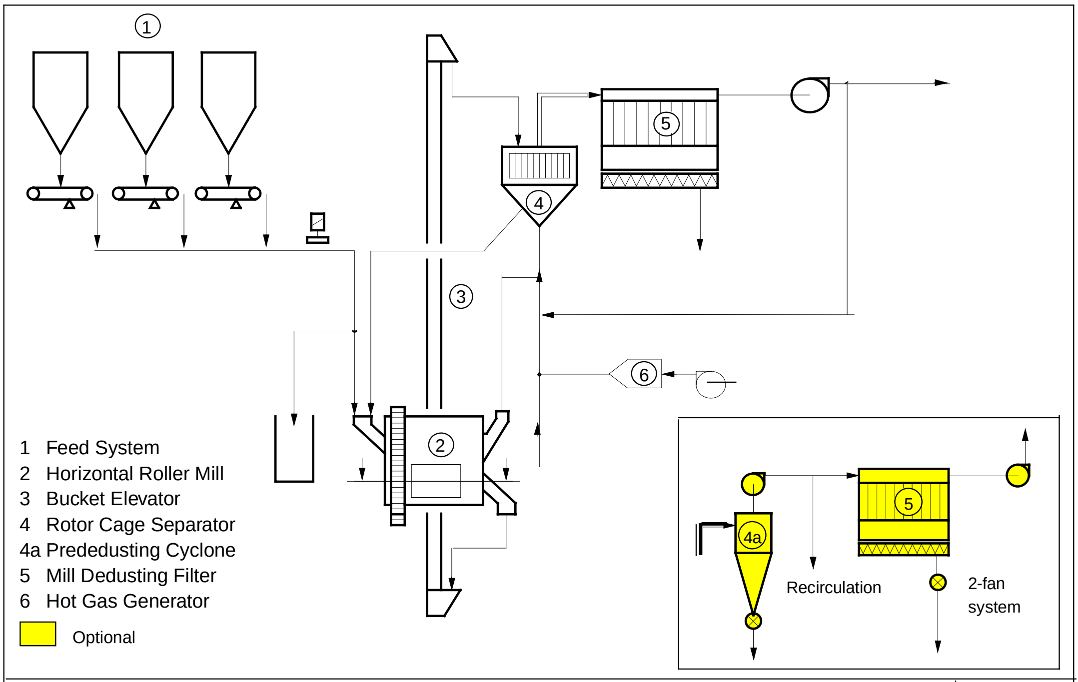
6.12.8 Roller Press (RP)



Cement Grinding with Roller Press **CG3**

- Mineral addition is rather limited, if not dry or predried.

6.12.9 HORIZONTAL ROLLER MILL (HRM)



Cement Grinding with Horizontal Roller Mill **CG4**

No.	BAT Evaluation Item	Cement Grinding, Finish Grinding Systems			
		TMCC	VRM	RP	HRM
1.	**Consumables:**				
1.1	Wear Parts	Mill lining, grinding media	Roller tyres, table liner	Grinding roll tyres	Mill & roller tyre lining, scrapers
1.2	Air, - ambient - compressed	Low Low	Low Low	Low Low	Low Low
1.3	Water	0 - 40 l/t	0 - 20 l/t	N.A.	N.A.
2.	**Energy Consumption:**				
2.1	Thermal	N.A.	N.A.	N.A.	N.A.
2.2	Electrical, - Mill - System w/o transport	32.0 kWh/t 36.5 kWh/t	22.0 kWh/t 28.5 kWh/t	20.0 kWh/t 24.5 kWh/t	21.0 kWh/t 25.5 kWh/t
3.	**Waste Generation:**				
3.1	Solid	Spent / worn wear parts			
3.2	Liquid	N.A.	N.A.	N.A.	N.A.
4.	**Emissions:**				
4.1	To air	Fugitive dust if equipment operates at positive pressure & is not properly maintained			
4.2	To water	N.A.	N.A.	N.A.	N.A.
4.3	Noise	high, ball charge	low	low	low
4.4	Odour	N.A.	N.A.	N.A.	N.A.
7.	**Relative Costs:**				
7.1	Investment costs	**100 %**	**120 %**	**115 %**	**120 %**
7.2	Operating costs	**100 %**	**75 - 80 %**	**70 - 75 %**	**70 - 75 %**

General Remarks:

Data to be understood as orders of magnitude.

Energy consumption and therefore the related costs depend very much on the specific type of mill, the mill's temperature as well as the grindability.

6.12.10 Systems for Capacity Upgrades of Existing Tube Mill Systems

6.12.10.1 Introductory Remarks

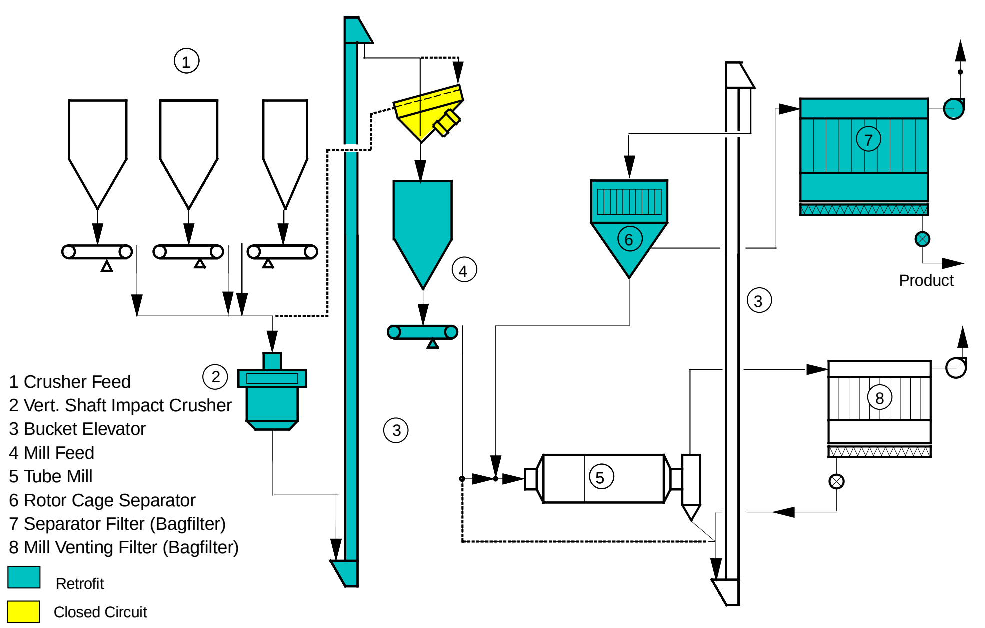
With the four concepts described below different capacity increases will result. The capacity increases are approximately the following:

❑ Pregrinding with Vertical Shaft Impact Crusher	15%
❑ Pregrinding with Roller Press or Vertical Roller Mill	25 – 35%
❑ Two-Stage Grinding with Roller Press	35 – 100%

The investment cost comparison is on the basis of ton of capacity increase.

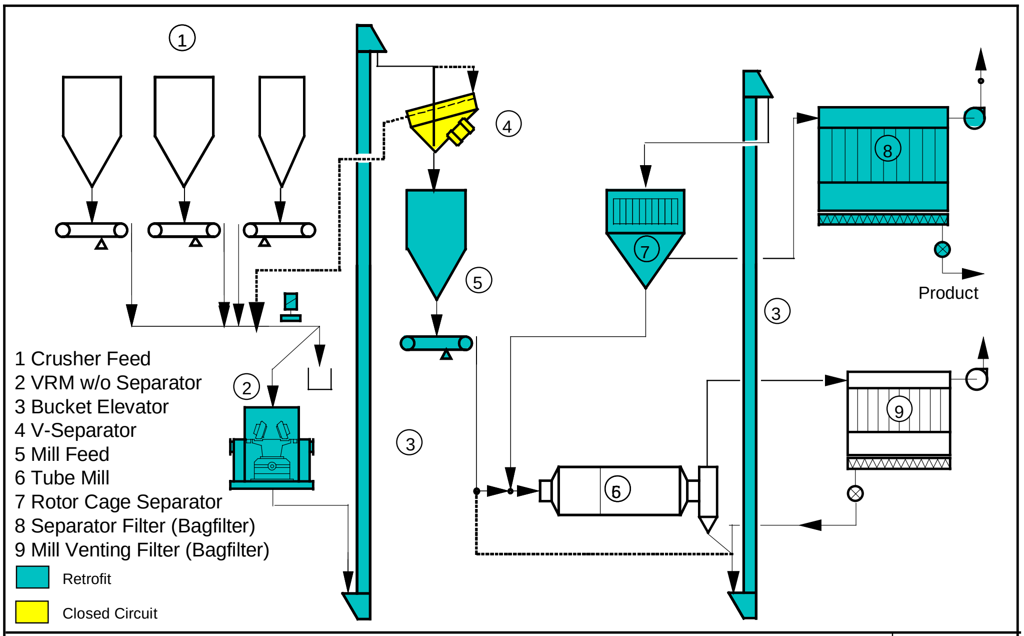
It should be noted that the layout of old plants often precludes the practicable application of these upgrades.

6.12.10.2 Pre-grinding with Vertical Shaft Impact Crusher in Open/Closed Circuit (PGVSIC)



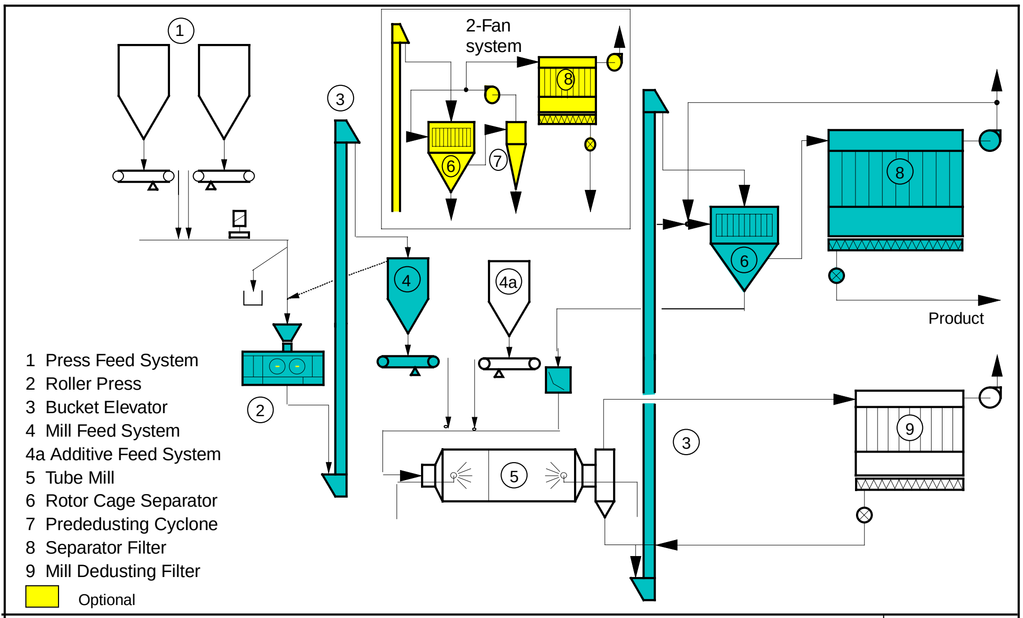
Cement Grinding, Pregrinding with Vertical Shaft Impact Crusher **CG6**

6.12.10.3 PREGRINDING WITH VERTICAL ROLLER MILL IN OPEN/CLOSED CIRCUIT (PGVRM)



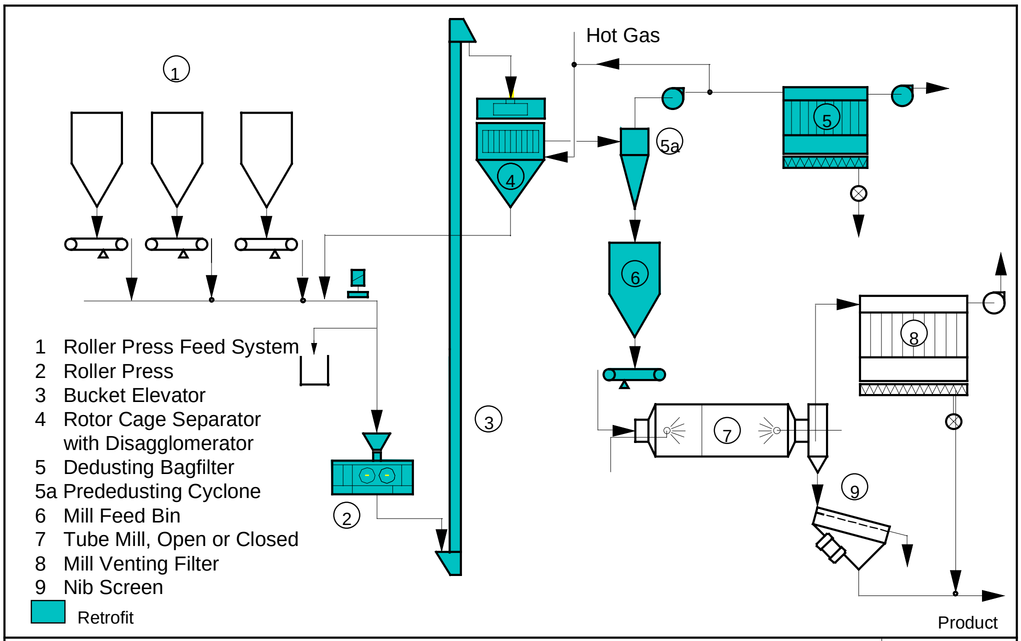
Cement Grinding, Pregrinding with Vertical Roller **CG7**

6.12.10.4 PREGRINDING WITH ROLLER PRESS (PGRP)



Cement Grinding, Pregrinding with Roller Press **CG8**

6.12.10.5 TWO - STAGE GRINDING WITH ROLLER PRESS (TSGRP)



Cement Grinding, Two.Stage Grinding with Roller Press and Tube Mill **CG9**

No.	BAT Evaluation Item	Cement Grinding Systems for Capacity Upgrading			
		PGVSIC	PGVRM	PGRP	TSGRP
1.	**Consumables:**				
1.1	Wear Parts	Rotor Parts, Lining	Roller tyres, table liners	Grinding roll tyres	Grinding roll tyres
1.2	Air, - ambient - compressed	Low Low	Low Low	Low Low	Low Low
1.3	Water	N.A.	N.A.	N.A.	N.A.
2.	**Energy Consumption:**				
2.1	Thermal	N.A.	N.A.	N.A.	N.A.
2.2	Electrical, - Mills Motors - System	29.0 kWh/t 34.0 kWh/t	27.5 kWh/t 32.5 kWh/t	27.5 kWh/t 32.5 kWh/t	24.0 kWh/t 32.0 kWh/t
3.	**Waste Generation:**				
3.1	Solid	Spent / worn wear parts			
3.2	Liquid	N.A.	N.A.	N.A.	N.A.
4.	**Emissions:**				
4.1	To air	Fugitive dust if equipment operates at positive pressure and is not properly maintained			
4.2	To water	N.A.	N.A.	N.A.	N.A.
4.3	Noise	Low	Low	Low	Low
4.4	Odour	N.A.	N.A.	N.A.	N.A.
7.	**Relative Costs:**				
7.1	Investment costs	**100%**	**150%**	**150%**	**115%**
7.2	Operating costs	**100%**	**95%**	**95%**	**95%**

General Remarks:

Data to be understood as orders of magnitude.

Energy consumption and therefore the related costs depend very much on the specific type of mill, the mill's temperature as well as the grindability.

6.13 CEMENT STORAGE

6.13.1 INTRODUCTORY REMARKS

For the storage of cement usually various silos are required. However new silo designs allow the storage of more than one type of cement in the same silo. Nowadays for cement storage the silo configurations described below are used.

There are four type of cement storages in use:

- ❑ Single Cell Silo with Discharge Hopper (SCSDH)
- ❑ Single Cell Silo with Central Cone (SCSCC)
- ❑ Multi-Cell Silo (MCS)
- ❑ Dome Silo with Central Cone (DSCC)

Compressed air is used to initiate and maintain the cement discharge process from these silos via aeration pads located at the silo bottom.

No.	BAT Evaluation Item	Bulk Cement Storage Systems			
		SCSDH	SCSCC	MCS	DSCC
1.	**Consumables:**				
1.1	Wear Parts	Negligible			
1.2	Air, - ambient - compressed	N.A Very low	N.A Low	N.A Low	N.A Low
1.3	Water	N.A.	N.A.	N.A.	N.A.
2.	**Energy Consumption:**				
2.1	Thermal	N.A.	N.A.	N.A.	N.A.
2.2	Electrical	0.15 - 0.3 kWh/t			
3.	**Waste Generation:**				
3.1	Solid	N.A.	N.A.	N.A.	N.A.
3.2	Liquid	N.A.	N.A.	N.A.	N.A.
3.3	Energy	N.A.	N.A.	N.A.	N.A.
4.	**Emissions:**				
4.1	To air	Fugitive raw meal dust if silo venting/dedusting system is not properly maintained			
4.2	To water	N.A.	N.A.	N.A.	N.A.
4.3	Noise	Low, if compressors are equipped with silencers			
4.4	Odour	N.A.	N.A.	N.A.	N.A.
7.	**Relative Costs:**				
7.1	Investment costs	**100%**	**120%**	**140%**	**100%**
7.2	Operating costs	**Negligible differences**			

General Remarks:

Data to be understood as orders of magnitude.

CHAPTER 7

AVAILABLE TECHNIQUES FOR CONTROL OF POTENTIAL EMISSIONS

7.1 INTRODUCTION AND GENERAL POINTS

To reduce the emission from a pyroprocessing system to a certain controlled level, three basically different methods are available:

- Maintain the existing process while reducing the input of emission precursors into the system
- Modify the existing process (primary or integrated reduction measures)
- Maintain the existing process while adding a separate gas cleaning unit for the exhaust gas (secondary reduction measures)

A ***reduction of precursors*** can be very efficient at reducing emissions but is usually impracticable to achieve. (E.g. it may be realistic to replace a minor sulphur-rich component with a material having a low sulphur content to reduce SO_2 emissions. But if the larger part of the sulphur is contained in the main raw feed component it is almost impossible to reduce the SO_2 emission by raw material replacement.)

Typical for ***primary reduction measures*** is that:

❑ their emission reduction efficiency is very difficult to estimate for a specific application;

❑ they are usually less expensive compared to secondary reduction measures;

❑ they often are more ecological than secondary reduction measures because they have lower energy and material consumption;

❑ they often require a trial and error process to reach the envisaged goal (long implementation time).

Typical for ***secondary reduction measures*** is that:

❑ they usually have the highest emission reduction efficiency;

❑ they often are the most expensive measure.

All three methods do have one thing in common:

❑ they are not always applicable.

In the discussion about emission reduction measures one should also keep in mind that ***application of these measures in a new plant and in an existing plant are completely different issues***. The application of a low NO_x precalciner in a new cement kiln can be very efficient at a marginal additional investment cost whereas the application of a low NO_x calciner in an existing preheater kiln with satellite cooler would be less efficient and very expensive due mainly to replacement of the cooler. In a long wet kiln, a long dry kiln and a Lepol kiln the installation of a low NO_x precalciner is not even possible. **Also, if existing equipment is still efficiently operable, its remaining economic value has to be added to the cost of any replacement equipment.**

The costs that are attached to each reduction measure are estimated average costs, based on a certain plant capacity (see Tables in the summaries). The investment cost does not include additional cost for equipment or civil constructions that may be required for the implementation of the reduction measures (e.g. it is possible that because of an additional reduction measure with a high power consumption a replacement of the electrical power supply system is required).

The need for emissions reduction and the best suited measure to achieve the required environmental performance must be established for each plant respecting their specific situations. Only with this approach is it technically possible ***to achieve the highest possible environmental performance per ECU spent.***

As explained in Chapter 5.4, the selection of BAT for the prevention or reduction of emissions is necessarily very site specific in the assessment of the BAT criteria including benefits and costs. Therefore it is advisable to consider a wide range of techniques. In the BAT evaluation tables in this chapter the conclusions on Candidate BATs reflect the need to have such a wide range available but the conclusions are general and based on judgement. Therefore they cannot be considered prescriptive and final conclusions on BAT must be made on a case by case basis.

