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BAT for cooling systems

Working Group
"Environmental Protection"

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EURELECTRIC

BAT for Cooling Systems

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Working Group "Environmental Protection"

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BAT for Cooling Systems

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EXECUTIVE SUMMARY

The European Union has set up several working groups within the scope of the IPPC (Integrated Pollution Prevention and Control) Directive. These groups are made up of delegates of the Member States and experts from the industrial sector. The aim of the working groups is to draw up BAT reference documents per industrial sector or per "technique". The Institute for Prospective Technological Studies (IPTS) office in SEVILLA is responsible for drafting these documents.

With this in mind, a "BAT for Cooling Systems" working group was set up in June 1997. The objective of the IPTS office is to define a horizontal approach, in other words, valid for all the industrial sectors.

In view of the specific character of power plant cooling systems (size of the condenser, cooling water flow rates etc.) *EURELECTRIC* had expressed the wish not to take part in this working group. However, the IPTS office considered that the know-how of electricity utilities was such that their participation was essential.

In order to synthesise this specific knowledge and enable other industries to benefit from it, this report has been drawn up within *EURELECTRIC*. It is the outcome of collaboration mainly between ELECTRICITE DE FRANCE, ELECTRABEL, LABORELEC and VDEW representing VGB (German Power Plant Operators). The work of various permanent working groups of UNIPEDE[1] and CORECH[2] have also been included.

It explains in a simplified way the operation of fossil-fired power plants. It sets out the main functions of condenser and auxiliary plant cooling systems. The possible environmental impacts of cooling systems are then examined in detail. This part of the document particularly concerns heat discharges, the suction of living organisms into water intakes, any discharges of treatment re-agents and other potential detrimental effects, such as noise.

An analysis of the various cooling techniques is then made. It relates mainly to the design of a new system. To be a reference for BAT as defined in IPPC Directive 96/91, art. 2.11 it

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1 The International Union of Producers and Distributors of Electrical Energy

2 Committee for the Co-ordination of Research

must take into consideration the peculiarities of each single existing plant in terms of costs, benefits and feasibility. It deals with not only the technical and economic aspects, but particularly the environmental and energy impact of the various solutions.

A number of main conclusions have emerged from this analysis:

- The impact of a cooling system on the environment must be studied before the power plant is designed; to do so, numerical modelling and on-site tests in pilot loops are recommended;
- The design of the cooling systems must be studied while taking into account the environmental and energy impact;
- The implementation of physical processes intended to limit fouling must be sought systematically (continuous mechanical cleaning, temperature increase, filtration, etc.);
- Chemical solutions must be studied on a case-by-case basis to limit their utilisation as far as possible;
- One best solution cannot be selected as too many local factors influence the choice of the cooling system of a power plant. They include not only the flow rates available, but also visual aspects.

1. INTRODUCTION

The thermodynamic cycle of conventional thermal power plants obeys CARNOT's principle. Efficiency levels reach about 40 % for conventional new design but can achieve 47 % in advanced design and under very favourable climatic conditions in particular when cooling water conditions are suitable (once through cooling system), even with hard coal firing. The result is that nearly 45 % of the amount of energy provided by combustion must be dissipated at the condenser level.

The condenser is the key point of the facility. Regardless of the mode of cooling adopted, it is in fact one of the main interfaces between the power plant and the surrounding environment. The efficiency and availability of a power plant depend to a great extent on the integrity and cleanness of the condenser. These are reasons why specific solutions have been adopted for a long time now: continuous mechanical cleaning by foam balls, corrosion-resistant alloys, such as titanium and stainless steel, etc. Also cooling water treatment systems have been developed and are in operation, in particular for circulating cooling systems.

Likewise, as cooling flowrates may reach several dozen m^3/s, the modes of treatment adopted and solutions selected may be difficult to extrapolate to other industries.

2. POWER PLANT COOLING SYSTEMS - PRINCIPLES AND REMINDERS

The operation of power plants is governed by CARNOT's principle. The heat source, the boiler, provides the energy required for water vaporisation. The cold source, the condenser, condenses the steam coming out of the low pressure cylinder of the turbine.

One of the main characteristics of a power plant, from the technical and economic standpoints, is its **specific consumption**, in other words, the amount of heat needed to produce one kWh of electrical energy. This specific consumption results from the thermal cycle balance (table 1).