The BAT evaluations give separately conclusions on Candidate BATs for existing plants and new plants. This is because, for economic and technical reasons given in Chapter 5.4, a particular technique is less likely to be BAT in an existing plant. Existing plants undergoing major upgrades at high cost, such as increasing production capacity very significantly and/or making major process changes, are classified with new plants. Plants which are undergoing more restricted investment, such as replacing or modernising limited areas of equipment, are classified as rehabilitations and considered in the same category as existing plant.

7.2 CONTROL OF DUST EMISSIONS FROM MAJOR POINT SOURCES

7.2.1 INTRODUCTORY REMARKS

There are three main sources of potential dust emissions from cement production plants. These are kiln systems, clinker coolers and cement mills. In each of these sub-processes kiln exhaust gas or air is passing through pulverised material and no primary reduction methods are possible. Various dedusting devices have been used in the past for these three duties but for new plants only bag filters or electrostatic precipitators are installed.

The paragraphs below consider first the environmental significance of dust releases from cement production and then the general features of the abatement techniques available. Finally the applicability of the techniques which may be considered BAT for the different sub-processes is addressed and data relevant to the evaluation of Candidate BATs are given.

7.2.2 SIGNIFICANCE OF DUST RELEASES

Where national dust emission limits are set in EU countries for kilns, coolers and cement mills they are generally at 50 mg/Nm^3 for new installations. Significantly higher limits are often permitted for existing installations.

Because of the nature of the cement production process dust in the kiln exhaust gas consists of ground raw material. Dust in the vent air of clinker coolers consists of clinker fines and dust from cement mills consists of the final cement product.

With today’s technology it is technically possible to reduce the dust emission from most cement plant stacks to below 50 mg/Nm^3 dry. Nevertheless, replacement of existing equipment is often related to major cost in the order of several million ECU.

The environmental significance of dust is the maximum ground level concentration occurring after dispersion of the emission from the exhaust stack and how this concentration, together with any existing background concentration, compares with standards based on ambient health standards.

Modelling techniques have been used to calculate the air dispersion factors for a wide range of kiln exhausts. The factors are generally between 500,000 and 3,000,000. The dispersion factor is the ratio between the stack emission concentration and the maximum annual mean ground level concentration and is influenced by stack height, exhaust gas temperature and speed, atmospheric conditions, topography around the plant, etc.

If the stack emission concentration was 100 mg/Nm^3, the dispersion factors quoted would result in maximum ground level concentrations of between 0.2 and 0.03 µg/m^3. The present EU TSP limit (TSP = Total Suspended Particulate) is 150 µg/m^3. Therefore a further reduction of the dust emission limits is not needed. A further reduction of the dust emission may from an overall ecobalance stand-point have a negative impact on the environment because of the high additional power and material consumption that outweighs the benefit of the very small change in ground level dust concentration (0.02 – 0.1% of the EU TSP limit).

7.2.3 ABATEMENT TECHNIQUES

7.2.3.1 BAG FILTERS

Bag Filters (BFs) have been used in the cement industry well before Electrostatic Precipitators (EPs) were developed. BFs use a filtering medium, the bags, to separate the dust particles from the exhaust gas. While the exhaust gas can pass the bag tissue the dust particles are captured on the bag surface.

To further reduce pressure drop and dust emission of a BF, bags with special surface treatment or cleaning support (e.g. acoustic horns) can be installed.

The main disadvantage of bag filters is the high pressure drop over the whole filter (8 – 20 mbar) causing comparatively high power consumption at the filter fan.

Although BFs have a very high efficiency, their performance deteriorates for mechanical and process reasons. Bags have a limited life and will give high emissions through the development of pinholes, the occasional tearing of a bag or the failure or gradual deterioration of the seal at the fixing point of bags. It is important to prevent hot particles being carried in the gas stream into the filter, and to avoid severe temperature surges, which can cause disastrous failure.

Large modern BFs can be divided into separate compartments which can be separately isolated. This increases the size and cost of the filter but it allows on-line maintenance. For the operator the problem is that, if the emission monitor indicates an increase in emission, and this increase has occurred progressively through a multiplicity of small holes/leaks, it can be time consuming and expensive to find and rectify the faults.

The main advantage of bagfilters is that the dedusting efficiency is always very high even if the process parameters are changed (e.g. during start up or shut down of the kiln, clinker cooler or cement mill, during switching from compound to direct operation (raw mill on -> raw mill off), during occurrence of CO peaks or any other process disturbance).

The BFs can be subdivided into reverse gas BFs and pulse jet BFs. The dedusting efficiency of the two systems is very similar.

<u>Reverse Gas BFs</u>

The main difference between a reverse gas BF and a pulse jet BF is the cleaning method for the bags.

The reverse gas cleaned bag filters usually contain woven filter bags (usually glass fibre bags with special surface coating). The raw gas enters the bags from the bottom. It flows from the bag centre to the outside of the bag. The dust is deposited on the inner surface of the bag. Removal efficiency is improved and maintained by these particulate deposits (residual dust cake). With time more and more particulates are deposited on the bags and increase the system resistance to the gas flow (pressure loss).

To allow the filter fan to operate within the design parameters and to reduce the fan power consumption, this dust cake must be partly removed. Bag cleaning methods must be designed properly – not over-cleaning or under-cleaning. Otherwise increased dust emission or high pressure loss result.

The bag cleaning process is triggered either by a timer or, better, when the pressure drop over the bag filter reaches some predetermined level. A reverse air bag filter consists of several compartments, usually more than ten. When the bag cleaning process is started, the outlet valves of one of the compartments are closed (off-line cleaning). Then, an auxiliary fan forces a relatively gentle flow of filtered gas backwards through the compartment and bags to be cleaned. This causes the bags to partially collapse inward, dislodging the dust cake. This falls through the bags, the thimble and the tubesheet into the hopper. Metal anticollapse rings sewn into the bags along their length prevent complete bag collapse. One square meter of a bag can filter up to 45 m^3/h of exhaust gas.

Reverse gas bag filters are very well established in North and South America for kiln exhaust gas dedusting. The operating and investment costs of reverse gas BFs are usually higher compared to pulse jet BFs and EPs because of the filter size and the more expensive bags.

Pulse Jet BFs

The application of pulse jet BFs for dedusting of air from mills, coolers and transport systems is already standard. However, the dedusting of kiln exhaust gas with pulse jet BFs is very new and only started a few years ago. They have some advantages because of the reduced space requirement and reduced investment and operating cost compared to reverse air BFs. Pulse jet BFs for kiln exhaust gas dedusting are mainly used in Europe.

Pulse jet cleaned BFs normally employ felted fabrics of various types. The raw gas enters the bags from the outside. The cleaned gas flows through the centre of the bag to the clean gas plenum and from there to the stack. The dust is deposited on the outer surface of the bag. To prevent bag collapse during filtering, metal cages are inserted inside each bag. Just like the reverse-gas cleaned bag filter, periodic bag cleaning is required to remove excess residual dust cake. This is accomplished by pulsing compressed air down into each filter bag. Bag cleaning can be carried out either with the compartment isolated or **not** isolated (on-line or off-line cleaning). One square meter of a bag can filter up to 90 m^3/h of exhaust gas.

7.2.3.2 ELECTROSTATIC PRECIPITATORS

EPs were developed for use in cement production, initially on kilns, in the 50s and 60s. EPs use electrostatic forces to separate the dust from the gas. Discharge electrodes under high negative voltages (50 – 100 kV) emit electrons which settle on the dust particles. The now negatively charged particles are directed towards and separated on the collecting electrodes because of the electrical field between the discharge and the collecting electrodes. Then the dust particles accumulated on the collecting electrodes are discharged to the dust hoppers by electrode rapping.

The efficiency of EPs can be reduced during changes of the process parameters (e.g. during start up or shut down of the kiln, during switching from compound to direct operation and during occurrence of CO peaks). EPs are easy to maintain although on-line maintenance is not possible.

The main advantage of the EPs is the low pressure loss over the filter and therefore a reduced power consumption of the filter fan. The other advantages are the separation of coarse and fine particles in the filter for efficient evacuation of circulating elements and a constant pressure loss over the filter which allows constant high clinker production.

There are also means available to upgrade and optimise already existing EPs. Especially improved exhaust gas conditioning (e.g. conditioning tower) and modern control systems for EP energization have been shown to be very effective.

7.2.3.3 OTHER ABATEMENT TECHNIQUES

Cyclones and gravel bed filters are not installed any more for the final dedusting stage because of their reduced efficiency and high operating cost.

Cyclones

Cyclones have been used in the distant past to reduce material loss from kilns and more recently high efficiency designs have been installed on clinker coolers. They are not capable of achieving the emission levels now needed for final exhaust and they are not now installed.

Gravel Bed Filters

Gravel bed filters have given good service on clinker coolers but their maintenance costs are high and their efficiency is not comparable with that obtainable from EPs and BFs. They are no longer installed.

7.2.4 PROCESS DUTY

7.2.4.1 KILNS

7.2.4.1.1 SUMMARY

The first cement kilns were working with natural draft across the kiln. The exhaust gas was emitted to the atmosphere without any special treatment. At a later stage dust separators, mainly cyclones and electrostatic precipitators (EPs), were installed to reduce product loss. Today very efficient separators with a reduction efficiency of up to 99.99% are used which virtually eliminate dust emissions from cement plants.

Today two types of dust separators are used for kiln exhaust gas dedusting: Bag Filters (BFs) and EPs. Both types have a very high dedusting efficiency during normal operation. During special conditions like high CO concentration, kiln start up, kiln shut down or switching from compound operation (raw mill on) to direct operation (raw mill off) the efficiency of EPs can be significantly reduced while the efficiency of BFs is not affected. Therefore BFs have a higher overall efficiency if they are well maintained and filter bags are replaced periodically. It is a disadvantage of BFs that the replaced filter bags are waste and have to be disposed of according to national regulations.

Because of the maximum operating temperature of the bags in a BF and because of the electrical resistivity of the dust going to an EP the exhaust gas must be conditioned before it is directed to the dust separator. The gas is conditioned by water injection into the conditioning tower or the exhaust gas duct, or is cooled by air to air heat exchanger, or by fresh air dilution.

The total cost per tonne of clinker caused by the dedusting is usually in favour of EPs if clean gas dust contents above about 30 mg/Nm^3 are required. Below 20 mg/Nm^3 the cost for dust filters is often lowest for pulse jet bag filters. This is only a general statement and can be different for specific applications. The reasons for the lower costs of EPs above 30 mg/Nm^3 are mainly the low pressure drop over the filter and the reduced maintenance cost.

To reduce the clean gas dust content further to 20 mg/Nm^3 the collecting area and power input into the EP must be increased exponentially.

To compare one dedusting system with another one all components exhaust gas conditioning, filter and filter fan, must be included.

The tables below show two possibilities (BF and EP) to reduce dust emission with efficiencies of up to 99.99%. The described technologies refer to a preheater kiln (representing modern cement kiln technology) with a production rate of 3000 t/day. Exhaust gas from long wet kilns and long dry kilns can also be dedusted with BFs and EPs with very high efficiencies (up to 99.99%).

In the case of kiln exhaust gas dedusting with EPs process optimisation can also improve the EP efficiency.

To make the information in the tables below comparable a common base was used:

- Clinker production: 3000 t/d
- Kiln type: Preheater/Precalciner
- Dust input to filter: Up to 500 gDust/Nm^3
- Power cost: 0.04 ECU/kWh
- Amortisation: 10 years
- Interest rate: 10%

Most information is retrieved from literature (see Chapter 7.2.7) and cement industry specific experience. To fit it into the common base, conversion of the relevant data was required.

7.2.4.2 INDEX OF DESCRIBED DUST REDUCTION MEASURES

7.2.4.3 ELECTROSTATIC PRECIPITATORS FOR CEMENT KILNS (EP)

No.	BAT Evaluation Items		Comments	Remarks
1	**Consumables**			
1.1	Materials	[g_{steel}/t_{cli}]	5 - 20	1)
1.2	Air		None	
1.3	Water	[kg/t_{cli}]	25 - 75	2) Estimated
2	**Energy Consumption**			
2.1	Thermal		None	
2.2	Electrical	[kWh/t_{cli}]	1.5 - 2.0 [1]	3)
3	**Waste Generation**			
3.1	Solids	[g_{steel}/t_{cli}]	5 - 20	
3.2	Liquids		None	
4	**Emissions**			
4.1	To air		None	
4.2	To water		None	
4.3	Noise		None	
4.4	Odour		None	
4.5	Dust reduction	[%]	Up to 99.99	4)
5	**Impact on Product Quality**			
5.1	Cement		None	
6	**Experience**			
6.1	Duration	[years]	> 30	
6.2	Number of Applications		> 100	
7	**Costs**			
7.1	Investment cost	[10^6 ECU]	1.5 - 3.8 0.6 - 0.8	5) Estimated 6) Estimated
7.2	Operating cost	[ECU/t_{cli}]	0.1 - 0.2	7) Estimated

7.3	Total cost [ECU/t_{cli}]	0.4 - 0.8	
8	**Conclusion on Candidate BAT**		
8.1	For existing plants and plant rehabilitations	Yes	
8.2	For new plants and major upgrades	Yes	

1) Because of corrosion, erosion or deformation the internals of an EP are replaced every 8 to 20 years. The required collecting area of the electrodes depends, among other things, on the required clean gas dust content.
2) The water consumption depends on the gas temperature at the preheater exit, the relative duration of direct operation (mill off) and the raw material humidity.
3) Electrical power consumption for energization of the EP and operation of the filter fan and the conditioning tower.
4) The maximum dust reduction efficiency is not a guaranteed efficiency for applications on any kiln but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on an initial dust input into the filter of about 500 g/Nm^3. High efficiency is only guaranteed during normal operation. During situations like kiln upset, transition phase from compound to direct operation and start up and shut down of the kiln lower efficiencies can be expected.
5) The size and investment costs for EPs increase exponentially with the reduction of the clean gas dust content. The indicated investment cost does not include conditioning tower and filter fan (about 0.6 – 0.8 106 ECU). When EPs are designed to work without conditioning tower (some cases in dry weather countries), the oversizing of the filter increases investment above the level of a filter + tower system.
6) Cost for conditioning tower and filter fan.
7) The electrical power consumption for EPs increases exponentially with the reduction of the clean gas dust content.

7.2.4.4 BAG FILTERS FOR CEMENT KILNS (BF)

No.	BAT Evaluation Items	Comments	Remarks
1	**Consumables**		
1.1	Materials [$g_{textile}/t_{cli}$]	1.0 - 5.0	1)
1.2	Air	None	
1.3	Water [kg/t_{cli}]	0 - 75	2) Estimated
2	**Energy Consumption**		
2.1	Thermal [kJ/t_{cli}]	None	

2.2	Electrical [kWh/t_{cli}]	1.8 - 2.2	3)
3	**Waste Generation**		
3.1	Solids [$g_{textile}/t_{cli}$]	1.0 - 5.0	
3.2	Liquids	None	
4	**Emissions**		
4.1	To air	None	
4.2	To water	None	
4.3	Noise	None	
4.4	Odour	None	
4.5	Dust reduction [%]	Up to 99.99	4)
5	**Impact on Product Quality**		
5.1	Cement	None	
6	**Experience**		
6.1	Duration [years]	> 30	
6.2	Number of Applications	> 100	5)
7	**Costs**		
7.1	Investment cost [10^6 ECU]	1.5 - 3.5 0.6 - 0.8	6) 7)
7.2	Operating cost [ECU/t_{cli}]	0.15 - 0.35	
7.3	Total cost [ECU/t_{cli}]	0.5 - 0.9	
8	**Conclusion on Candidate BAT**		
8.1	For existing plants and plant rehabilitations	Yes	
8.2	For new plants and major upgrades	Yes	

1) The bags must be replaced every 2 to 4 years.

2) The water consumption depends on the gas temperature at the preheater exit, the relative duration of direct operation (mill off) and the raw material humidity. In the case of reverse gas filters it is possible to cool with fresh air only.

3) Electrical power consumption of filter fan conditioning tower and bag cleaning.

4) The maximum dust reduction efficiency is not a guaranteed efficiency for applications on any kiln but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on an initial dust input to the filters of about 500 g/Nm^3.

5) This applies for reverse air BFs. Pulse jet BFs have only recently been applied for cement kiln dedusting. Therefore their application number is still comparatively small.

6) Bag filter size is a function of the maximum gas flow through the filter. Bag filter price without conditioning tower and filter fan.

7) Cost for conditioning tower and filter fan. Conditioning towers are only needed for low temperature applications with e.g. polyacrylnitril bags.

7.2.5 CONTROL OF DUST EMISSION FROM CLINKER COOLERS

7.2.5.1 SUMMARY

The overall efficiency of the electrostatic precipitator (EP) is not much lower than the efficiency of a bag filter (pulse jet type) combined with an air to air heat exchanger (BFHE) but many new installations are of the BFHE type. Depending on the bag quality that is used for the pulse jet filter, the size of the air to air heat exchanger ahead of the pulse jet filter is designed to cool the clinker cooler vent air under all circumstances to below 120 to 180° C.

To make the information in the tables below comparable a common base was used:

- Clinker production: 3000 t/d
- Kiln type: Preheater/Precalciner
- Clinker cooler type Grate cooler
- Dust input into filter: Up to 20 gDust/Nm^3
- Power cost: 0.04 ECU/kWh
- Amortisation: 10 years
- Interest rate: 10%

Most information is retrieved from literature (see Chapter 7.2.7) and cement industry specific experience. To fit it into the common base, conversion of the relevant data was required.

7.2.5.2 INDEX OF DESCRIBED DUST REDUCTION MEASURES

7.2.5.3 Electrostatic Precipitators for Clinker Coolers (EP)

7.2.5.4 Pulse Jet Bag Filter with Air to Air Heat Exchanger for Clinker Coolers (BFHE)

7.2.5.3 ELECTROSTATIC PRECIPITATORS FOR CLINKER COOLERS (EP)

No.	BAT Evaluation Items		Comments	Remarks
1	**Consumables**			
1.1	Materials	[g_{steel}/t_{cli}]	5 - 20	1)
1.2	Air		None	
1.3	Water	[kg/t_{cli}]	None	
2	**Energy Consumption**			
2.1	Thermal		None	
2.2	Electrical	[kWh/t_{cli}]	1.0 - 1.6	2)
3	**Waste Generation**			
3.1	Solids	[g_{steel}/t_{cli}]	5 - 20	
3.2	Liquids		None	
4	**Emissions**			
4.1	To air		None	
4.2	To water		None	
4.3	Noise		None	
4.4	Odour		None	
4.5	Dust reduction	[%]	Up to 99.9	3)
5	**Impact on Product Quality**			
5.1	Cement		None	
6	**Experience**			
6.1	Duration	[years]	> 10	
6.2	Number of Applications		> 100	
7	**Costs**			
7.1	Investment cost	[10^6 ECU]	0.8 - 1.2	4)
7.2	Operating cost	[ECU/t_{cli}]	0.09 - 0.18	5)
7.3	Total cost	[ECU/t_{cli}]	0.22 - 0.38	
8	**Conclusion on Candidate BAT**			
8.1	For existing plants and plant rehabilitations		Yes	
8.2	For new plants and major upgrades		Yes	

1) Because of erosion or deformation the internals of an EP are replaced every 20 to 30 years. The required collecting area of the electrodes depends on the final clean gas dust content.
2) Electrical power consumption for energization of the EP and operation of the filter fan.
3) The maximum dust reduction efficiency is not a guaranteed efficiency for applications on any clinker cooler but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on a dust input to the filter of about 20 g/Nm^3. High efficiency is only guaranteed during normal operation. During situations like cooler upset and start up / shut down procedures of the kiln significantly lower efficiencies can be expected.
4) The size and investment costs for EPs increase exponentially with the reduction of the clean gas dust content.
5) The electrical power consumption for EPs increases exponentially with the reduction of the clean gas dust content.