	Energy (kJ)	(%)	Efficiency (%)
Energy from combustion	9 000	100	100
Steam generator loss	1 050	- 11.7	88.3
Condenser loss	4 200	- 46.5	41.8
Feedwater heating	(2 000)	(22.2)	(Looping)
Turbogenerator losses	65	- 0.75	41.05
Power supply of auxiliaries	65	- 0.75	40.3
Loss in main transformer	25	- 0.2	40.1
Overall efficiency of the facility			40.1

Table 1: Example of simplified balance of a thermal cycle for conventional new design

The presence of the cold source is the main consideration. A look at the thermal cycle balance shows that 4 200 kJ must be yielded for each kWh generated. In addition, this energy cannot be recovered because its exergy is low.

New generation systems, especially combined cycles (or gas-steam turbines), make it possible to obtain higher efficiencies of, or even more than 55 %.

The cooling system which serves to evacuate this energy is generally called the **circulating system.** The condenser tube bundle contains cold water drawn from a river, the sea or a lake. The heating and flowrate of this water depend on the installed capacity (table 2).

Rated capacity of the unit (MW)	Circulating water flowrate (m^3/s)	Heating of water in the condenser (K)
125	3	7 - 12
250	6	7 - 12
600	14	7 - 12

Table 2: Relationship between the installed capacity and cooling parameters (Values as an example, depending on type of the circulating system, the ambient air temperature, cooling water resource temperature)

Each unit also has an auxiliary cooling water system. It ensures the cooling of:

- generator seal oil coolers,
- compressor coolers;

Systems for

- generator stator cooling water coolers,
- generator hydrogen coolers

are closed-loop cooling systems, supplied with demineralised water.

Depending on the units, the cooling water flowrate of this cooling sytem of the **auxiliaries** represents normally about 4 to 8 % of the circulating water flowrate. Heating is limited and amounts up to 10 K, according to the auxiliaries in operation. However, even with a low thermal load, it can remain in service several days after the shut down of the unit to evacuate the residual heat.

3. POSSIBLE ENVIRONMENTAL IMPACTS OF COOLING SYSTEMS

The heat releases at the cold source mainly concern two receiving environments: air and water. But, in fact, even if the discharge occurs into an aquatic environment, the ultimate heat sink remains the atmosphere. Indeed, the water gradually transfers there the heat received by various natural processes: evaporation, convection, radiation. For economic reasons, water is the first area where one looks.

Before wondering what techniques may be acknowledged as BAT for cooling systems, it seems desirable to make an analysis of any detrimental effects on the natural environment, estimate their nature and amplitude and judge them, in other words decide whether they remain tolerable or not.

3.1 HEAT DISCHARGES TO THE ATMOSPHERE

Regardless of the type of cooling system, all of the heat conveyed to the cold source is transferred to the atmosphere. This is carried out on a specific basis in the case of cooling towers, air-cooled condensers and dry cooling towers. In the case of once-through cooling systems on a river, lake or the sea, the heat is transferred via the surface of the receiving water body, over a large area and with a certain time lag, depending on the local situation.

In power plants cooled by a **once-through system** (Figure 1, see Annex II), pumped water is generally heated from 10 to 12 K when the units operate at their rated capacity. The heated water in the condenser is progressively cooled when mixed with the mass of receiving water. The heat is then transferred to the atmosphere by three conventional processes: evaporation (35 to 45 % of the energy released), by radiation of the water surface (25 to 35 %) and by convection with air (20 to 30 %). Depending on the local situation the outlet temperature could be limited by the local authority.
Energy transfer by evaporation represents a steam flowrate of 18 kg/s per 100 MWe. Considering the rapid decrease of water heating downstream of the discharge, the only atmospheric phenomena likely to be modified are occurrence frequencies and the persistance of evaporation fog in the area close to the release where temperature differences are still considerable, but the extent of which is limited.

It is worthwhile noting that, all things considered equal, the temperature of the formation or disappearance of evaporation fog is higher above salt water than above soft water. This circumstance is therefore favourable to power plants sited in estuaries or along sea coasts.

For power plants equipped with **wet cooling towers** (Figure 2, see Annex II), everything occurs as if the heat was released directly to the atmosphere. Two kinds of operation methods are in practice:

- once-through cooling with cooling tower (Figure 3, see Annex II) and
- recirculating cooling (Figure 4, see Annex II).