7.2.5.4 PULSE JET BAG FILTER WITH AIR TO AIR HEAT EXCHANGER FOR CLINKER COOLERS (BFHE)

No.	BAT Evaluation Items		Comments	Remarks
1	**Consumables**			
1.1	Materials	[$g_{textile}/t_{cli}$]	0.5 - 0.8	1)
1.2	Air		None	
1.3	Water	[kg/t_{cli}]	None	
2	**Energy Consumption**			
2.1	Thermal	[kJ/t_{cli}]	None	
2.2	Electrical	[kWh/t_{cli}]	1.8 - 2.2	2)
3	**Waste Generation**			
3.1	Solids	[$g_{textile}/t_{cli}$]	0.5 - 0.8	
3.2	Liquids		None	
4	**Emissions**			
4.1	To air		None	
4.2	To water		None	
4.3	Noise		Low	3)
4.4	Odour		None	
4.5	Dust reduction	[%]	Up to 99.9	4)

5	**Impact on Product Quality**			
5.1	Cement		None	
6	**Experience**			
6.1	Duration	[years]	> 10	
6.2	Number of Applications		> 50	
7	**Costs**			
7.1	Investment cost	[10^6 ECU]	1.0 - 1.4	5)
7.2	Operating cost	[ECU/t_{cli}]	0.10 - 0.15	6)
7.3	Total cost	[ECU/t_{cli}]	0.26 - 0.38	
8	**Conclusion on Candidate BAT**			
8.1	For existing plants and plant rehabilitations		Yes	
8.2	For new plants and major upgrades		Yes	

1) The bags must be replaced every 2 to 3 years.

2) Electrical power consumption of filter fan, heat exchanger and bag cleaning.

3) Fans of air to air heat exchanger can cause additional noise. Several countermeasures to limit the additional noise are available.

4) The maximum dust reduction efficiency is not a guaranteed efficiency for applications on any clinker cooler but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on a dust input into the filter of about 20 g/Nm^3.

5) Bag filter size is a function of the maximum gas flow through the filter. Price includes air to air heat exchanger, filter and fan.

6) The operating cost is mainly a function of the cost for bag replacement (bag quality) and the power cost for the filter fan.

7.2.6 CONTROL OF DUST EMISSION FROM CEMENT MILLS

7.2.6.1 SUMMARY

Most plants use pulse jet BF’s for dedusting of cement mill vent air. Electrostatic precipitators (EP) were also installed in the past and are still in operation. EPs are not installed any more for cement mill dedusting. Because of the low vent air temperature no vent air conditioning is required for the pulse jet BFs.

To make the information in the tables below comparable a common base was used:

•	Clinker production:	3000 t/d
•	Cement mill production:	160 t/h
•	Cement mill type:	Ball mill
•	Initial emission:	Up to 300 gDust/Nm^3
•	Power cost:	0.04 ECU/kWh
•	Amortisation:	10 years
•	Interest rate:	10%

Most information is retrieved from literature (see Chapter 7.2.7) and cement industry specific experience. To fit them into the common base, conversion of the relevant data was required.

7.2.6.2 INDEX OF DESCRIBED DUST REDUCTION MEASURES

7.2.6.3 PULSE JET BAG FILTER FOR CEMENT MILLS (BF)

No.	BAT Evaluation Items		Comments	Remarks
1	**Consumables**			
1.1	Materials	[$g_{textile}/t_{cli}$]	0.3 - 0.4	1)
1.2	Air		None	
1.3	Water	[kg/t_{cli}]	None	
2	**Energy Consumption**			
2.1	Thermal	[kJ/t_{cli}]	None	
2.2	Electrical	[kWh/t_{cli}]	0.4 - 0.6	2)
3	**Waste Generation**			
3.1	Solids	[$g_{textile}/t_{cli}$]	0.3 - 0.4	
3.2	Liquids		None	
4	**Emissions**			
4.1	To air		None	
4.2	To water		None	
4.3	Noise		None	
4.4	Odour		None	
4.5	Dust reduction	[%]	Up to 99.99	

5	**Impact on Product Quality**			
5.1	Cement		None	
6	**Experience**			
6.1	Duration	[years]	> 30	
6.2	Number of Applications		> 100	
7	**Costs**			
7.1	Investment cost	[10^6 ECU]	0.3 - 0.5	4)
7.2	Operating cost	[ECU/t_{cli}]	0.03 - 0.04	5)
7.3	Total cost	[ECU/t_{cli}]	0.08 - 0.12	
8	**Conclusion on Candidate BAT**			
8.1	For existing plants and plant rehabilitations		Yes	6)
8.2	For new plants and major upgrades		Yes	

1) The bags must be replaced every 2 to 4 years.
2) Electrical power consumption of filter fan, conditioning tower and bag cleaning.
3) The maximum dust reduction efficiency is not a guaranteed efficiency for applications on any cement mill but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on a dust input into the filter of about 300 g/Nm^3.
4) Bag filter size is a function of the maximum gas flow through the filter. Price includes filter and fan.
5) The operating cost is mainly a function of the cost for bag replacement (bag quality) and the power cost for the filter fan.
6) If the existing plant is equipped with an efficient electostatic precipitator (EP) then the potential advantage of a bag filter would not justify the replacement of the EP.

7.2.6.4 ELECTROSTATIC PRECIPITATORS FOR CEMENT MILLS (EP)

No.	BAT Evaluation Items		Comments	Remarks
1	**Consumables**			
1.1	Materials	[g_{steel}/t_{cli}]	5 - 20	1)
1.2	Air		None	
1.3	Water	[kg/t_{cli}]	None	

2	**Energy Consumption**			
2.1	Thermal		None	
2.2	Electrical	[kWh/t_{cli}]	1.0 - 1.6	2)
3	**Waste Generation**			
3.1	Solids	[g_{steel}/t_{cli}]	5 - 20	
3.2	Liquids		None	
4	**Emissions**			
4.1	To air		None	
4.2	To water		None	
4.3	Noise		None	
4.4	Odour		None	
4.5	Dust reduction	[%]	Up to 99.99	3)
5	**Impact on Product Quality**			
5.1	Cement		None	
6	**Experience**			
6.1	Duration	[years]	> 10	
6.2	Number of Applications		> 100	
7	**Costs**			
7.1	Investment cost	[10^6 ECU]	0.8 - 1.2	4)
7.2	Operating cost	[ECU/t_{cli}]	0.09 - 0.18	5)
7.3	Total cost	[ECU/t_{cli}]	0.22 - 0.38	
8	**Conclusion on Candidate BAT**			
8.1	For existing plants and plant rehabilitations		Yes	
8.2	For new plants and major upgrades		No	

1) Because of erosion or deformation the internals of an EP are replaced every 20 to 30 years. The required collecting area of the electrodes depends on the final clean gas dust content.

2) Electrical power consumption for energization of the EP and operation of the filter fan.

3) The maximum dust reduction efficiency is not a guaranteed efficiency for applications on any cement mill but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on a dust input to the filter of about 20 g/Nm^3. High efficiency is only

guaranteed during normal operation. During situations like cooler upset and start up / shut down procedures of the kiln significantly lower efficiencies can be expected.

4) The size and investment costs for EPs increase exponentially with the reduction of the clean gas dust content.

5) The electrical power consumption for EPs increases exponentially with the reduction of the clean gas dust content.

7.2.7 BIBLIOGRAPHY

Some of the references are internal documents which are not readily available.

[1] "Betriebskosten-Vergleich Schlauchfilter gegenüber E-Filter", Höver, K Grosse, 1997

[2] "Dedusting – Concepts for Exhaust Gas and Vent Air Dedusting", P. Kutschera HMC/PT, Bericht PT 96/14158/E, 2nd "Holderbank" Course on Environment September 2 to 13, 1996, Holderbank – Switzerland

[3] "HCB Ciments et Bétons, Eclépens – Evaluation of Offers for New Kiln Dedusting Equipment Technical Part", P. Kutschera/D. Galuzzi HMC/PT, Bericht PT 96/14193/E

[4] "HCB Ciments et Bétons, Eclépens – New Dedusting Concepts for Kiln and Clinker Cooler", P. Kutschera HMC/PT, Bericht PT 96/14147/E

[5] "Visit of four Cement Plants in Italy Equipped with Jet Filters for the Dedusting of the Kiln/Rawmill Exhaust Gas", P. Kutschera HMC/PT, Bericht VA 95/4296/E

[6] "Kiln and Raw Mill Dedusting at Lorca Plant – Comparison between Electrostatic Precipitators and Bag Filters", W. Flückiger/P. Kutschera/Th. Watterlot HMC, Bericht VA 94/4188/E

[7] "Dedusting, HMC/Process Technology, Cement Course", P. Kutschera, 1996

[8] "Vertrag E-Filter Ofen 11", Walther- Alsen-Breitenburg Zement- und Kalkwerke GmbH, Vertrag IN 50022/94

[9] "Hornos Ibéricos Alba S.A., Jerez – Desempolvado Horno / Molino de crudo – Comparación de las ofertas", H. Meier /U. Hinden HMC

[10 Fax; Lurgi Umwelt GmbH; H. Schlaffer, May 6 1997

[11] "Cement Mill Dedusting", W. Flückiger, May 14 1997

[12] Fax, Redecam SpA, A. Semenza, May 20 1997

7.3 CONTROL OF NO_x-EMISSIONS

7.3.1 SUMMARY

Nitrogen oxide, NO, is formed during fuel combustion by oxidation of the molecular nitrogen of the combustion air as well as the nitrogen compounds in the fuels and raw materials. Significant oxidation of the molecular nitrogen of the combustion air takes place in oxidizing flames with temperatures above 1200° C (thermal NO). Since the flame temperature in the rotary kiln is well above 1400° C considerable amounts of thermal NO are produced, but also in zones with lower temperatures such as in precalciners, at any kiln inlet burner and in the preheater significant amounts of NO can be produced (fuel NO). Less than 10% of NO produced in a kiln system is converted to NO_2 prior to leaving the system. The sum of NO and NO_2 emission expressed as NO_2 is called NO_x emission.

The NO_x emissions of cement kilns expressed as NO_2 vary generally between 500 and 2000 mg/Nm^3.

To reduce the NO_x emission from a pyroprocessing system to a certain controlled level, two basically different methods are available:

- Modify the existing process (primary or integrated reduction measures, Chapters 7.3.3 to 7.3.7)
- Maintain the existing process while adding a separate gas cleaning unit for the exhaust gas (secondary reduction measures, Chapters 7.3.8 and 9.1.1)

The tables below show a number of possibilities to reduce NO_x emission with efficiencies between 0 and 65%. Each reduction measure needs certain preconditions before it can be applied. The SNCR (Selective Non-Catalytic Reduction) for example needs a temperature window (900 to 1000° C) with a reasonable residence time of the exhaust gas in the active zone. Many kilns do not provide these conditions because they use secondary firing at the kiln inlet, have a very short riser duct, etc. In some cases it is possible to modify the existing kiln system to allow the application of the required reduction measure. This, however, usually causes major additional investment cost.

The reduction efficiencies described hereafter are based on the reduction of NO_x concentration in the exhaust gas. Most European countries use concentration limits for the pollutants in the exhaust gas from cement plants to limit the emission impact to an acceptable degree. Because of the nature of the cement production process the normal NO_x concentration in the kiln exhaust gas varies over a wide range within short periods of time.

To comply with short term (½ hour, 1 day) emission limits without secondary reduction measures major adjustments to the kiln control may be required. This can result in the overall output of NO_x in terms of t/year being higher than for kiln operation without such adjustments. Since NO_x from the cement kiln stack contributes very little to ground level NO_x and O_3 [37] concentration which can vary from one day or one hour to the other, it would be wise to focus more on long term average emission concentration (mg/m^3).

The primary reduction measures (Chapters 7.3.3 to 7.3.7) have a limited reduction efficiency regarding peak emissions. It is widely agreed today that with the most sophisticated equipment and procedures, the NO_x emission from most new preheater/precalciner kilns can be kept below 500 mg/Nm^3 if long term (e.g. one year) averages are considered. For existing kilns it is much more difficult to determine the lowest achievable NO_x emission because of the large variety of different kiln systems. Many of the existing dry kilns probably would emit less than 1200 mg/Nm^3 (long term average).

When applicable, the only available secondary reduction measure, selective non-catalytic reduction (SNCR) (see Chapter 7.3.8), could in some cases reduce the NO_x emission to as low as 500 mg/Nm^3. At high ammonia injection rates the molar utilisation of the injected ammonia is very low and the ammonia slip can become significant. This may further increase the ammonia emission and pollute the filter dust and thereby prevent dust recycling. In other words a very high reduction efficiency (> 65%) with SNCR is ecologically and economically not recommendable. Further investigation into this matter will be carried out by VDZ [36].

Selective catalytic reduction (SCR) is not yet available as a full scale installation in cement plants. SCR is presently being tested in pilot plants in different locations. First full scale applications are not expected before the year 2000 [36]. See Chapter 9 – Emerging Techniques.

Secondary emissions that are emitted either during the production and transportation of agents (ammonia, etc.) or in power generation that are used to reduce emissions are not included in this investigation.

The reduction efficiencies of the NO_x reduction measures reported below can of course not be summed up to calculate the final NO_x reduction capacity. Some measures cannot even be combined with others. Furthermore the reduction efficiency is always highest at highest emissions. This means that the lower the emissions the harder and more costly it is to reduce them further. Especially for the primary reduction measures it is often very difficult to predict the NO_x reduction efficiency for a specific kiln. The reduction efficiency can be anywhere between the maximum efficiency listed below and zero.

To make the information in the tables below comparable a common base was used:

- Clinker production: 3000 t/d
- Kiln type: Preheater/Precalciner (if not indicated differently)
- Initial emission: Up to 2000 mg/Nm^3 (NO_x expressed as NO_2)
- Coal cost: 60 ECU/t
- Power cost: 0.04 ECU/kWh
- Ammonia costs: 100 ECU/t NH_3 25%(costs between 80 and 120 are known)
- Amortization: 10 years
- Interest rate: 10%

Most information is retrieved from **literature** (see Chapter 7.3.9) and cement industry specific experience. To fit them into the common base, conversion of the relevant data was required.

7.3.2 INDEX OF DESCRIBED NOX REDUCTION MEASURES

7.3.3 OPTIMISATION OF CLINKER BURNING PROCESS (OCBP)

Optimisation of the clinker burning process is usually done to reduce the heat consumption, to improve the clinker quality and to increase the lifetime of the equipment through the stabilization of process parameters. NO_x reduction is a side effect of the optimisation. The reduction is usually caused by the reduced flame and burning temperatures and the reduced heat consumption.

The application of a high level control system is a special case of kiln optimisation and is described in the next Section.

The addition of mineralisers to the raw material is a technology to improve the clinker quality and to reduce the sintering zone temperature. Its contribution to NO_x reduction is not yet known quantitatively but it was found that during test runs with mineralisers that NO_x was reduced. Mineralisers are not further considered in this report.

No.	BAT Evaluation Items	Comments	Remarks
1	**Consumables**		
1.1	Materials	None	
1.2	Air	None	
1.3	Water	None	
2	**Energy Consumption**		
2.1	Thermal	Reduced	
2.2	Electrical	Reduced	
3	**Waste Generation**		
3.1	Solids	None	
3.2	Liquids	None	

4	**Emissions**		
4.1	To air	None	
4.2	To water	None	
4.3	Noise	None	
4.4	Odour	None	
4.5	NO_x reduction [%]	0 - 20 [5,6]	1) Estimated
5	**Impact on Product Quality**		
5.1	Cement	Less fluctuation in product quality	
6	**Experience**		
6.1	Duration	Years	
6.2	Number of applications	Numerous	
7	**Costs**		
7.1	Investment cost [10^6 ECU]	0 - 5 [6]	2)
7.2	Operating cost [ECU/t cli]	-	3)
7.3	Total cost [ECU/t cli]	-	4)
8	**Conclusion on Candidate BAT**		
8.1	For existing plants and plant rehabilitations	Yes	
8.2	For new plants and major upgrades	Yes	

1) The maximum NO_x reduction efficiency is not a guaranteed efficiency for applications on any kiln but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on an initial NO_x emission of about 2000 mg/Nm^3. Most kiln optimisations are executed to reduce operating cost and improve product quality. The effect of kiln optimisation on NO_x emission is known qualitatively but not quantitatively.

2) Kiln optimisation can include many elements ranging from instruction/training of the kiln operators up to installation of new equipment such as dosing systems, homogenization silos, preblending beds, new clinker coolers, etc.

3) Most kiln optimisations were executed to reduce operating cost, increase capacity and improve product quality. The operating cost of an optimised kiln is usually reduced compared to the non-optimised state. The savings result from reduced fuel and refractory consumption, lower maintenance cost, higher productivity and other factors. The cost reduction cannot be indicated generally because kiln optimisation is a very individual step by step process extending for each kiln often over a long period of time.

4) Partially offset by lower energy consumption.

7.3.4 COMPUTER BASED EXPERT SYSTEM FOR KILN OPERATION (ES)

Expert systems allow emission data to be monitored and process parameters to be kept much closer to the set points, in particular also those parameters which are decisive for NO formation.

No.	BAT Evaluation Items	Comments	Remarks
1	**Consumables**		
1.1	Materials		
1.2	Air	None	
1.3	Water	None	
2	**Energy Consumption**		
2.1	Thermal	Reduced	
2.2	Electrical	Reduced	
3	**Waste Generation**		
3.1	Solids		
3.2	Liquids	None	
4	**Emissions**		
4.1	To air	None	
4.2	To water	None	
4.3	Noise	None	
4.4	Odour	None	
4.5	NO_x reduction [%]	Up to 30 [1,2,3,4,5,6,7]	1)
5	**Impact on Product Quality**		
5.1	Cement	Less fluctuation in product quality	
6	**Experience**		
6.1	Duration [years]	> 10	
6.2	Number of applications	> 50	
7	**Costs**		
7.1	Investment cost [10^6 ECU]	0.3 - 2.5 [6]	2)

7.2	Operating cost [ECU/t cli]	< 0.1	
7.3	Total cost [ECU/t cli]	0.14 - 0.51	3)
8	**Conclusion on Candidate BAT**		
8.1	For existing plants and plant rehabilitations	Yes	
8.2	For new plants and major upgrades	Yes	

1) The maximum NO_x reduction efficiency is not a guaranteed efficiency for applications on any kiln but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on an initial NO_x emission of about 2000 mg/Nm^3.

2) The investment cost for the high level control system only is about 300,000 ECU. Additional investment may be necessary to install the required measuring and dosing systems in the plant.

3) Partially compensated by lower energy consumption.

7.3.5 OPTIMIZATION OF MAIN BURNER (LOW-NOX BURNER, LNB)

The reduced NO_x formation with low-NO_x burners is partly caused by a more uniform flame flow pattern without high temperature peaks and partly caused by the flame flow pattern also creating a flame internal reducing atmosphere. It is very difficult if not impossible to predict the NO reduction efficiency of low-NO_x burners for individual applications.

No.	BAT Evaluation Items	Comments	Remarks
1	**Consumables**		
1.1	Materials	None	
1.2	Air	None	
1.3	Water	None	
2	**Energy Consumption**		
2.1	Thermal [kJ/kg cli]	Reduced by 0 - 80 [17]	
2.2	Electrical	Slightly reduced	
3	**Waste Generation**		
3.1	Solids	None	
3.2	Liquids	None	

4	**Emissions**			
4.1	To air		None	
4.2	To water		None	
4.3	Noise		None	
4.4	Odour		None	
4.5	NO_x reduction	[%]	0 - 30 [1,2,5,6,7,8,9,11, 12,13,14,15,16, 17,18,27,28]	1)
5	**Impact on Product Quality**			
5.1	Cement			5)
6	**Experience**			
6.1	Duration	[years]	> 10	
6.2	Number of applications		> 100	
7	**Costs**			
7.1	Investment cost	[10^6 ECU]	0.2 - 0.35 0.6 - 0.8 [6,9]	2) 3)
7.2	Operating cost	[ECU/t cli]	0	
7.3	Total cost	[ECU/t cli]	0.03 - 0.19	4)
8	**Conclusion on Candidate BAT**			
8.1	For existing plants and plant rehabilitations		Yes	
8.2	For new plants and major upgrades		Yes	

1) The maximum NO_x reduction efficiency is not a guaranteed efficiency for application on any kiln but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on an initial NO_x emission of about 2000 mg/Nm^3. The application of low-NO_x burners is not always followed by a reduction of the NO_x emission. An investigation by VDZ [17] shows that 50% of the tested kilns with low-NO_x burners did not show a significant NO_x reduction.

2) New burner.

3) If the existing firing system is direct firing it must be changed to an indirect firing system to allow combustion with low primary air flow.

4) Partially compensated by lower energy consumption.

5) May result in a slightly increased free lime content.

7.3.6 ADDITION OF WATER TO THE FLAME OR FUEL OF THE MAIN BURNER (AWFF)

Addition of water to the fuel or directly to the flame (e.g. in the form of organically polluted water) reduces the temperature and increases the concentration of hydroxyl radicals. This has a positive effect on NO_x reduction in the burning zone. Optimum results were achieved with alternative fuels containing a certain amount of water.

No.	BAT Evaluation Items		Comments	Remarks
1	**Consumables**			
1.1	Materials		None	
1.2	Air		None	
1.3	Water	[kg/t cli]	3 - 20 [10]	1)
2	**Energy Consumption**			
2.1	Thermal	[MJ/t cli]	10 - 65 [8,12]	
2.2	Electrical	[kW/ t cli]	0.02 - 0.15	2)
3	**Waste Generation**			
3.1	Solids		None	
3.2	Liquids		None	
4	**Emissions**			
4.1	To air		H_2O, CO_2	3)
4.2	To water		None	
4.3	Noise		None	
4.4	Odour		None	
4.5	NO_x reduction	[%]	up to 50 [8,10,11,12,27, 28]	4)
5	**Impact on Product Quality**			
5.1	Cement		None	
6	**Experience**			
6.1	Duration	[years]	> 5	
6.2	Number of known applications		> 3	
7	**Costs**			
7.1	Investment cost	[10^6 ECU]	0 - 0.2	Estimated

7.2	Operating cost [ECU/t cli]	0.03 - 0.25 [8] plus 0.0 - 0.25	5)
7.3	Total cost [ECU/t cli]	0.03 - 0.52	
8	**Conclusion on Candidate BAT**		
8.1	For existing plants and plant rehabilitations	Yes	1)
8.2	For new plants and major upgrades	Yes	1)

1) Can cause kiln operating problems.
2) Additional power consumption of kiln ID fan and filter.
3) The additional CO_2 emission is caused by the additional heat requirement for water evaporation. This causes a small additional CO_2 emission (approx. 0.1 – 1.5%) compared to the total CO_2 emission of the kiln. Additional CO_2 emission will be reduced if waste water is used.
4) The maximum NO_x reduction efficiency is not a guaranteed efficiency for applications on any kiln but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on an initial NO_x emission of about 2000 mg/Nm^3.
5) If the kiln, fan or filter gas handling capacity is limited (which is often the case) the maximum clinker production may be reduced while injecting water. This cost is very specific for the situation of each kiln and is difficult to estimate.

7.3.7 MULTI-STAGE COMBUSTION FOR IN-LINE PRECALCINERS (MSCI)

By introducing fuel through a burner in the kiln inlet zone or the riser duct a reducing environment is set up in this second combustion stage. The resulting intermediate products from the consecutive reactions of combustion act as reducing agents for NO created in the sintering zone and at the same time prevent the formation of more NO. After this second combustion stage, in the direction of the gas flow, tertiary air and more fuel (third combustion stage) are added to complete the combustion of the fuel from the second combustion stage. The use of multi-stage combustion is mainly suited to new kilns or an upgrade of kiln production rate.

Lump fuel firing can be a variant of the staged combustion. In case of a preheater kiln lump fuel can be introduced at the kiln inlet or at the precalciner (e.g. tyres). In the case of a wet kiln the lump fuel can be added via a mid-kiln valve (see below). Lump fuel firing is reported to have a positive effect on NO_x reduction. It is however very difficult to produce a controlled reducing atmosphere with lump fuel firing.

Long wet and long dry kilns usually have no access to a temperature zone of about 900 to 1000° C (kiln inlet in preheater kilns). For the sake of firing alternative fuels that cannot pass the main burner, mid-kiln firing systems were installed in a few plants. NO_x reduction can be a side effect of mid-kiln firing. It is however very difficult to produce a controlled reducing atmosphere with a mid-kiln firing system and very high operating and investment cost are associated with it.

No.	BAT Evaluation Items		Comments	Remarks
1	**Consumables**			
1.1	Materials		None	
1.2	Air		None	
1.3	Water		None	
2	**Energy Consumption**			
2.1	Thermal		None	
2.2	Electrical		None	
3	**Waste Generation**			
3.1	Solids		None	
3.2	Liquids		None	
4	**Emissions**			
4.1	To air		CO, SO_2 [13,19,20,24,26]	1)
4.2	To water		None	
4.3	Noise		None	
4.4	Odour		None	
4.5	NO_x reduction	[%]	10 - 50 [2,6,13,19,20,21,22, 23,24,24,26]	2)
5	**Impact on Product Quality**			
5.1	Cement		None	
6	**Experience**			
6.1	Duration	[years]	> 5	
6.2	Number of applications		> 20	
7	**Costs**			
7.1	Investment cost	[10^6 ECU]	1 - 4 [6,9,19] 15 - 20 [6]	3) 4)
7.2	Operating cost	[ECU/t cli]	0	

7.3	Total cost	[ECU/t cli]	0.16 - 0.65 2.4 - 3.3	3) 4)
8	**Conclusion on Candidate BAT**			
8.1	For existing plants and plant rehabilitations		No	4), 5)
8.2	For new plants and major upgrades		Yes	

1) CO and SO_2 emission can be increased if the combustion process is not completed in the precalciner.
2) The maximum NO_x reduction efficiency is not a guaranteed efficiency for application on any kiln but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on an initial NO_x emission of about 2000 mg/Nm^3. Only a limited number of in-line precalciners with staged combustion are presently in operation. Therefore only limited information based on long term experience is available for the time being
3) Cost for precalciner and tertiary air duct for a preheater kiln that is suitable for transformation into a precalciner kiln.
4) Cost of the transformation of a preheater kiln with a satellite cooler into a precalciner kiln with a grate cooler.
5) MSCI is candidate BAT for existing kilns only if they are already equipped with a precalciner or an increase in the production rate is foreseen and the clinker cooler is of the grate cooler type.

7.3.8 SELECTIVE NON-CATALYTIC REDUCTION (SNCR) FOR PREHEATER/ PRECALCINER KILNS

Selective Non-Catalytic Reduction is the only available secondary reduction measure at the moment. NH_2-X compounds are injected into the exhaust gas at a temperature of about 950 to 1000° C to reduce NO to N_2. The required temperature window must provide sufficient retention time for the injected agents to react with NO. Experience shows that for most applications ammonia water is the best agent for SNCR at preheater/precalciner kilns. The transport and storage of ammonia water is a potential danger for the environment.

No.	BAT Evaluation Items		Comments	Remarks
1	**Consumables**			
1.1	Materials	[gNH_3/t cli]	ca. 500 [29]	1)
		[gNH_3/t cli]	ca. 250 [30]	2)
			1700	3)

	[g urea/t cli]	[32]	
1.2	Air	None	
1.3	Water [kg/t cli]	1.5 140 1.5	1) 2) 3)
2	**Energy Consumption**		
2.1	Thermal [kJ/kg cli]	5 500 0	1), Estimated 2), Estimated 3), Estimated
2.2	Electrical [kW/t cli]	Negligible ca. 2 [30]	1),3), Estimated 2),4)
3	**Waste Generation**		
3.1	Solids	Ammonia aerosols	5)
3.2	Liquids	None	
4	**Emissions**		
4.1	To air	Ammonia, N_2O, CO_2, aerosols, dust [6,9,18] CO [32]	1),2),3),9) 3)
4.2	To water	None	
4.3	Noise	None	
4.4	Odour	None	
4.5	NO_x reduction [%]	Up to 65 [7,9,18,28,29,31] Up to 50 [30] Up to 65 [16,18,32]	1),6),12),16) 2),12),16) 3),6),12),16)
5	**Impact on Product Quality**		
5.1	Cement	Higher NH_3 concentration [9]	11)

6	**Experience**			
6.1	Duration	[years]	> 5 Short time test Short time test	1) 2) 3)
6.2	Number of known applications		> 3 1 1	1) 2) 3)
7	**Costs**			
7.1	Investment cost	[10^6 ECU]	0.5 - 1.5 [6,9,29] 0.4 - 0.6 [30] 0.5 - 1.0 [8,32]	1),7) 2) 3)
7.2	Operating cost	[ECU/t cli]	0.3 - 0.5 [6,9,29] 1.9 - 2.7 [30] plus 0 - 2.8 1.0 - 1.5 [8,9,18]	1),8) 2),10) 2), 13) 3)
7.3	Total cost	[ECU/t cli]	0.38 - 0.74 2.0 - 5.6 1.1 - 1.7	1) 2) 3)
8	**Conclusion on Candidate BAT**			
8.1	For existing plants and plant rehabilitations		Yes No No	1),14) 2) 3)
8.2	For new plants and major upgrades		Yes No No	1),15) 2) 3)

1) Injection of ammonia water.

2) Injection of bio solids.

3) Injection of urea.

4) Additional power consumption relative to the normal power consumption of the kiln ID fan, mill fan and filter fan (if present), estimated on the basis of the additional exhaust gas volume.

5) If an ammonia slip occurs the released ammonia can react with SO_2 and other compounds in the exhaust gas to form fine particulates also called aerosols.

6) Higher reduction efficiencies can be achieved by injecting higher NH_3 quantities. Experience shows that after a reduction of 55 to 65% of NO_x a significant NH_3 slip occurs. Therefore the ecological and economical limit for SNCR NO_x reduction is at about 65%.

7) The investment costs are very much influenced by local regulations for storing ammonia water.

8) The operating costs are mainly determined by the cost for the injected ammonia.

9) If ammonia is injected at high molar ratios an ammonia slip is likely to occur. If urea is used for NO_x reduction the risk for additional N_2O and ammonia emission is increased. The additional CO_2 emission is caused by the additional heat consumption of 5 – 500 kJ/kg cli. (water evaporation). This corresponds to an additional CO_2 emission of about 0.1 – 10%.

10) The operating costs are mainly determined by the cost for the injected bio solids and by additional fuel cost.

11) Released ammonia can partially be adsorbed in the filter dust which later may be added to the cement. This would increase the ammonia content of the cement.

12) Only NO_x produced in the kiln is reduced. NO_x from precalciner and preheater cannot be influenced.

13) If the kiln, fan or filter gas handling capacity is limited the maximum clinker production may be reduced while adding bio solids. This cost is very specific for the situation of each kiln and is difficult to estimate.

14) Candidate BAT only for suspension preheater/precalciner kilns where temperature window and residence time are available.

15) Only if required emission target cannot be reached with primary reduction measures.

16) The maximum NO_x reduction efficiency is not a guaranteed efficiency for applications on any kiln but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on an initial NO_x emission of about 2000 mg/Nm^3.

7.3.9 BIBLIOGRAPHY

Some of the references are internal documents which are not readily available.

[1] “Emission Reduction Measures Proposed By FLS”, P. Kutschera / U. Gasser / R Hasler

[2] “An overview of the formation of SO_x and NO_x in various pyroprocessing systems”, Peter Bechtoft Nielsen & Ove Lars Jepsen, F.L. Smidth & Co, A/S, Copenhagen, Denmark, IEEE Cement Industry Technical Conference May, 1990, Nr. 96

[3] “Experience with the kiln control system PYROEXPERT® at Leimen cement plant”, Dr.-Ing. A. Scheuer und M. Principato, Heidelberger Zement AG

[4] “Application of LINKman graphic in Untervaz”, A. Schmid (Bündner Cementwerke AG), 33rd Technical Meeting/10th Aggregates and Ready-Mixed Concrete Conference March 1994 – Basel, Schweiz (MA 94/3129/E)

[5] “NO_x reduction – a systematic approach”, K. Thomson, Valby/Dänemarkt, Verein Deutscher Zementwerke Kongress 1993

[6] “NO_x-Minderung in Zementwerken – Stand der Technik”, Bundesamt für Umwelt, Wald und Landschaft (Buwal) Bern 1996, Schriftenreihe Umwelt Nr. 274

[7] “SO_2 and NO_x emissions from modern cement kilns with a view to future regulations”, P.B. Nielsen, Kopenhagen, Dänemark, Zement-Kalk-Gips – Nr. 9/1991 (44. Jahrgang)

[8] “ATILH Meilleures Techniques disponibles Réduction émissions NO_x”, Lafarge Ciments, Centre de Viviers, Recherche et Formation, Service Etudes, 1997

[9] “Begrenzung der Stickstoffoxid-Emissionen in der Zementindustrie”, Länderausschuss für Immissionsschutz (LAI) 20.05.1996, Ministerium für Umwelt, Raumordnung und Landwirtschaft des Landes Nordrhein-Westfalen in Düsseldorf

[10] “NO_x-Reduktion durch Wassereindüsung in die Flamme”, Lg / 08.01.1993, UV/RK/Retznei, VA-Datenbank-Blatt Nr. 1397

[11] “NO_x-Minderung durch Primärmassnahmen”, VSZKGF-Tagung vom 24/25.01.1996

[12] “Betriebsergebnisse und NO_x-Emissionen mit dem Rotaflam-Brenner im Zementwerk Retznei”, C. Breitenbaumer, Retznei (Oesterreich), Zement-Kalk-Gips Nr. 5/1992 (45. Jahrgang)

[13] “Klinkerbrand mit reduzierter NO_x-Emission”, Dr. M. Deussner, KHD Humboldt Wedag AG

[14] “Die ideale Flamme – der Schlüssel zur Ofenoptimierung”, F. Schneider, HMB/TS/Verfahrenstechnische Abteilung

[15] “The effect of burner design and operating parameters on flame shape, heat transfer, NO_x and SO_3 cycles”, T.M. Lowes und L.P. Evans, Greenhithe, Grossbritannien, überarbeitete Fassung eines Vortrages zum VDZ Kongress 93, Düsseldorf

[16] “Cement Kiln NO_x Control”, A.T. McQueen, S.J. Bortz, M.S. Hatch, H.J. Buening, D.E. Shore, R.L. Leonard, E.f. Bouse (Radian Corporation, 7 corporate Park, Suite 240, Irvine, CA-92714, 35th Conference Record IEEE Cement Industry

Technical Conference Toronto, Canada, May 23-27 1993, IEEE Catalogue No. 93CH3268-0

[17] “Einflüsse von Brenner und Brennstoff auf den Betrieb und die NO$_x$-Emissionen von Drehöfen der Zementindustrie”, V. Hönig und S. Gajewski, Forschungsinstitut der Zementindustrie, Düsseldorf/Deutschland, Zement-Kalk-Gips Nr. 8/1994 (47. Jahrgang)

[18] “State of NO$_x$ Emission Reduction Efforts at the Untervaz Plant”, A.G. Caluori, Bündner Zementwerke AG, Switzerland, 32nd Technical Meeting 1992 Montreux (VA 92/5993/E)

[19] “Begrenzung der NO$_x$-Emissionen bei der Zementklinkerproduktion”, Alsen-Breitenburg Zement- und Kalkwerke GmbH, VA Nr. 1281 vom 24.06.1996

[20] “Messbericht Inbetriebnahme Ofeneinlaufbrenner TERNAVER”, Adler (Krupp-Polysius AG, Beckum), Bericht-Nr. 311-/32/93

[21] “Stepped fuel supply – an effective way of reducing NO$_x$ emissions”, W. Rother und D. Kupper, Beckum, Zement-Kalk-Gips Nr. 9/1989 (42. Jahrgang)

[22] “Activities of VDZ Committee „ NO$_x$ reduction“”, J. Kirsch, Wiesbaden, und A. Scheuer, Forschungsinstitut der Zementindustrie, Düsseldorf, Zement-Kalk-Gips Nr. 1/1988 (41. Jahrgang)

[23] “Reducing NO$_x$ at the Brevik cement works in Norway – Trials with stepped fuel supply to the calciner”, Ø. Høidalen, A. Thomassen und T. Syverud, Brevik/Norwegen, überarbeitete Fassung eines Vortages zum VDZ Kongress 93, Düsseldorf (27.09-01.10.1993)

[24] “3. Sitzung des Arbeitskreises „ NO$_x$-Minderung“”, Verein Deutscher Zementwerke e.V. Düsseldorf,

[25] “Staged combustion for NO$_x$ control at the Calaveras Tehachapi plant”, Dennis Dusome, S.A. Cimenteries CBR, Belgium, Portland Cement Association General Technical Committee Autumn Meeting 1994

[26] “Utilization of chipped car tyres for reducing NO$_x$ emissions in a precalciner kiln”, Tor Syverud, Arnulf Thomassen and Tor Gautestad, Norcem R&D, Norway, World Cement November 1994

[27] “Low Emission Cement Kiln Study: NO$_x$”, P. Kutschera, „ Holderbank“ Working Committee 1995, Report No. PT 95/4393/E October 1995

[28] “Sources and Reduction of NO$_x$-Emissions”, P. Kutschera, PT 96/14160/E

[29] “Visite de l’installation Polvitec à l’usine „ HCB“ Siggenthal”, HMB/CEA Th. Lang 18.03.1996, CETIC Sous-Commission „ Environnement“

[30] “BioSolids Injection Technology: An Innovation in Cement Kiln NO$_x$ Control”, H.O. Biggs, Plant Manager Mitsubishi Cement Corporation, 5808 State Hwy 18, Lucerne Valley, CA-92356-9691

[31] “Effektive Emissionsminderung bei Einsatz von Sekundärstoffen im schweizerischen Zementwerk Siggenthal”, D. Rose und L. Brentrup, Beckum/Deutschland, Sonderdruck aus ZKG International Heft 4, 48. Jahrgang (1995)

[32] “Reduction of NO_x Emissions from a Dry Process Preheater Kiln with Calciner through the Use of the Urea Based SNCR Process”, H.E. Steuch, J. Hille, W.H. Sun, M.J. Bisnett, D.W. Kirk

[33] “Non-Catalytic Reduction of NO_x in a Wet Kiln”, Michael Beaupre, Scarth Macdonnell, Michael Nisbet

[34] “NO_x-Reduktion von Zementofenabgasen mit dem SCR-Verfahren der Firma Elex”, Josef Waltisberg, Technische Forschungs- und Beratungsstelle, Wildegg, TFB-Wa-96-14 vom 24.07.1996

[35] “Messbericht Untersuchung zur NO_x-Minderung durch die POLYSIUS-Mehrstufenver-brennung (MSC)”, KRUPP POLYSIUS, Beckum, Deutschland, Versuche im Zementwerk Lägerdorf der ALSEN-BREITENBURG Zement- und Kalkwerke GmbH vom 26.04-29.05.1996

[36] “Niederschrift des NO_x-Gespräches vom 04.12.1996 in Düsseldorf”, Forschungsinstitut der Zementindustie Düsseldorf

[37] “Massnahmenplan Luftreinhaltung”, Regierungsrat des Kantons Aargau März 1991

[38] “Stand der NO_x-Minderung in der Zementindustrie”, Verein Deutscher Zementwerke e.V. Forschungsinstitut der Zementindustrie, Aus der Gemeinschaftsarbeit-Für die Praxis Bericht Nr. 8 (1996)

[39] “Primäre und sekundäre Massnahmen zur Minderung von NO_x-Emissionen an einer Drehofenanlage mit Vorcalcinator zum Brennen von Zementklinker”, Dr.-Ing. Dietrich Locher, Dr.-Ing. Werner Ruhland, Dyckerhoff Zement GmbH Werk Geseke, Umweltbundesamt für Luftreinhaltung Abschlussbericht 50 441-5/205 (Januar 1996)

[40] “Gyro-Therm Technology Boots Cement Kiln Output, Efficiency and Cuts NO_x Emissions”, R. Vidergar, Ash Grove Cement Company, D. Rapson, FCT International, IEEE Cement Industry Technical Conference, April 1997

[41] “Industrial Application and Results of Low NO_x Precalciner Systems”, G. H. Conroy, KHD Humboldt Wedag Atlanta, IEEE Cement Industry Technical Conference, April 1997

[42] “New Generation of Low NO_x Calciners”, O. L. Jepsen, Fuller Company, S. Miller Fuller Company, IEEE Cement Industry Technical Conference, April 1997

[43] „ Optimierung der Verbrennung im Calcinator eriner Zementdrehofenanlage“, R. Jeschar, R. Jennes TU Clausthal, H. Kremer, Th. Kellerhoff, Ruhr-Universität Bochum, ZKG Internatinal Nr. 6/1996

7.4 CONTROL OF SO_2-EMISSIONS

7.4.1 SUMMARY

Sulfur dioxide, SO_2, is formed during fuel combustion (fuel sulfur), releases of SO_2 in the burning zone of the kiln (from sulfates, e.g. $CaSO_4$) and oxidation of pyrite/marcasite (sulfide) and organic sulfur in the preheater or in the kiln inlet of long wet or long dry kilns. The behaviour of sulfur in preheater kilns and long wet or long dry kilns is significantly different.