The discharge takes place in a concentrated way over a small area. Wet cooling towers transfer to the atmosphere about 70 % of residual heat in the form of latent heat (wet steam) and about 30 % by sensitive heat. Thus, the steam flowrate released to the atmosphere is roughly twice that resulting from once-through cooling without cooling tower. Air saturated with humidity is released to the atmosphere at a temperature of about 20 K above ambient temperature and at a velocity up to 5 m/s in the case of natural draught cooling towers. This velocity is doubled in the case of forced draught cooling towers. This air saturated with humidity, by cooling through turbulent mixing with ambient air, may give rise to the formation of artificial clouds or plumes.

To this release of water steam is added the carrying along, by the ascending air current of water drops at the rate of about 1 kg/s per 100 MWe (priming phenomenon), when the cooling towers are not equipped with droplet retaining devices. They are responsible for fine precipitation, as well as the possible occurrence of frost in winter.

The risks of fog formation on the ground resulting from the lowering of the condensation plume may be relatively frequent especially with mechanical draught cooling towers (Figure 5, 6 and 7, see Annex II), due to their low height. This frequency is considerably reduced as the cooling towers get higher. In plains, one may estimate that the lowering of plumes reaching the ground is exceptional as of a height of 50 to 75 m, depending on the local situation.

The formation of frost may result from the contact with the ground frozen either by the fog due to the lowering of the plume, or by precipitations linked to priming, or by sprays from the base of the cooling towers. However, the impact of such sprays remains confined to an area near the cooling tower and concerns at the very most the several dozen metres close to the base of the cooling tower.

The main climatic modification due to the operation of wet cooling towers concerns a local increase of nebulosity by the development of the condensation plume which results in the slight reduction of sunshine in the vicinity of the power plant.

For power plants equipped with **dry cooling towers** (Figure 9a, see Annex II) or **dry condensers,** the absolute humidity of the air is not changed, but its temperature is higher by about 15 to 20 K above the ambient temperature. All of the heat is released in sensitive form and the non-saturated hot air which rises in the atmosphere seldom leads to cloud formation.

Hybrid cooling towers (wet/dry) (Figure 9b, see Annex II) make it possible most of the time to avoid the formation of plumes. Water comsumption (i.e. make up water) is 20 % less than that of a wet cooling tower. However, at the present time, the only hybrid cooling towers available are of the mechanical draught type. And the resulting energy consumption is similar to that of mechanical draught wet cooling towers.

Since a few years at fossil fired p.st. the discharge of desulphurised flue gases via cooling tower is state of the art at least in Germany. It is an alternative to traditional discharge by stack and has ecological and economical advantages.

3.2 HEATING OF RECEIVING AQUATIC ENVIRONMENTS

Although the final heat sink is the atmosphere, in most cases, a fairly large part of the discharge of a thermal power plant takes place in the aquatic environment. Various physical phenomena come into play here: turbulent diffusion, convection in water, flow of fluids of variable density, evaporation, radiation, convection in the air. Depending on the extent of the discharge and according to the receiving environment, such a phenomenon is preponderant and affects the way the heat is distributed in the receiving environment.

The near field of the cooling water discharge should be distinguished from the far field.

The **near field** is defined in a river as the area in which the mixing of the thermal plume with river water is incomplete.

The water temperature in the near field depends upon the mixing of water released by the power plant with the water of the receiving environment. Heating can be reduced in this area by rapidly mixing the effluent with the water of the receiving environment by means of specific devices.

The **far field** is the plume geometry that is fully mixed with depth within the water column and is thus a backgound heat field. The excess temperature in the far field is gradually reduced due to the dilution with ambient waters and heat exchange with the atmosphere.

As concerns discharges in a **tidal sea or sea with strong currents**, the hot plume formed by the discharge of the power plant is mainly governed by the existence of major velocities in the receiving environment. They bring about a rapid mixture of the water preventing any stratification caused by the difference in density between the hot water and cold water. The temperature drop in the hot water plume principally comes from the mixing and not from heat losses at the surface of the water area. The extent of the thermal plume, defined as the area within the 1 K heating isotherm, covers an area from 2 to 10 km^2 for a discharge corresponding to that of a 5 000 MW_e nuclear power plant.

The behaviour of the hot water plume in a **tideless sea** is first of all that of a stratified flow. The temperature drops very quickly through dilution due to friction and turbulence. In a tideless sea (or lake) the spreading or transport of cooling waters is strongly influenced by wind-induced currents and thermocline conditions.