Summarized it can be said that under normal conditions any sulfur introduced into the rotary kiln or the secondary firing/precalciner part of a preheater/precalciner kiln system only marginally contributes to the kiln's SO_2-emissions. This is different with sulfur in the form of sulfides and organic sulfur contained in the raw meal and fed in the usual way to the preheater top cyclone. About 30% of this sulfide and organic sulfur input leave the preheater as SO_2. During direct operation most of it is emitted to the atmosphere while during compound operation (that is when the kiln exhaust gases are passing through the raw mill, typically 60 – 85% of the operation time) 30 to 90% of the SO_2 is absorbed in the raw mill. In long wet and long dry kiln systems as well as in preheater bypass systems(very rare in EU) all types of sulfur input can contribute to SO_2 emissions, although in some cases the absorbtion of fuel sulfur can reach up to 90%.

The SO_2 emissions of cement kilns vary between 10 and 3,500 mg/Nm^3.

To reduce the SO_2 emission from a pyroprocessing system to a certain controlled level, three basically different methods are available:

- Maintain the existing process while reducing the sulfur input into the system (Chapter 7.4.3)
- Modify the existing process (primary or integrated reduction measure, Chapter 7.4.4)
- Maintain the existing process while adding a separate gas cleaning unit for the exhaust gas (secondary reduction measures, Chapters 7.4.5 to 7.4.8)

The tables below show a number of possibilities to reduce SO_2 emissions with efficiencies between 0 and 95%. Each reduction measure needs certain preconditions before it can be applied. In some cases it is possible to adjust the existing kiln system to allow the application of the required reduction measure. This, however, usually causes major additional investment cost.

The reduction efficiencies described are based on the reduction of the SO_2 concentration in the exhaust gas. Most European countries use concentration limits for the pollutants in the exhaust gas from cement plants to limit the emission impact to an acceptable degree. Because of the nature of the cement production process, the fuels and the raw materials, the observed SO_2 concentrations in the kiln exhaust gas vary in a wide range within short periods of time. To comply with limits over short term periodes (½ hour, 1 day) very strong corrective actions with secondary reduction measures may be required. It should be investigated from case to case if emission limits based on averages of longer time periods would improve the efficiency of environmental protection (e.g. with the same amount of slaked lime added to a kiln feed, lower total SO_2 emission can be achieved if the time intervals for the calculation of the SO_2 emission are extended).

The primary reduction measures (Chapters 7.4.3 and 7.4.4) have a limited reduction efficiency regarding peak emissions. Even if all possible primary measures are taken the SO_2 emission can still be anywhere between 10 and 3,500 mg/Nm^3. Prediction of reduction efficiencies of primary reduction measures can be very difficult. The presently existing secondary reduction measures (Chapters 7.4.5 to 7.4.8) can reduce the SO_2 emissions below 500 mg/Nm^3. The only economical secondary reduction measure (0.1 – 0.4 ECU/t_{cli}), the addition of slaked lime to the kiln feed, is limited to a maximum raw gas SO_2 content of about 1,200 mg/Nm^3 if an emission level of 400 mg/Nm^3 is to be achieved. All other secondary reduction measures significantly increase the production cost of clinker (2.7 – 3.1 ECU/t_{cli}).

The reduction efficiencies of the SO_2 reduction measures reported below can of course not be summed up to calculate the final SO_2 reduction capacity. Some measures cannot even be combined with others. Furthermore the reduction efficiency is usually highest at highest emissions. This means that the lower the emissions the harder and more costly it is to reduce them further.

Secondary emissions that are emitted during the production and transportation of agents (slaked lime, activated carbon...), and power used for emission reduction, are not included in this investigation.

To make the information in the tables below comparable a common base was used:

- Clinker production: 3000 t/d
- Kiln type: Preheater/Precalciner (if not indicated differently)
- Initial emission: Up to 3000 mgSO_2/Nm^3
- Coal cost: 60 ECU/t
- Activated coke cost: 240 ECU/t
- Slaked lime cost: 85 ECU/t
- Power cost: 0.04 ECU/kWh
- Amortization: 10 years
- Interest rate: 10%

Most information is retrieved from literature (see Chapter 7.4.9) and cement industry specific experience. To fit them into the common base, conversion of the relevant data was required.

7.4.2 INDEX OF DESCRIBED SO_2 REDUCTION MEASURES

7.4.3 REDUCTION OF SULFUR CONTENTS IN FUELS AND KILN FEED (RSC)

The sulfur behaviour in cement kiln systems and the emissions resulting therefrom can be summarized as follows:

	Lepol, Preheater/ precalciner kilns	**Other kilns**
Fuel sulfur	O	√
Volatile sulfur in raw materials (pyrites, marcasite, organic sulfur)	√	√
Non-volatile sulfur in raw materials (sulfates)	O	√

O = No effect on sulfur emissions

√ = May increase sulfur emissions

Fuel sulfur in preheater/precalciner kilns practically does not leave the kiln system as SO_2 emission because of the very efficient scrubbing by the hot meal in the preheater or/and in the precalciner. In preheater kilns all fuel sulfur must leave the system as a well defined compound like K_2SO_4 and $Ca_2K_2(SO_4)_3$ or in solid solution in the clinker minerals (e.g. belite). Therefore fuel sulfur does not contribute significantly to SO_2 emissions from preheater/precalciner kilns.

Fuel sulfur in other kilns than cyclone and grate preheater kilns, however, can have a significant impact on the SO_2 emission. This is due to a somewhat less intensive contact between the raw meal and the exhaust gas (reduced scrubbing effect). An average of 10 to 50% of the fuel sulfur leaves the kiln as SO_2.

Raw material sulfur in form of sulfides (pyrite, marcasite) or organic sulfur can increase the SO_2 emission of preheater/precalciner kilns. An average of 30 to 50% of the kiln feed sulfides leave the preheater kilns as SO_2. Raw material sulfur in the form of sulfates does not contribute to the SO_2 emissions but leaves the kiln in the same way as the fuel sulfur, i.e. integrated in the clinker.

Raw material sulfur in other kilns than preheater/precalciner kilns can contribute to the SO_2 emission in a similar manner as the fuel SO_2. Sulfides are oxidised to SO_2 at the kiln feed end and the sulfates are dissociated and SO_2 is released in the burning zone. 10 to 50% of the sulfur input may leave the kiln as SO_2.

Therefore a reduction of the sulfide input can reduce the SO_2 emission from preheater/precalciner kilns. Fuel sulfur and sulfate reduction has no influence on preheater/precalciner kilns SO_2 emission.

In other kilns than preheater kilns all sulfur input can contribute to SO_2 emissions. The costs for the reduction of sulfur inputs into such kiln systems cover a wide range. A solution could be a reduction of the fuel sulfur by replacing a normal fuel like a sulfur rich coal, with an alternative fuel with low sulfur content, provided this is economically feasible.

7.4.4 OPTIMIZATION OF THE CLINKER BURNING PROCESS (OCBP)

Optimization of the clinker burning process is usually done to reduce the heat consumption, to improve the clinker quality and to increase the lifetime of the equipment (e.g. refractory). SO_2 reduction is a side effect of the optimization. The reduction is usually caused by the reduced SO_2 volatility (lower flame and burning temperatures and oxidizing instead of reducing atmosphere in the kiln) as well as stable kiln operation. The effect of kiln optimization on SO_2 emission is very strong for long wet and long dry kilns and marginal for preheater kilns.

The application of a high level control system is a special case of kiln optimization.

No.	BAT Evaluation Items	Comments	Remarks
1	**Consumables**		
1.1	Materials	None	
1.2	Air	None	
1.3	Water	None	
2	**Energy Consumption**		
2.1	Thermal	Reduced	
2.2	Electrical	Reduced	
3	**Waste Generation**		
3.1	Solids	None	
3.2	Liquids	None	
4	**Emissions**		
4.1	To air	NO_x	1)
4.2	To water	None	
4.3	Noise	None	

4.4	Odour	None	
4.5	SO_2 reduction [%]	0 - 50 [19]	2)
5	**Impact on Product Quality**		
5.1	Cement	Less fluctuation in product quality	
6	**Experience**		
6.1	Duration	Years	
6.2	Number of applications	Numerous	
7	**Costs**		
7.1	Investment cost [10^6 ECU]	0 - 5 [6]	3)
7.2	Operating cost [ECU/t cli]	0	4)
7.3	Total cost [ECU/t cli]	0 - 0.81	
8	**Conclusion on Candidate BAT**		
8.1	For existing plants and plant rehabilitations	Yes	
8.2	For new plants and major upgrades	Yes	

1) If the oxygen concentration in the kiln is increased to avoid reducing atmosphere the NO_x production rate can be higher.

2) The maximum SO_2 reduction efficiency is not a guaranteed efficiency for applications on any non-cyclone preheater kiln but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on an initial SO_2 emission of about 3000 mg/Nm^3. Influence of kiln optimisation on SO_2 from preheater kilns is usually negligible.

3) Kiln optimisation can include many elements ranging from instruction/training of the kiln operators up to installation of new equipment such as new burner, dosing systems, homogenisation silos, preblending beds, new clinker coolers, etc.

4) Most kiln optimisations have been executed to reduce operating cost, increase capacity and improve product quality. The operating cost of an optimized kiln is usually lower if compared to the non optimised state. The savings result from reduced fuel and refractory consumption, lower maintenance cost, higher productivity and other effects. No general cost reduction can be indicated because kiln optimisation is a very individual step by step process extending for each kiln often over a long period of time.

7.4.5 ADDITION OF SLAKED LIME ($Ca(OH)_2$) TO THE KILN FEED OF PREHEATER KILNS (SLKF)

The addition of slaked lime to the exhaust gas of the kiln can absorb some of the SO_2. It has been found that the best method of introducing the slaked lime is to add it to the kiln feed (it was found that direct injection of slaked lime into the exhaust gas is less efficient compared to the addition of slaked lime to the kiln feed). Once injected into the exhaust gas it absorbs SO_2 in the top cyclones:

$$Ca(OH)_2 + SO_2 \dashrightarrow CaSO_3 + H_2O$$

The $CaSO_3$ then moves into the kiln together with the raw material. The $CaSO_3$ reacts with the exhaust gas to form $CaSO_4$ which becomes incorporated in the clinker. The reactivity of the slaked lime is not very high. Therefore molar ratios between $Ca(OH)_2$ and SO_2 of 3 to 6 have to be applied. If an emission level of 400 mg/Nm^3 is to be achieved, the SO_2 concentration in the raw gas should not be above 1,200 mg/Nm^3. For higher initial SO_2 emissions, the addition of slaked lime to the kiln feed is economically and ecologically not feasible.

No.	BAT Evaluation Items		Comments	Remarks
1	**Consumables**			
1.1	Materials	[kg$Ca(OH)_2$/t_{cli}]	2 - 8 [5,8,11,12,15,18]	1)
1.2	Air		None	
1.3	Water		None	
2	**Energy Consumption**			
2.1	Thermal		None	
2.2	Electrical	[kWh/ t_{cli}]	0.2 - 0.5 [11]	
3	**Waste Generation**			
3.1	Solids		None	
3.2	Liquids		None	
4	**Emissions**			
4.1	To air		None	
4.2	To water		None	
4.3	Noise		None	
4.4	Odour		None	
4.5	SO_2 reduction	[%]	Up to 65 [5,8,9,12,15,18]	2)

5	**Impact on Product Quality**			
5.1	Cement		None	
6	**Experience**			
6.1	Duration	[years]	> 5	
6.2	Number of known applications		> 4	
7	**Costs**			
7.1	Investment cost	[10^6 ECU]	0.2 - 0.3	Estimated
7.2	Operating cost	[ECU/t_{cli}]	0.1 - 0.4 [5,11]	
7.3	Total cost	[ECU/t_{cli}]	0.13 - 0.45	
8	**Conclusion on Candidate BAT**			
8.1	For existing plants and plant rehabilitations		Yes	
8.2	For new plants and major upgrades		Yes	

1) The required $Ca(OH)_2$ input is a function of the average SO_2 raw gas emission, the required clean gas SO_2 concentration and the situation in the top stage cyclones (temperature, retention time). 2 to 8 kg/t_{cli} are average figures. Maximum input can be up to 20 kg/t_{cli}.

2) The maximum SO_2 reduction efficiency is not a guaranteed efficiency for applications on preheater kilns but the maximum efficiency that may be achieved under optimum conditions. The maximum lime utilisation efficiency is obtained with an initial SO_2 emission of about 3000 mg/Nm^3.

7.4.6 CIRCULATING FLUIDIZED BED ABSORBER (CFBA)

To reduce very high SO_2 emissions (more than 1500 mg/Nm^3) to 500 or 400 mg/Nm^3 a separate scrubber is required if the primary reduction measures remain insufficient. The CFBA uses a Venturi reactor column to produce a fluidised bed consisting of a blend of slaked lime and raw meal. The intensive contact between gas and absorbent, the long residence time and the low operating temperature close to the dew point allow a very efficient absorption of SO_2. The gas leaving the Venturi is loaded with absorbent which is collected in the downstream electrostatic precipitator. A portion of the extracted absorbent is returned to the CFBA and the other portion is added to the kiln inlet where the absorbent is converted into clinker.

No.	BAT Evaluation Items		Comments	Remarks
1	**Consumables**			
1.1	Materials	$kgCa(OH)_2/t_{cli}$ $kgRawMeal/t_{cli}$	13 30	1)
1.2	Air		None	
1.3	Water		Yes	
2	**Energy Consumption**			
2.1	Thermal		None	
2.2	Electrical	kWh/t_{cli}	8.5	
3	**Waste Generation**			
3.1	Solids		None	
3.2	Liquids		None	
4	**Emissions**			
4.1	To air		None	
4.2	To water		None	
4.3	Noise		None	
4.4	Odour		None	
4.5	SO_2 reduction	[%]	Up to 90 [3,5,12,17]	2)
5	**Impact on Product Quality**			
5.1	Cement		None	3)
6	**Experience**			
6.1	Duration	[years]	> 9	
6.2	Number of applications		> 1	
7	**Costs**			
7.1	Investment cost	[10^6 ECU]	11 [5]	
7.2	Operating cost	[ECU/t_{cli}]	1.6 (1.4)	4)
7.3	Total cost	[ECU/t_{cli}]	3.4 (3.2)	4)

8	**Conclusion on Candidate BAT**		
8.1	For existing plants and plant rehabilitations	No	5)
8.2	For new plants and major upgrades	No	5)

1) The absorbent of the CFBA is fully recovered in the cement production process. Therefore the CFBA is neutral regarding the mass balance of the cement production.
2) The maximum SO_2 reduction efficiency is not a guaranteed efficiency for applications on any kiln but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on an initial SO_2 emission of about 3000 mg/Nm^3. It was found that also compounds of the exhaust gas, other than SO_2, are adsorbed in the CFBA.
3) The additional sulfur content of the clinker reduces the required addition of gypsum to the cement mill.
4) If the contribution from gypsum replacement is also included in the cost evaluation the values in brackets are valid. The contributions are subject to strong variations from one plant to another.
5) Yes only in case very high SO_2 emissions have to be reduced.

7.4.7 WET SCRUBBER (WS)

An alternative to the CFBA (dry scrubbing) is wet scrubbing. A system presently in operation [16] works as follows. The exhaust gas from the kiln passes first a gas/water heat exchanger before it enters the SO_2 scrubber at a temperature of about 115° C. In the scrubber SO_2 is absorbed in a slurry loaded with 6 – 10% solids consisting of 98% $CaSO_4.2H_2O$ and 2% $CaCO_3$. The slurry is sprayed in counter current to the exhaust gas and collected in the recycle tank at the bottom of the scrubber where it is oxidised with air ($CaSO_3 + 0.5O_2$ ---> $CaSO_4$). A part of the slurry is pumped to a centrifuge where water and gypsum are separated. The rest is reinjected through a circulation line into the scrubber. A chalk slurry of 30% moisture is injected into the circulation line before the spray nozzles to replace the used and extracted absorbent ($CaCO_3+SO_2$ ---> $CaSO_3$ + CO_2). The exhaust gas leaves the scrubber with a temperature of about 70° C.

No.	BAT Evaluation Items		Comments	Remarks
1	**Consumables**			
1.1	Materials	[kg$CaCO_3$/t_{cli}]	35 [25]	
1.2	Air	[m3/t_{cli}]	63 [25]	
1.3	Water	[kg/t_{cli}]	None	

2	**Energy Consumption**		
2.1	Thermal	None	
2.2	Electrical [kW/t_{cli}]	24 [25]	
3	**Waste Generation**		
3.1	Solids	None	1)
3.2	Liquids		
4	**Emissions**		
4.1	To air	None	
4.2	To water [m3/h]	0.5 [25]	
4.3	Noise	None	
4.4	Odour	None	
4.5	SO_2 reduction [%]	75 - 90 [16]	2)
5	**Impact on Product Quality**		
5.1	Cement	None	
6	**Experience**		
6.1	Duration [years]	6	
6.2	Number of known applications	1 [16]	
7	**Costs**		
7.1	Investment cost [10^6 ECU]	10 - 14 [25]	3)
7.2	Operating cost [ECU/t_{cli}]	2.7 [25]	4)
7.3	Total cost [ECU/t_{cli}]	4.3 - 5.0	4)
8	**Conclusion on Candidate BAT**		
8.1	For existing plants and plant rehabilitations	No	1), 4)
8.2	For new plants and major upgrades	No	1), 4)

1) The scrubber produces gypsum that is used in the cement production.

2) The maximum SO_2 reduction efficiency is not a guaranteed efficiency for applications on any kiln but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on an initial SO_2 emission of about 3000 mg/Nm^3.

3) The reported investment cost from a wet scrubber for cement kiln exhaust gas is 12.2 Million ECU (including heat recovery system). The kilns that are equipped with this wet scrubber only produce about half of the BAT reference kiln (3000 t_{cli}/day) but are wet kilns with a high specific heat consumption and a high specific exhaust gas quantity. The total exhaust gas that is treated in the wet scrubber is about twice the exhaust gas from a modern preheater kiln for 3000 t/d. The estimation of the cost for a 3000 t/d kiln is very difficult.

4) 2.7 ECU/$_{tcli}$ is the operating cost in the reference plant including material and power consumption as well as maintenance cost. This cost is offset by the plant generating a benefit: 3.5 ECU/t_{cli} for the heat sold to the community and 0.18 ECU/t_{cli} for the gypsum. If these revenues are included in the cost calculation the total cost amounts to 0.3 – 0.8 ECU/t_{cli} . The high revenues from the heat recovery are however very specific for this unique application, mainly because of the very high heat output of the kilns which is significantly higher than that of most other kilns in Europe built more recently.

7.4.8 ADSORPTION ON ACTIVATED COKE, POLVITEC (AAC)

The POLVITEC consists of several packed beds of activated coke. The dedusted kiln exhaust gas is passed across the activated coke where compounds like SO_2 and NH_3 are efficiently adsorbed. The cleaned gas is then released to the atmosphere. The used activated coke is periodically extracted to a separate silo and replaced with fresh adsorbent. From the used coke silo the coke is fed to the kiln together with other fuels. The adsorbed SO_2 is thereby subsequently embedded in the clinker.

No.	BAT Evaluation Items	Comments	Remarks
1	**Consumables**		
1.1	Materials [kgCarbon/t_{cli}]	4.5 [22]	
1.2	Air	None	
1.3	Water	None	
2	**Energy Consumption**		
2.1	Thermal	None	
2.2	Electrical [kWh/t_{cli}]	6 [22]	
3	**Waste Generation**		
3.1	Solids	None	
3.2	Liquids	None	
4	**Emissions**		
4.1	To air	None	

4.2	To water	None	
4.3	Noise	None	
4.4	Odour	None	
4.5	SO_2 reduction [%]	Up to 95 [7,22]	1)
5	**Impact on Product Quality**		
5.1	Cement	None	
6	**Experience**		
6.1	Duration [years]	3	
6.2	Number of known applications	1	
7	**Costs**		
7.1	Investment cost [10^6 ECU]	21 [7,22]	
7.2	Operating cost [ECU/t_{cli}]	0.9 (0.5) [7,22]	2)
7.3	Total cost [ECU/t_{cli}]	4.3 (3.9)	2)
8	**Conclusion on Candidate BAT**		
8.1	For existing plants and plant rehabilitations	No	3)
8.2	For new plants and major upgrades	No	3)

1) The maximum SO_2 reduction efficiency is not a guaranteed efficiency for applications on any kiln but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on an initial SO_2 emission of about 3,000 mg/Nm^3.

2) If the contributions from gypsum and coal replacement are also included in the cost evaluation the values in brackets are valid. The contributions are subject to strong variations from one plant to another.

3) Adsorption on activated carbon is too expensive. In the case of the Polvitec installed in a Swiss cement plant only the financial contribution of the communities burning their sewage sludge in the kiln, the fees for burning other alternative fuels in the kiln and the complex problem with different emission components made the project ecologically and economically feasible.

7.4.9 BIBLIOGRAPHY

Some of the references are internal documents which are not readily available.

[1] "Nordcement, Werk Hoever Entschwefelungsversuch mit Kalkhydrat", J. Waltisberg (HMB/VA), Bericht VA 89/5610/D

[2] "Möglichkeiten der Entstehung und Minderung von SO_2-Emissionen in Zementwerken", R. Schütte, Beckum, Zement-Kalk-Gips Nr. 3/1989 (42. Jahrgang)

[3] "Inbetriebnahme einer trockenen Rauchgas-Entschwefelungsanlage nach dem Prinzip der zirkulierenden Wirbelschicht (CFBA)", K. Kühle, J. Eschenburg, Frankfurt und O. Beck, Untervaz/Schweiz, Zement-Kalk-Gips Nr. 9/1989 (42. Jahrgang)

[4] "Die SO_2- und NO_x- Emissionen bei modernen Zementdrehofenanlagen mit Blick auf zukünftige Verordnungen", P. B. Nielsen, Kopenhagen, Dänemark, Zement-Kalk-Gips Nr. 9/1991 (44. Jahrgang)

[5] "Sources and Reduction of SO_2-Emissions", P. Kutschera, "Holderbank" Manual on Environment Bericht Nr. VA 95/4331/E

[6] "The FLS-Gas Suspension Absorber (GSA) – a novel generation of semidry flue gas cleaning processes", Peter Bo Olsen, Process manager, FLS miljØ, FLS miljØ Environmental Management

[7] "Effektive Emissionsminderung bei Einsatz von Sekundärstoffen im schweizerischen Zementwerk Siggenthal", D. Rose und L. Brentrup, Beckum/Deutschland, Zement-Kalk-Gips 48. Jahrgang (1995) Heft 4, Seiten 204-214

[8] "Emissions de SO_2 dans la production de clinker", VICAT, Paris, Version 2 du 6 février 1997

[9] "Operational Solutions to Environmental Problems", O. L. Jepsen

[10] "1995 SO_2 Control Symposium", Leif Mortensen, SK Power Company, Copenhagen, Denmark, Stig Bue Lading, FLS miljØ a/s, Copenhagen, Denmark, Mark C. Woods, NOXSO Corporation, Bethel Park, Pennsylvania, EPRI Electric Power Research Institute, Book 3: Thursday, March 30, 1995 Sessions 6A, 6B, 7A, 7B,

[11] "Kalkhydrat-Aufgabe – Ihr Gespräch mit Herrn Heinemeyer vom 25.04.1995", Nordcement, Werk Höver, Brief vom 27.04.1995/He-Ks

[12] "Source and Reduction of Emissions Gaseous", HMB, Environmental Protection Seminar, Bericht VA 91/5882/E

[13] "Presentations from Nordcement Copies of Transparencies", HMB, Environmental Protection Seminar

[14] "Exhaust gas scrubbing for environmental protection", A. Ondraschek, Bündner Cementwerke AG, Switzerland, 31st Technical Meeting June 1990 – Baden, Switzerland, MA 90/3773/E,D

[15] "Cementfabrik "Holderbank", Rekingen Entschwefelung mit einem Kalkhydrat der Firma Lonza", J. Waltisberg (HMB), Aktennotiz Nr. VA 90/47/D

[16] “A new heat recovery and desulphurization plant for 4 wet kilns in Aalborg Portland”, E. Borgholm, Aalborg Portland, Denmark, 0-7803-0960-X / 93 $ 3.00 © 1993/EEE

[17] “Trockene Entschwefelung mit der CFBA”, Norbert Christen BCU, LURGI – Kolloquium Zement 24.11.92

[18] “Possibilities of SO_2 reduction in the cement industry by sorption processes, W. Rother & D. Rose, Krupp Polysius, Germany, International Cement Conference, Production Expertise – Management Skills, Prague April 1991

[19] “Auswirkung der Brennerbauart und der Betriebsparameter auf Flammenform, Wärmeübergang, NO_x und SO_3-Kreisläufe”, T.M. Lowes und L.P. Evans, Greenhithe, Grossbritannien, VDZ Kongress 1993, Fachbereich 3

[20] “SO_2 Emissions History and Scrubbing System, Santa Cruz Plant, California RMC Lonestar”, Satish H. Sheth Plant Manager RMC Lonestar, Santa Cruz Plant, Davenport, 33rd IEEE Cement Industry Conference Mexico City, Mexico, May 1991

[21] “Massnahmen zur Minderung der SO_2-Emission beim Klinkerbrennen im Werk Höver der Nordcement AG”, K.-H. Boes, Hannover/Deutschland, VDZ Kongress 1993, Fachbereich 4

[22] “Visite de l’installation Polvitec à l’usine HCB Siggenthal”, HMB/CEA Th. Lang, Cetic Sous-Commission “Environnement“ Réunion à Baden, Suisse du 20 au 22 mars 1996, Bericht vom 18.03.1996

[23] “Fuzzy Logic Control – Four 8 – ENCI-Maastricht”, F. Erens, ENCI Nederland B.V. October 16, 1992 DS92-111/PvD

[24] “Nordcement, Werk Hoever Entschwefelungsversuch mit Kalkhydrat”, J. Waltisberg (HMB), Bericht VA 89/5610/D

[25] Telefax, Aalborg Portland, Preben Andreasen, May 1997

7.5 CONTROL OF VOC-EMISSIONS

7.5.1 SUMMARY

The main source of VOC emissions (VOC means Volatile Organic Compounds) from cement kiln stacks is organic matter present in or attached to the raw material. A portion of this organic matter is expelled when the raw material is exposed to the heat in the kiln system. Some of the expelled organic compounds are oxidised but others leave the kiln as organic emissions. The lower the organic content of the raw material and the higher the required temperature for expulsion of the organic compounds the lower is the VOC emission from the kiln. The conditions for formation of dioxins and furans (D/F) are different from those for VOC formation. Formation (de novo synthesis) is considered to be able to occur by reactions in the gaseous phase at a temperature between 350 and 450° C in the exhaust gas system provided precursors and other components are available. D/F are never caused by the combustion process. D/F, which might be present in the fuel, are completely destroyed at the high temperatures in the kiln.

Especially in the USA, it is assumed that unfavourable raw materials (high content of organic matter in natural raw materials or in alternative materials) in combination with high chlorine content in the exhaust gas can increase the D/F emission in some kiln systems. In such cases emission concentrations above 0.1ng TE/Nm^3 (most stringent emission limit for D/F) have been observed. In contrast this kind of formation is low in European kilns, probably due to lower concentrations of precursors.

The expulsion behaviour of the organic matter in the raw materials depends, among other things, on the kiln type. The oxygen concentration in the exhaust gas of preheater kilns has only a marginal effect on the VOC emission while the oxygen concentration in long wet and long dry kilns has a very high VOC reduction potential. With increased oxygen content the VOC emissions from wet kilns are lower for the same raw material compared to preheater kilns. This finding can be explained by the higher temperature difference between raw meal and exhaust gas in the long wet and long dry kilns compared to preheater kilns.

The combustion in the burning zone produces flame temperatures of up to 2,000° C. Therefore all organic compounds that are injected through the main burner are completely oxidised (burned) and cannot contribute to VOC emissions. Secondary and precalciner firing produce temperatures between 900 and 1,100° C. Therefore, careful choice, preparation and injection of the fuels completely prevent VOC emission from secondary and precalciner firing. Since VOC emissions result from raw materials VOC emission cannot be used as an indicator for good combustion conditions in the kiln.

The VOC emission is the sum of the concentrations of all volatile organic compounds in the exhaust gas. Flame ionisation detectors (FID) are used to measure the VOC emissions. They are expressed as ppm or mg/Nm^3 methane or propane equivalents depending on which of the two gases were used for calibration of the FID.

The VOC emissions of cement kilns are typically between 10 and 100 mg/Nm^3. There are a few cases known where the VOC emission can reach as much as 500 mg/Nm^3 because of the raw material characteristics.

The emission of CO is also very strongly related to the content of organic matter in the raw material. VOCs that are expelled from the raw materials can be oxidised to CO_2 or CO. Especially in areas of the kiln where only very little O_2 and/or not very high temperatures are available the incomplete oxidation of VOC can produce CO. Due to the contribution of the organic matter in the raw materials to the CO emissions, CO emissions are not suitable as an indicator for good combustion conditions in the kiln.

To reduce the VOC emission from a pyroprocessing system to a certain controlled level, three basically different methods are available:

- Maintain the existing process while reducing the input of organic matter into the system (Chapter 7.5.3)
- Modify the existing process (primary or integrated reduction measures, Chapters 7.5.4 and 7.5.5)
- Maintain the existing process while adding a separate gas cleaning unit for the exhaust gas (secondary reduction measures, Chapter 7.5.6)

The tables below show a number of possibilities to reduce VOC emissions with efficiencies between 0 and 95%. Each reduction measure needs certain preconditions before it can be applied. In some cases it is possible to adjust the existing kiln system to allow the application of the required reduction measure. This, however, usually causes major additional investment cost.

The reduction efficiencies described hereafter are based on the reduction of VOC concentrations in the exhaust gas. Most European countries use concentration limits for the pollutants in the exhaust gas from cement plants to limit the emission impact to an acceptable degree.

The application of the primary reduction measures (Chapters 7.5.4 and 7.5.5) is limited to specific cases and very often connected to very high investment and operating cost. No compliance with any VOC emission limit can be guaranteed with primary reduction measures without exceeding reasonable investment and operating cost. Maximum VOC emissions of a specific raw material can be estimated with the help of an Expulsion Test. [10]

The only presently available secondary reduction measure, POLVITEC (see Chapter 7.5.6), can reduce VOC emissions of organic compounds larger than C_6 (C_6 = hydrocarbons with 6 carbon atoms) to below all known emission limits. Compounds smaller or equal to C_5 are not very efficiently removed. It must be mentioned that up to 80% of cement kiln VOC emission can consist of compounds equal or smaller than C_5 compounds.

Secondary emissions that are emitted during the production and transportation of adsorbents, or in generation of power used to reduce emissions are not included in this investigation.

The reduction efficiencies of the VOC reduction measures reported below can of course not be summed up to calculate the final VOC reduction capacity. Some measures cannot even be combined with others. Furthermore the reduction efficiency is always highest at highest emissions. This means that the lower the emissions the harder and more costly it is to reduce them further.

To make the information in the tables below comparable a common base was used:

• Clinker production:	3000 t/d
• Kiln type:	Preheater/Precalciner (if not indicated differently)
• Initial emission:	10 – 100 (normal) up to 500 (exceptional) mgC_3H_8eq/Nm^3
• Coal cost:	60 ECU/t
• Activated coke cost:	240 ECU/t
• Power cost:	0.04 ECU/kWh
• Amortization:	10 years
• Interest rate:	10%

Most information is retrieved from literature (see Chapter 7.5.7) and cement industry specific experience. To fit them into the common base, conversion of the relevant data was required.

7.5.2 INDEX OF DESCRIBED VOC REDUCTION MEASURES

7.5.3 REDUCTION OF ORGANIC MATTER CONTAINED IN THE RAW MATERIALS (ROC)

Depending on the geological history of the rock that is used as a raw material more or less organic matter is included in it. A portion of this organic matter is expelled after being introduced into the kiln. Some of the expelled organic compounds are oxidised, others leave the kiln as organic emissions. The lower the organic content of the raw material and the higher the required temperature for expulsion of the organic compounds the lower is the organic emission from the kiln.

A reduction of the organic matter in the natural raw material is virtually impossible.

7.5.4 ADDITION OF ORGANIC MATTER CONTAINING RAW MATERIAL COMPONENTS TO THE HOT ZONE OF THE KILN (AHZ)

If a component of the raw material that is responsible for the high emission of VOC is added directly to the hot zone of the kiln (e.g. kiln inlet) the organic compounds are burned before they can escape to the atmosphere. This is, however, only reasonable for components that represent a small portion of the raw material. The disadvantages of this addition are an increased heat consumption of the kiln, possibly additional build ups at the injection point and a less homogeneous and constant kiln feed which can lead to reduced clinker quality.

If the main portion of the raw material is responsible for the VOC emission it would be possible to add the whole raw material to a flash calciner where the sharp temperature increase destroys almost all organic compounds. To install such a flash calciner with all the additionally required equipment major investment is necessary. The heat consumption for a kiln with flash calciner is significantly higher compared to a preheater kiln.

No.	BAT Evaluation Items		Comments	Remarks
1	**Consumables**			
1.1	Materials		None	
1.2	Air		None	
1.3	Water		None	
2	**Energy Consumption**			
2.1	Thermal	[kJ/t_{cli}]	0 - 3300	1)
2.2	Electrical	[kWh/t_{cli}]	0 - 2.5	
3	**Waste Generation**			
3.1	Solids		None	
3.2	Liquids		None	
4	**Emissions**			
4.1	To air	[kg CO_2/t_{cli}] [NO_x]	200 Yes	
4.2	To water		None	
4.3	Noise		None	
4.4	Odour		None	
4.5	VOC reduction	[%]	Up to 95%	4)
5	**Impact on Product Quality**			
5.1	Cement		Reduced quality possible	See above

6	**Experience**			
6.1	Duration	[years]	5	
6.2	Number of Applications		> 1	
7	**Costs**			
7.1	Investment cost	[10^6 ECU]	Up to 25	2)
7.2	Operating cost	[ECU/t_{cli}]	Up to 8.9	1)
7.3	Total cost	[ECU/t_{cli}]	Up to 13	
8	**Conclusion on Candidate BAT**			
8.1	For existing plants and plant rehabilitations		No	1),2),3)
8.2	For new plants and major upgrades		No	1),2),3)

1) If small portions of the raw material are directly added to the hot zone the additional heat consumption will be small to negligible. If all raw material is added to a flash calciner a very high additional heat input is required which increases the operating cost.

2) If only a very small portion of the raw material has to be added directly to the hot zone of the kiln the additional investment cost may be low. If a flash calciner must be built the costs are very high.

3) AHZ is considered candidate BAT if only small portions of the raw materials would have to be added to the hot zone.

4) The maximum VOC reduction efficiency is not a guaranteed efficiency for applications on any kiln but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on an initial VOC emission of about 100 mg/Nm^3.

7.5.5 INCREASED OXYGEN CONCENTRATION AT THE KILN INLET OF LONG WET OR LONG DRY KILNS (IOC)

An increase of the oxygen concentration can significantly reduce the organic emission from the raw materials in long wet and long dry kilns. It is assumed that the large temperature difference between raw meal and exhaust gas at the point of release of the organic compounds is responsible for the emission reduction. An increase of the oxygen concentration always causes an increase of the heat consumption and the CO_2 and NO_x emission, and a reduction of the maximum production capacity.

No.	BAT Evaluation Items		Comments	Remarks
1	**Consumables**			
1.1	Materials		None	
1.2	Air		Yes	
1.3	Water		None	
2	**Energy Consumption**			
2.1	Thermal	[MJ/t_{cli}]	50 - 60	
2.2	Electrical	[kW/t_{cli}]	0.1 - 0.2	
3	**Waste Generation**			
3.1	Solids		None	
3.2	Liquids		None	
4	**Emissions**			
4.1	To air		CO_2, NO_x	
4.2	To water		None	
4.3	Noise		None	
4.4	Odour		None	
4.5	VOC reduction	[%]	Up to 40 [1]	1)
5	**Impact on Product Quality**			
5.1	Cement		None	
6	**Experience**			
6.1	Duration	[years]	> 10	
6.2	Number of applications		> 10	
7	**Costs**			
7.1	Investment cost	[10^6 ECU]	0	2)
7.2	Operating cost	[ECU/t_{cli}]	0.13 - 0.15 0 - 1.2	3),4) 5)
7.3	Total cost	[ECU/t_{cli}]	0.13 - 1.4	
8	**Conclusion on Candidate BAT**			
8.1	For existing plants and plant rehabilitations		Yes	
8.2	For new plants and major upgrades		N.A.	

1) The maximum VOC reduction efficiency is not a guaranteed efficiency for applications on any kiln but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on an initial VOC emission of about 100 mg/Nm^3.
2) Additional equipment is not required.
3) Example for an increase of the oxygen concentration from 1.2 to 2.3%.
4) Cost of additional heat consumption.
5) Because of the additional excess air (excess oxygen) the production rate is reduced. If the market is such that all cement can be sold, the production loss is estimated to be 0.2 ECU/t_{cli} per % production reduction.

7.5.6 ADSORPTION ON ACTIVATED COKE, POLVITEC (AAC)

The POLVITEC consists of several packed beds of activated coke. The dedusted kiln exhaust gas is passed across the activated coke where compounds like VOC, SO_2 and NH_3 are adsorbed. The cleaned gas is then released to the atmosphere. The used activated coke is periodically extracted to a separate silo and replaced with fresh adsorbent. From the used coke silo the coke is fed to the kiln together with other fuels where the adsorbed VOCs are burned. Due to the character of the activated coke only organic compounds larger than C_5 are adsorbed with a high efficiency.

Adsorption on activated coke is too expensive. In the case of the Polvitec installed in a Swiss cement plant only the financial contribution of the communities burning their sewage sludge in the kiln, the fees for burning other alternative fuels in the kiln and the complex problem with different emission components made the project ecologically and economically feasible.

7.5.7 BIBLIOGRAPHY

Some of the references are internal documents which are not readily available.

[1] “Expulsion Test Conversion of the Result of an Expulsion Test into Emission Values of a Cement plant”, P. Kutschera/HMC, Report PT97/14225/E dated 28.02.1997

[2] “Groupe de Travail ATILH: Meilleures Techniques Disponibles – Composés organiques volatils – Dioxines et furanes”, J-B Desrumaux, février 1997, version no. 3

[3] “Effektive Emissionsminderung bei Einsatz von Sekundärstoffen im schweizerischen Zementwerk Siggenthal”, D. Rose und L. Brentrup, Beckum/Deutschland, Zement-Kalk-Gips 48. Jahrgang (1995) Heft Nr. 4

[4] “Visite de l’installation Polvitec à l’usine HCB Siggenthal”, HMB/CEA Th. Lang, CETIC Sous-Commission “Environnement“, 18.03.1996

[5] “Waste Co-Processing in Industry – Criteria for optimal waste management in the Cement industry”, J.P. Degré, Ciments d’Obourg SA, November 1996

[6] “Environmental Technology for Cement Plants”, F.L.S. F.L.Smidth

[7] “Study on Wet Kiln Emission Behaviour”, Step 1, Executive Summaries of Literature available at HMC as per May 1994

[8] “Sources and Reduction of VOC-Emissions”, J. Waltisberg, “Holderbank“ Manual on Environment, Report No. VA 95/4330/E

[9] “Raw materials, the main cause of the emission of organic matter”, J. Waltisberg/HMC, 33rd Technical Meeting/10th Aggregates and Ready-Mixed Concrete Conference March 1994 – Basel, Switzerland, MA 94/3147/E

[10] Developed at “Holderbank” Management and Consulting, contact person: J. Waltisberg, Technische Forschungs- und Beratungsstelle der Schweizerischen Zementindustrie, Lindenstr. 10, CH-5103

7.6 CONTROL OF HEAVY METAL EMISSIONS

7.6.1 INTRODUCTORY REMARKS

All metals heavier than Titanium (4.51 g/cm^3) are considered as heavy metals(HM).The heavy metals make up a small but definite proportion of the materials in the Earth's crust like soil, rock, fuels (e.g. carbon) etc. Not all heavy metals are toxic and not all toxic heavy metals have the same toxicity. Therefore some countries differentiate between different toxicity classes: (e.g. TA-Luft, Germany)

- Class I: Cd, Hg, Tl
- Class II: As, Co, Ni, Se, Te
- Class III: Pb, Cr, Cu, Pt, V, Sn, Pd, Sb, Mn, Rh

The HM in class I are the most, the HM in class III the least toxic heavy metals.

The main sources of heavy metal (HM) emissions from cement kiln stacks are raw materials and fuels containing heavy metals. Regarding the behaviour of the HM in the kiln system three classes can be distinguished.

The *non or low volatile HM* (As, Be, Co, Cr, Cu, Mn, Mo, Sb, Se, Te, V, Zn) are incorporated in the clinker to almost 100% and therefore do practically not appear as emissions. As a general rule the sum of the emissions of all non-volatile HM of a preheater kiln is always much below 0.1% of the corresponding metal input.

The semi-volatile HM such as Tl, Pb, and Cd are not completely (Pb, Cd) to very little (Tl) incorporated directly in the clinker. The remaining part which is not incorporated in the clinker is almost completely adsorbed on the surface of the dust particles in the kiln exhaust gas system. Kiln filters like electrostatic precipitators and bag filters can therefore efficiently remove the semi-volatile HM from the exhaust gas. The dust collected in the filter is usually reintroduced into the kiln which leads to an internal accumulation of these HM in the kiln system. To eliminate the semi-volatile elements from the kiln system a portion of the dust collected in the kiln filter is extracted and fed to the cement mills.

Volatile HM cannot be efficiently controlled by dedusting of the kiln exhaust gas because a portion of the volatile HM always remains volatile (not attached to dust particles). The most prominent and only example of relevance to the cement industry is mercury (Hg). Hg is suspected to be emitted to a large degree in vaporous form. The lower the exhaust gas temperature is at the filter inlet the higher is the proportion of Hg attached to dust particles that can be removed from the exhaust gas.

Unlike preheater kilns, long wet and long dry kilns have been studied less in their heavy metal emission behaviour. From the basic principle and from the higher stack gas temperatures one could expect a less favourable situation but the practical evidence is incomplete. In fact the only data that are available contradict the assumption that long wet kilns are less favourable regarding HM scrubbing compared to preheater kilns.

The HM emissions of cement kilns are usually significantly below a total of 0.5 mg/Nm^3 and therefore in compliance with most regulations.

To reduce the HM emission from a pyroprocessing system to a certain controlled level, three basically different methods are available:

- Maintain the existing process while reducing the input of HM into the system
- Modify the existing process (primary or integrated reduction measures)
- Maintain the existing process while adding a separate gas cleaning unit for the exhaust gas (secondary reduction measures)

Each reduction measure needs certain preconditions before it can be applied. In some cases it is possible to adjust the existing kiln system to allow the application of the required reduction measure. This, however, usually causes major additional investment cost.

The most common HM emission reduction measures are reduction of HM input and efficient dedusting. To avoid accumulation of HM in the kiln system a portion of the filter dust should continuously or periodically be extracted from the dedusting system. Additional secondary reduction measures like the adsorption on activated coke are only required if the content of the volatile HM (e.g. Hg) is very high.

The reduction efficiencies of the HM reduction measures reported below can of course not be summed up to calculate the final HM reduction capacity. Some measures cannot even be combined with others. Furthermore the reduction efficiency is always highest at highest emissions. This means that the lower the emission are the harder and more costly is it to reduce them further.

Most information is retrieved from literature (see Chapter 7.6.6) and cement industry specific experience. To fit them into the common base, conversion of the relevant data was required.

7.6.2 INDEX OF DESCRIBED HM REDUCTION MEASURES

7.6.3 REDUCTION OF HEAVY METALS IN THE RAW MATERIALS AND FUELS (RMR)

Heavy metals (HM) are naturally contained in the cement raw materials. The non-volatile heavy metals reach the dedusting unit incorporated in natural concentrations in the dust particles. The semi-volatile and volatile HM can reach the dedusting equipment either in the same form as above, bound to the dust (e.g.Tl) or as vapour (e.g. Hg). The higher the content of the volatile HM in the raw material and the fuels the higher is usually the emission of these HM but at a generally low level.

A reduction of the semi-volatile and volatile HM in the raw materials and fuels is virtually impossible. However, the use of waste materials or alternative fuels excessively enriched in HM to replace regular raw materials and fuels should be avoided.

7.6.4 HIGH EFFICIENCY DEDUSTING (HED)

Portions of some of the semi-volatile heavy metals (HM) and much of the volatile HM mercury leave the kiln attached to the surface of the emitted dust particles. The dust emission reduction efficiency is therefore very important for the HM emission reduction. High dedusting efficiencies can be achieved with electrostatic precipitators (EP) and bag filters (BF). Especially existing EPs can be optimised with various measures starting with exhaust gas conditioning and ending with enlargement or replacement of the filter. (See also Chapter 7.2)

7.6.5 ADSORPTION ON ACTIVATED COKE, POLVITEC (AAC)

The POLVITEC consists of several packed beds of activated coke. The dedusted kiln exhaust gas is passed across the activated coke where compounds like HM, VOC, SO_2 and NH_3 are adsorbed. The cleaned gas is then released to the atmosphere. The used activated coke is periodically extracted to a separate silo and replaced with fresh adsorbent. From the used coke silo the coke is fed to the kiln together with other fuels where the adsorbed HM are integrated in the clinker or again emitted from the kiln system. If volatile or semi-volatile compounds are enriched in the system between kiln and adsorber the HM should be removed from the system by extracting a small portion of the dust collected in the kiln dust filter and by feeding it to the cement mill.

Since volatile and semi-volatile HM are effectively adsorbed on activated coke and since the clean gas dust content downstream of the AAC device is down to a few mg/Nm^3 the emission of HM is practically zero.

Adsorption on activated coke is too expensive. In the case of the Polvitec installed in a Swiss cement plant only the financial contribution of the communities burning their sewage sludge in the kiln, the fees for burning other alternative fuels in the kiln and the complex problem with different emission components made the project ecologically and economically feasible.

7.6.6 BIBLIOGRAPHY

Some of the references are internal documents which are not readily available.

[1] “Low Emission Cement Kiln Study: Heavy Metals”, A. Obrist, Report N° PT 95/4397/E

[2] “Sources and Reduction of HM-Emissions”, “Holderbank“ Manual on Environment, Dr. I. Jmlach, Report N° MA 95/3389/E

[3] “Thermische Reststoffentsorgung im Zementwerk – ein Vergleich mit anderen Verfahren der Abfallbehandlung”, W. Kreft, Ennigerloh/Deutschland, Zement-Kalk-Gips-Nr. 1/1995 (48. Jahrgang)

[4] “Emissionen beim Einsatz von Reststoffen in Drehrohröfen der Zementindustrie”, Hans-Dieter Winkler, Aus der Tätigkeit der LIS 1991. Essen 1992

[5] “Heavy metal balances for a cement kiln plant with grate preheater”, W. Weisweiler and W. Krêmer, Institute for Industrial Chemistry, Karlsruhe University, Zement-Kalk-Gips N° 5/1990 (Translation of N° 3/90)

[6] “Zur Problematik gasförmiger Quecksilber-Emissionen aus Zementwerken”, W. Weisweiler und A. Keller, Institut für Chemische Technik der Universität Karlsruhe
Zement-Kalk-Gips – Nr. 10/1992 (45. Jahrgang)

[7] “Selected trace metals in cement & kiln dust”, The Portland Cement Association, USA, International Cement Review

[8] “Measurement of Gaseous and Particulate Emissions from a Cement Process at Blue Circle, Cauldon Works”, CRE Technical Services Report N° 553343, 26 November 1993

[9] “Behaviour of Toxic Elements in Cement Kilns”, A. Iskraut, Report N° VA 87/5423/E, Technical Meeting Bern, 1987

[10] “Energetische Verwertung nach KrW- / AbfG – ein Ausblick”, Uwe Lahl, Barbara Zeschmar-Lahl, Oyten, Umwelt Bd. 27 (1997), Nr. 3 – März

[11] “Visite de l’installation Polvitec à l’usine HCB Siggenthal”, CETIC Sous-Commission “Environnement“, HMB/CEA Th. Lang, 18.03.1996

[12] “Effektive Emissionsminderung bei Einsatz von Sekundärstoffen im schweizerischen Zementwerk Siggenthal”, D. Rose und L. Brentrup, Beckum/Deutschland, Zement-Kalk-Gips 48. Jahrgang (1995), Heft 4, Seite 204-214

[13] “Sprung S., Technologische Probleme beim Brennen des Zementklinkers, Ursache und Lösung, Kap.7”, Schriftenreihe der Zementindustrie, Heft 43/1982, Beton-Verlag, Düsseldorf

[14] “Klärschlammstudie Teil5: Bestimmung von Emissionswerten und Produktqualität bei Klärschlammverbrennung”, A. Obrist, VA 95/5170/D

[15] “Quecksilberemissionen in der Zementindustrie Ergebnisse bisheriger Untersuchungen / Literaturstudien”, A. Obrist, A. Iskraut, VA 85/09/85/D

[16] “Zur Problematik gasförmiger Quecksilber-Emissionen aus Zementwerken”, W. Weisweiler, A. Keller, Zement-Kalk-Gips Nr. 10/1992

[17] “Comportement des métaux lourds dans les fours d’Obourg”, J.P. Degré, Obourg-Bericht JPD/ID/94.471, 23.08.94

7.7 CONTROL OF FUGITIVE DUST EMISSIONS

7.7.1 INTRODUCTORY REMARKS

Fugitive emission sources are mainly related to:

- ❑ storage of raw materials and clinker;
- ❑ handling of raw materials and clinker;
- ❑ vehicle traffic at the manufacturing site.

For new installations the prevention of fugitive dusts emissions is an essential element of the project, which has to be built with the aim of minimising any possible source of fugitive dust. From this point of view simple and linear lay-out is the best. For existing installations the reduction of fugitive dust is not always possible or easy to achieve through simple methods and major modifications of plant lay-out are often required. Proper and complete maintenance of the installation has always the indirect result of reducing fugitive dust, through the reduction of air leakage and spillage points. The use of automatic devices and control systems also helps in fugitive dust reduction, as well as continuous trouble-free operations.

7.7.2 AVAILABLE TECHNIQUES FOR FUGITIVE DUST ABATEMENT

According to the different dust generation mechanisms we consider the following control measures:

- ❑ open piles wind protection;
- ❑ water spray and chemical dust suppressors;
- ❑ paving, road wetting and housekeeping;
- ❑ mobile and stationary vacuum cleaning equipment;
- ❑ ventilation and collection in fabric filters;
- ❑ closed storage with automatic handling system.

Open Piles and Wind Protection

Granted that storage piles of dusty materials placed in a temporary outdoor location should be avoided, it is possible to reduce fugitive dust emissions from open piles using properly designed wind barriers.

These are essentially natural or artificial obstacles behind which the storage pile can be hidden to reduce the force of wind and its erosion effect. The barrier can be completed with rows of evergreen trees.

This control measure can be improved if it is coupled with particular precautions taken during pile formation, such as lowering the height of pile, compressing the surface, using wetting agents.

Water Spray and Chemical Dust Suppressors

Some operations such as truck dumping, or material transfer from a conveying system to another one or to a pile in a store may produce fugitive dust to varying extent. When the point where the dust comes from is well localised a water spray injection system can be installed.

The humidification of dust particles through the contact with fine water droplets aids agglomeration and so helps dust to settle.

A wide variety of chemical agents is also available to improve the overall efficiency of the water spray, with production of dilute solutions or foams.

The positive effect of water spray is strongly affected by good positioning of spray nozzles, to be placed as close as possible to dust source; liquid flow rate should also be controlled at minimum level.

Paving, Road Wetting and Housekeeping

The aim is evidently to prevent settled dust being transformed to suspended particulate matter. Areas likely to be used by lorries should be paved when possible and the surface should be maintained as clean as possible. Specific lanes must be indicated and vehicle speed limited. Wetting the roads can be considered to reduce dust emissions especially in dry season.

In conjunction with these measures good housekeeping practices should be used in order to avoid fugitive dust emissions as far as possible.

Mobile and Stationary Vacuum Cleaning

During maintenance operations or in the case of trouble with conveying systems, spillage of materials can take place. To prevent the formation of fugitive dust during removal operations, vacuum systems should be used. A high pressure fan, connected with a bag filter, maintains high negative pressure in a pipe network, with inlets to branch pipes being fitted with valves. By opening the appropriate valve it is possible to suck up dust and even aggregates, which are finally collected in a bag filter.

New buildings can be easily equipped with this kind of system, while existing buildings are normally better fitted with mobile systems and flexible connections.

The material recovered during a cleaning operation can be recycled in the process.

This equipment reduces a lot of heavy manual operations.

Ventilation and Collection in Fabric Filters

To keep in closed conveying systems, or bins or silos, all the materials handled within the process is a primary measure to be coupled with systems able to maintain them under negative pressure.

The suction air for this purpose must be then dedusted by a fabric filter before being emitted into the atmosphere.

Best practical engineering design should be applied to optimise the efficiency of this control technique, common to many industrial sectors, in order to reduce air leakage, energy loss and the volume of air to be dedusted.

A fabric filter of the jet pulse cleaning type fits this kind of application very well due to its flexibility in flow rate (0.5 to 10 m^3/s or more); in dust burden (few mg/m^3 to hundreds g/m^3), in quality of available fabric and in its geometrical arrangement and dimensions. These characteristics make this kind of filter suitable even for mobile installations, such as stacker and reclaimer systems. For normal operation at ambient temperature polyester or acrylic fabric should be used; when wet materials are handled specific humidity resistant fabrics are available, as well as heat resistant fabrics when hot materials, such as clinker, are treated.

Care must be given to the collected dust discharge design or conveying systems. The dust has to be returned to a point just after the dedusted zone along the conveying system, to avoid dust recycling.

Closed Storage with Automatic Handling System

Clinker silos and fully automated raw material storage are considered today the most efficient solution to solve the problem of fugitive dust generated by high volume stocks.

Plenty of different technical solutions have been developed to deal with specific characteristics of almost every kind of material, from very wet and sticky clays to dry and dusty sands.

Closed fully automated stores for raw material are more complex because, generally, they must handle many different raw materials, possibly providing for prehomogeneisation of them or between them.

While clinker silos can be fitted in existing plants when enough room is available, the same is not generally possible for automated raw material storage, because the whole lay-out of the plant may need to be greatly modified.

These types of storage are equipped with one or more fabric filters to prevent fugitive dust formation in loading and unloading operations.

7.8 CONTROL OF NOISE EMISSIONS

7.8.1 INTRODUCTORY REMARKS

Any operations concerning cement production must be performed having regard to the relevant objectives of any prevailing regulations which include noise control.

Noise reduction is claimed to be a growing challenge for cement manufacturing in the future, maybe not because of the hi-tech demands for existing plants but certainly because of the high investment costs and difficulties faced in carrying out major modifications.

Differently from airborne emissions the evaluation of the noise to the environment depends very much on the immediate neighbourhood of a plant. Thus noise reduction measures have to be discussed site specifically taking into account e.g. the noise impacts to the nearest residential area.

In practice, the best noise reduction techniques, in the majority of cases, can be adopted only in new plants. This points out the relevancy of good acoustic design, starting from the preliminary study of plant lay-out, and the right choice of machinery: the most effective noise reduction is made at source.

In existing plants, solutions depend on space availability, conditions of previous structures and even architectural considerations.

BAT listed below should be adopted to attain the above mentioned objectives. Efficiency is based on the reduction of noise in dB.

Air-flow generated noise, machine generated noise and residual noise escaping from buildings are outlined as the three major types of noise source.

7.8.2 AIR-FLOW GENERATED NOISE

This applies to stack, fan inlet/outlet or air intake and ventilation units. Generally, air flowing in a duct, pipe or stack generates noise whose sound power level depends on cross section, flow contours and speed. Flow speed higher than 15-20 m/s generates itself a noise which has to be reduced. If a fan or compressor adds its mechanical contribution the sound power level get louder and is characterised with the typical frequency spectrum of the machine, depending on its performance in pressure and flow.

Primary measures to control noise at source, such as good sizing of inlet/outlet ducts to reduce speed, or modification of existing machines (e.g. fan with aerofoil blades and low rpm), can be only moderately effective. Installation of silencers may be the only available technology for the reduction of air-flow generated noise. Silencers must be installed as close as possible to the noise source and as far as possible from the noise outlet, having regard to maintaining air speed after the reduction device.

Silencers can be mainly of three types: simple **lining of ducts** with deadening materials as rockwool or glasswool, **parallel baffles silencers and "plenum" silencers**. **Mufflers** used for the inlet/outlet of compressors are normally designed specifically by machine suppliers. Simple linings with deadening materials are suitable for many purposes and cause very low pressure drop, but require, with an average reduction efficiency of 1 – 2 dB/m, installation over a considerable length. Parallel baffles silencers are suitable for ducts with flow rates up to 250,000 m³/h with an average reduction efficiency of 10 – 15 dB/m, but for high flow rate could cause rather high pressure drop (40 – 60 mmWG). In any case for very high flow rate "plenum" silencers (a series of expansion chambers lined with deadening materials) are preferable, because of high noise reduction efficiency and very low pressure drop (max. 20 mmWG), but they have higher investment costs.

7.8.3 MACHINE GENERATED NOISE

This regards mainly process machines (crushers, grinding mills), fan casings, motors/couplings and compressors. Compressors are normally coupled with an insulating box designed specifically by machine suppliers.

Otherwise noise can, in some cases, be reduced primarily by choosing a less noisy machine. In some other cases noise can be reduced by **insulating the machine** with soundproof materials or enclosing the machine inside a **soundproof box**. In any case it is necessary to provide a proper cooling device, which must be sound-insulated too, in order to dissipate heat.

Insulating materials used are multilayer rockwool (up to 120 kg/m³) or glasswool (up to 80 kg/m³) boards (up to 120 mm) combined, for heavy duty fans, with a lead plate (1 – 2 mm).

7.8.4 NOISE ESCAPING FROM BUILDINGS

When the above mentioned insulation measures are not possible, because of space availability or plant lay-out, or do not work well enough, the only solution is to enclose the machine in a building or to create curtain walls to reduce sound propagation. Also in this case it may be necessary to install a cooling device, which must be sound-insulated too, in order to dissipate heat. For these cooling devices, the same precautions adopted for air inlet/outlet should be utilised.

Many kind of materials can be used to build curtain walls, with a common recommendation being to avoid solid transmission of vibrations from machinery to the floor or to the structure of the building. If this happens, the whole façade could be made to vibrate as a loudspeaker membrane, generating rather low frequency sound levels but very high sound power levels taking into account the total vibrating surface.

The sound-proofing efficiency of a curtain depends proportionally on its specific mass (kg/m^3) and sound frequency. Thus efficiency seems to be higher for high frequency, but every material has its own critical frequency, where efficiency drops because of its intrinsic rigidity.

Concrete blocks or hollow bricks, because of their rigidity, give best noise reduction beyond an overall thickness of 200 mm (150 kg/m^2).

Prefab concrete, for the same reason, must preferably be thicker than 80 mm (175 kg/m^2).

Windows must be made of 30 kg/m^2 laminated glass, two glass sheets (7 and 3 mm) joined by a plastic layer (1 mm).

"**Sandwich boards**" made of metal plates/rockwool (glasswool), dimensioned depending on required noise reduction, can be sound proofing (25 – 50 kg/m^2) and deadening (25 kg/m^2 with an internal 40% perforated iron plate).

Main doors and gates must be considered as "sandwich boards", taking care of sealing.

7.9 REDUCTION OF ODOURS

7.9.1 INTRODUCTORY REMARKS

To eliminate misunderstanding, odour should be used to define either the perception of smell or that which is smelled and odorant should be defined as any odorous substances. Odour intensity, then, is the magnitude of the olfactory sensation produced on exposure to an odorant. Odour control is a term that can be used to describe any process that makes olfactory experiences more acceptable to people. The perceptual route to this objective is usually, but not always, the reduction of odour intensity.

When, referring to a cement plant operation, the reduction of odour intensity is accomplished by removal of odorants from the atmosphere, the process is equivalent to gas, vapour and even particles abatement, but with some special considerations. These include problems related to the need to attain very low concentration, often approaching threshold levels, uncertainties with regard to the reliability of sensory or chemical analysis and difficulties associated with diffuse or sporadic sources.

The olfactory identification of an odorant is based on two parameters: the odour detection threshold and the odour index.

Odour detection threshold is defined as the odorant concentration which is detected as often as not over a series of presentations. 50% and 100% occurrence of recognition of an odorant give respectively the 50% and 100% detection threshold, which are the two parameters normally available in literature.

Odour index takes into account also the evaporation as a ratio between vapour pressure and 100% detection threshold of odorant.

In general gases and vapours are odorous. The relatively few odourless or practically odourless exceptions include 0_2, N_2, H_2, H_2O, H_2O_2, CO, CO_2, CH_4, NO and the noble gases. Odours can be also associated with airborne particulate matter, as some particles can stimulate the sense of smell because the particles themselves are volatile or because they are desorbing a volatile odorant.

7.9.2 STACK EMISSIONS

Odorous chemicals released by a cement plant are mainly SO_2 and, at a lower level, NH_3 and organics, all with a 50 – 100% detection threshold window ranging from 100 ppt to 10 ppm.

7.9.3 DIFFUSE EMISSIONS

The problem of diffuse odorous emissions is related mainly to fuel unloading and stocking facilities.

Good management of unloading operations and storage purging is required. Careful maintenance of fuel distribution network helps to avoid spillage and related odours.

7.10 REDUCTION OF VIBRATION

7.10.1 INTRODUCTORY REMARKS

Recent years have seen the rise of vibration problems associated with structures which are more delicate and intricate, and machines which are faster and more complex. The problems have been coupled with demands for lower running costs and increased efficiency. Moreover vibrations now stand out as potential source of nuisance outside as well as inside the industrial site.

Vibration intensity is measured as speed (m/s) or acceleration (m/s^2).

Actually few national regulations set up standards for vibration of structures or for maximum vibrations nuisance to people. Solid transmission of vibrations from machinery to the floor or to the structure of industrial building is rather seen as a potential source of noise as shown in Chapter 7.8. Examples of potential causes of vibration are roller mill vibration or clinker silo vibration.

7.10.2 ROLLER MILLS VIBRATIONS

All machines characterised by high rotation speed and mechanical stress of structure potentially generate vibrations. Good practice is to install them on vibration-dampening mounts and a concrete foundation. If this measure does not work correctly it may be necessary, involving great investment, to isolate the foundation of the machine in order to avoid transmission of vibration to the rest of structure and to let it vibrate independently. These are actually the available technologies.

7.10.3 CLINKER SILOS VIBRATIONS

Clinker silo vibration, a very rare event, is avoidable or at least reducible through correct sizing of structure, control of clinker constancy of quality and temperature, good distribution and a number of extraction hoppers.

7.11 CONTROL OF RELEASES TO SURFACE WATERS

7.11.1 INTRODUCTORY REMARKS

Cement production does not normally involve significant quantities of liquid wastes, surplus water usually being limited to surface run off and process/cooling water only. However process waters, site drainage waters, emergency fire water and chemically contaminated waters should, where appropriate, be contained and where necessary treated before release to controlled waters or sewer.

7.11.2 PROCESS WATERS

Waters used in the process to make up slurry or granulated meal and to operate spray conditioning towers are completely evaporated and then emitted at the stack.

7.11.3 COOLING WATERS

Mechanical cooling waters are recycled after use and, if necessary, restored. This closed system, if not yet operating, is quite easy to set up also in existing plants. However cooling water should be recycled within the process from which it issues. Where that is not practicable, it should be recycled to another part of the process which has a lower water quality requirement.

7.11.4 LABORATORY WATER RELEASE

Water released from the site chemical laboratory may be contaminated by chemicals such as acids or alkalis. It should be treated at least in a neutralisation tank, in order to control the resultant pH. It is to be said that the water consumption of a chemical laboratory is more or less 10 – 20 m^3/day and is continuously being reduced because of substitution of the traditional chemical analysis methods with physical methods.

7.11.5. STORM WATER

Rainwater should be collected and subsequently treated every time it does not fall directly on the soil. These waters may be, because of spillage of fuels, motor oils and because of vehicle traffic which generates fugitive dust, contaminated by oils, greases, fuels or simply suspended particles. Good housekeeping of pavements is the first method to control pollution.

Moreover, settling and/or oil removal tanks may be installed before the release to water. The size of these devices should be specified carefully in order to handle the most likely emergencies.

Also areas where spillages are most likely, such as storage tanks, should be bunded. Rainwater collected should not be disposed of via surface water drains or soakaways and the composition of any wastes collected should be checked prior to treatment or disposal. Bunds should:

- be impermeable;
- have no outlet;
- drain to a sump;
- be designed to catch leaks from any likely failure of tank or its fittings;
- be hydraulically tested on initial construction and subsequently where there is any doubt about their integrity;
- have a suitable capacity related to the tank;
- where not frequently inspected, fitted with a high level probe and appropriate alarm;
- have the fill points within the bund where possible.

7.11.6 SEWER DISCHARGE

Sewer discharge from office or industrial facilities activities should be treated as any other sewer discharge from residential buildings.

CHAPTER 8

CLUSTERS OF BATs FOR CONTROLLING EMISSIONS

8.1 SELECTION OF BATS FOR CONTROLLING EMISSIONS

8.1.1 INTRODUCTORY REMARKS

The attached Tables summarise the leading information from the BAT evaluation tables in Chapter 7 on the available techniques for controlling emissions of dust, NO_x and SO_2.

Best Available Techniques can be selected which may be of broadly equal applicability on a new installation for the abatement of the different potential pollutants. For this purpose a new installation is assumed to be a modern dry process kiln of large capacity. Selection of a particular BAT from the clusters of BATs will require evaluation of the factors relevant to a particular case.

Many BATs are only suitable for dry preheater process plants and, where appropriate, references are made to long dry or wet kilns.

High dust emissions, before abatement, are inherent in the process. So too are NO_x emissions but these can also be influenced by the plant equipment used and the way the plant is operated. The potential for emissions of SO_2, VOC and dust is primarily dependent on the nature of the raw materials.

Assessment of BAT for existing plants is more complex than for new plants because of the greater variety in the processes and equipment designs in use, space and layout restrictions, etc., as well as the nature of the raw materials. These factors can have a very marked effect on the costs of applying abatement techniques and so the ‘ availability’ of a BAT is affected. This means that a wider range of BATs needs to be available and evaluated for each case. It also means that it will often not be economically viable to achieve the emission standards that can be achieved with a new plant.

When evaluating alternative investments at an existing plant, it is important that the remaining economic value of existing pollution equipment is added to the investment cost, if the existing pollution control equipment to be replaced is still efficiently operable.

Emissions from cement manufacture essentially have no cross-media impact as there are rarely significant emissions to land or water. Abatement techniques for emissions to air can be interlinked in two main respects. Control of kiln burning to minimise SO_2 emission can increase NO_x formation, and vice versa, so an operating balance has to be struck. Secondly some techniques may abate more than one type of emission.

The degree of abatement achievable, particularly for primary reduction measures, is not accurately predictable.

In the attached Tables distinction is made between new kilns (and major upgrades) and existing kilns (and rehabilitation). The distinction is made on economic grounds. Existing plants are not excluded from operating already installed techniques or from installing the techniques if the techniques are economically viable at the particular site.

8.1.2 BAT CLUSTERS

Dust (Table 8.1)

Electrostatic precipitators (EPs) and bag filters (BFs) are BAT for dust emissions from both kilns and clinker coolers.

For cement mills, efficiently operable EPs continue to be used. When they have to be replaced, as when new abatement equipment has to be built, bag filters are BAT.

Costs preclude bag filters from being installed for kilns and coolers of existing installations if electrostatic precipitators are already fitted.

Generally the environment will be well protected by an emission level of 50 mg/Nm^3.

NO_x (Table 8.2)

For new kilns one cluster of BATs may be identified as:

- ☐ optimisation of clinker burning process (OCBP);
- ☐ expert system for kiln operation (ES);
- ☐ low NO_x burner (LNB);
- ☐ multi-stage combustion in pre-calciners (dry kilns only) (MSCI);
- ☐ add water to flame or fuel to kiln (AWFF);
- ☐ selective non-catalytic reduction (dry process) (SNCR).

SNCR is distinguished by relatively limited operational experience but abatement efficiency can be quite high. AWFF may enable the use of alternative fuels to reduce NO_x.

OCBP can also contribute to SO_2 reduction.

For new kilns an emission level of 500 mg/Nm^3 (long term average) should be achievable and many of the existing dry kilns probably would emit less than 1,200 mg/Nm^3 (long term average).

Table 8.1 – Control of Dust Emissions from Major Point Sources – Chapter 7.2

Technique	Duty	BAT	Reduction Potential	Costs		Experience		Notes
			%	investment 10^6 ECU	operating (total) ECU/t	years	number	
Electrostatic precipitator (EP)	Kiln	√	Up to 99.99	2.1-4.6	0.4-0.8	> 30	> 100	The very great increase in costs of techniques to achieve, on a continuous basis, emissions below 50 mg/Nm^3 does not qualify such techniques as BAT as maximum ground level concentrations at an emission of 50 mg/Nm^3 will normally have a negligible effect on air quality.
	Clinker grate cooler	√	Up to 99.9	0.8-1.2	0.2-0.4	> 10	> 100	
	Cement mill	[1]						
Bag filter (BF)	Kiln	[2]	Up to 99.99	2.1-4.3	0.5-0.9	> 30	> 100	
	Clinker grate cooler	[2]	Up to 99.9	1.0-1.4	0.3-0.4	> 10	> 50	
	Cement mill	√	Up to 99.99	0.3-0.5	0.1	> 30	> 100	

Notes:

[1] For cement mills EPs are not regarded as BAT on new installations because of relativity high emissions at startup / shut down.

[2] For kilns and coolers, costs preclude consideration of BFs for existing installation if EP is already fitted.

Table 8.2 – Control of NO_X Emissions – Chapter 7.3

Technique	BAT	Reduction Potential	Costs		Experience		Notes
		%	investment 10^6 ECU	operating (total) ECU/t	years	number	
1. Optimise clinker burning process (OCBP)	√	0-20	0-5	-	many	many	should be considered to gain operational and cost benefit and may additionally bring NO_x benefit – but investment costs are very site specific and can preclude adoption
2. Expert system for kiln operation (ES)	√	up to 30	0.3-2.5	0.1-0.5	> 10	> 50	application of expert system is a further extension of optimising burning process
3. Low NO_X burner (LNB)	√	0-30	0.2-0.8	0-0.2	> 10	> 100	1. fuel savings may be obtained 2. depending on existing system, investment cost may be very high 3. NO_x benefit very variable
4. Add water to flame or fuel to kiln (AWFF)	√	10-50	0-0.2	0-0.5	> 5	> 3	1. increased operating costs, and can cause operating problems and capacity reduction 2. optimum results when combined with alternative fuels or the use of waste water with organics
5. Multi-stage combustion in precalciners (MSCI)	[1]	10-50	1-4	0.2-0.7	> 5	> 20	only applicable to cyclone preheater kilns
6. Selective non-catalytic reduction – preheater/ calciners (SNCR)	√	up to 65	0.5-1.5	0.4-0.8	> 5	> 3	1. only ammonia water considered here as experience and costs do not favour bio solids and urea 2. suitable temperature/time conditions needed 3. only reduces kiln NO_x – ammonia emission possibility

Notes:

Both reduction potential and (particularly for an existing process) costs are very uncertain so abatement possibilities have to be assessed on a case by case basis. The uncertainties, and therefore risk, are greater for techniques with more limited available experience.

[1] MSCI is not a candidate BAT for existing kilns unless already fitted with a precalciner suitable for conversion and a grate cooler.

SO$_2$ (Table 8.3)

The following techniques form a BAT cluster:

- optimise clinker burner process (OCBP);
- slaked lime addition to kiln feed (dry process) (SLKF).

Experience of SLKF is relatively limited but these two techniques have relatively modest costs and their maximum reduction potential is significant.

For a new dry process kiln an emission level of 500 mg/Nm^3 should be attainable as a long term average unless the raw material is high in sulphur occurring as sulphides. In such a case there needs to be special dispensation on the emissions if secondary reduction methods are not available – for instance due to high cost penalties.

Table 8.3 – Control of SO_2 Emissions – Chapter 7.4

Technique	BAT	Reduction Potential	Costs		Experience		Notes
		%	investment 10^6 ECU	operating (total) ECU/t	years	number	
1. Optimise clinker burning process (OCBP)	√	0-50	0-5	0-0.8	many	many	1. reduction potential significant for long wet/dry kilns, not for preheater kilns 2. technique should be considered to reduce operational costs as well as SO_2 3. may increase NO_x.
2. Slaked lime addition to kiln feed (SLKF)	√	up to 65	0.2-0.3	0.1-0.4	> 5	> 4	only applicable to cyclone preheater kilns and only for reduction of high sulphur emissions

CHAPTER 9

EMERGING TECHNIQUES

9.1 CONTROL OF NO_x EMISSIONS

9.1.1 SELECTIVE CATALYTIC REDUCTION (SCR) FOR HIGH DUST APPLICATIONS

Selective catalytic reduction reduces NO and NO_2 to N_2 with the help of NH_3 and a catalyst. This technology is already successfully applied in other industries. No full scale installations, only pilot plants, have been installed for NO_x reduction in cement plants up to today. The characteristics of cement kiln exhaust gas require that the existing SCR technology from other industries is successfully modified before it can be applied in the cement industry. Main outstanding questions include wear of catalyst, dust cleaning technology and dust pollution of the catalyst. Of the two possible SCR systems, “high dust“ application and “low dust“ application, only the high dust load is discussed because its investment and operating cost and its heat consumption are much lower than the “low dust“ variant (no BAT candidate).

Literature: see 7.3.10.

No.	BAT Evaluation Items		Comments	Remarks
1	**Consumables**			
1.1	Materials	[gNH_3/t cli] [10^{-5}m3 cat./t cli]	500 [34] 3.5 [34]	
1.2	Air		Compressed air	
1.3	Water	[kg/t cli]	1.5 [34]	
2	**Energy Consumption**			
2.1	Thermal	[MJ/t cli]	5	Estimated
2.2	Electrical		depends on pressure drop	
3	**Waste Generation**			
3.1	Solids		Ammonia - aerosols	1),2)
3.2	Liquids		None	
4	**Emissions**			
4.1	To air		Ammonia (<5ppm), SO_3, CO_2, aerosols, dust [34]	1),2)

4.2	To water	None	
4.3	Noise	None	
4.4	Odour	None	
4.5	NO_x reduction [%]	85 - 95 [34]	
5	**Impact on Product Quality**		
5.1	Cement	Higher or lower NH_3 concentration	3)
6	**Experience**		
6.1	Duration Number of applications	2 years 3 pilot plants	
7	**Relative Costs**		
7.1	Investment cost [10^6 ECU]	3.5 - 4.5 [34]	4)
7.2	Operating cost [ECU/t cli]	[34]	
7.3	Total cost [ECU/t cli]		
8	**Conclusion on Candidate BAT**		
8.1	For existing plants and plant rehabilitations	No	5)
8.2	For new plants and major upgrades	No	5)

1) The ammonia slip of an SCR system is much smaller than with an SNCR system for high reduction efficiency. If significant amounts of ammonia are released by the raw material the SCR system would use this ammonia in the catalyser to reduce NO_x and at the same time reduce the total amount of emitted ammonia.

2) If an ammonia slip occurs the released ammonia can react with SO_2 and other compounds in the exhaust gas to form fine particulates also called aerosols.

3) Depending on the original ammonia emission the ammonia input into the cement via filter dust can be increased or be slightly reduced.

4) Since SCR is not available yet at cement plants, the cost situation is unknown so far. Investment costs indication is only known from supplier not including the plant modifications. Operating costs are very much determined by the catalyst’s lifetime under exhaust gas conditions of a cement kiln.

5) Not yet available and excessive costs.

9.2 CONTROL OF DUST EMISSIONS FROM MAJOR POINT SOURCES

9.2.1 CONTROL OF DUST EMISSION FROM CEMENT KILNS

9.2.1.1 CO-PEAK MANAGEMENT FOR ELECTROSTATIC PRECIPITATOR (COEP)

A disadvantage of Electrostatic Precipitators (EP) for kiln exhaust gas dedusting is that the CO explosions protection can cause periods of very high dust emission. In most plants EPs are protected from CO explosion by stopping the energisation of the electrodes in the event that high CO concentrations are measured in the exhaust gas. During a CO shut down the dust emissions can be high. Generally CO shut downs occur about 5 to 20 times per year. Good CO peak management may reduce this number. Today most plants have a CO analyser installed that is analysing the CO content in gas extracted from the main exhaust gas duct. If the CO concentration exceeds a certain value the energisation is stopped. These CO limits for de-energisation of the EP are usually far below the CO explosion limit of about 12%. The reason for this is the slow response of the analyser and the time delay caused by the gas extraction and transportation.

A good CO-peak management system should include a fast CO analysis ahead of the EP, automatic interpretation of the CO concentration (slope of signal), correlation of measured CO concentration and real CO concentration to establish CO alarm levels, adequate reaction of the EP (stepwise de-energisation or reduction of the voltage below corona onset), automatic reduction of fuel input at higher CO levels.

Complete CO-peak management systems are not yet available on the market. Some companies however can already today supply very fast in situ CO analysers.

Attention: CO-peak management does not replace combustion optimisation to reduce CO production! CO-peak management only optimises the reaction to CO concentration in the exhaust gas. It does not influence the CO itself.

No.	BAT Evaluation Items	Comments	Remarks
1	**Consumables**		
1.1	Materials	None	
1.2	Air	None	
1.3	Water	None	
2	**Energy Consumption**		
2.1	Thermal	None	
2.2	Electrical	Negligible	

3	**Waste Generation**		
3.1	Solids		
3.2	Liquids	None	
4	**Emissions**		
4.1	To air	None	
4.2	To water	None	
4.3	Noise	None	
4.4	Odour	None	
4.5	Dust reduction [%]	1 - 15	Estimated
5	**Impact on Product Quality**		
5.1	Cement	None	
6	**Experience**		
6.1	Duration Number of applications		
7	**Relative Costs**		
7.1	Investment cost [10^6 ECU]	ca. 0.06 [34]	1)
7.2	Operating cost [ECU/t cli]	0.000 [34]	
7.3	Total cost [ECU/t cli]	0.01	
8	**Conclusion on Candidate BAT**		
8.1	For existing plants and plant rehabilitations	No	2)
8.2	For new plants and major upgrades	No	2)

1) Not yet available.

2) Not yet technically developed.

N° Editeur: D/1999/5457/December

CEMBUREAU

Published by CEMBUREAU
The European Cement Association

Rue d'Arlon 55 - B-1040 Brussels

Tel.: + 32 2 234 10 11
Fax: + 32 2 230 47 20

E-mail: secretariat@cembureau.be
Internet: http://www.cembureau.be

Printing by CEMBUREAU