Normally for coastal power plants the Cooling Water is discharged to the sea surface through an open discharge channel.

The behaviour of the hot water plume in an **estuary** is similar to that in a tidal sea with strong currents. The alternative movement of water plays an essential role. The river flow will tend to transport the heat towards the sea. The incoming tide will slow down or change the direction of flow, and will thus affect the spreading of the hot water plume in the estuary.

The assessment of the heating of a river subsequent to a hot water discharge is relatively complex. Indeed, the cooling mechanics of the river downstream mainly results from the exchange of energy between the river and the atmosphere. The energy flow between the stretch of water and the atmosphere fluctuates considerably depending on the meteorological conditions and the time of day.

In a river, diffusers distributed all along the width of a waterway serve to carry out the mixture over a distance of several dozen to several hundred metres. If the discharge is performed along the bank, complete mixing by natural flow is carried out over a few kilometres.

In all cases, **recirculation in the river must be avoided** or the recirculation rates for discharges into the sea and especially in the estuary reduced to a minimum to ensure efficiency and safe operation of power plants. The position and design of water intake and outlet structures are determined to eliminate the risk of recirculation.

Preliminary studies make it possible to design water intake and outlet structures and devices best adapted to avoid recirculation and favour the initial mixing of heated water discharges. They rely on physical models (hydraulic models) and numerical models. Where possible the numerical modelling etc. should be based on site specific hydrographic survey data.
The use of these tools as part of the impact study of projected facilities serves to give assurance that regulatory thermal limitations will be respected, whether they concern maximum heating in the mixing area or the temperature level after the mixing.

3.3 SUCTION OF ORGANISMS INTO WATER INTAKES

When pumping the water needed for cooling, thermal power plants draw in microscopic organisms (algae and planktonic animals), as well as organisms which swim in the open water (some crustacea and fish). The plankton passes through the rotating filters the mesh of which is generally between 1 mm and 5 mm. This does not hold true for crustacea and fish which are flattened against the filtering panels, drawn up and discharged with the washing water of the filters.

Some studies have shown that most of the organisms drawn into the water intakes are small in size: Shrimps, larvae and alevin in the sea and estuary, alevin in rivers. The case of young salmon migrating downstream which are particularly drawn into the water intakes is specific.

To limit the drawing in of these species, three types of measures may be taken:

- Place the intakes outside critical areas (spawning grounds and "fish nurseries" on the seaside, migration routes for eel larvae in estuaries);
- Design intake structures which minimise the drawing in of organisms;
- Equip intakes with repulsive devices or eqipment which restore organisms to the environment without damage.

The first two actions, of a preventive nature, are preferable to curative actions the efficiency of which presently remains problematical.

3.4 ALTERATION OF THE RECEIVING ENVIRONMENT BY CHEMICAL DISCHARGES

The water withdrawn for cooling purposes may sometimes be the cause of chemical releases into the receiving environment. The following may be concerned in particular:

- reagents used to avoid the scaling of cooling systems equipped with cooling towers,
- reagents used to fight against biological developments, reaction products of some of them,
- iron sulphate anti-corrosion treatments to protect, in some cases, copper alloy condensers,
- corrosion products of heat exchangers and piping.

As concerns the **marine environment,** the purpose of the biocide treatment is to maintain the systems sufficiently clean so as to ensure their proper operation. For the sea intakes, the main problem is to avoid the development of molluscs (mussels, oysters, etc.) inside the cooling system. The current practice is the injection of chlorine. It is generally produced on site by sea water elctrolyses. This process avoids the risk involving the transport of NaOCl by truck. The chlorination can be made on continuous or discontinuous (seasonal) basis depending on many factors such as meteclimatic character-istics of the site, cooling circuit design and biofouling typology. Mainly the injection takes place in low doses so that the concentration in free chlorine in the discharge is generally between 0.1 and 0.5 mg/l normally sporadically 0,7 mg/l. The value of this limit concentration is set by local regulations.

However, when it reacts with some organic matter, chlorine may lead to the formation of organo halogenated substances (mainly bromoform in sea water). Some studies nevertheless show that bromoform concentrations in the plumes of hot water discharges from coastal sited power plants remain extremely low (about 15 µg/l).

It would be advisable here to compare this figure with the natural production of organohalogenated substances in the oceans. Thus, according to Grimvall and deLeer (1995), the annual production of a number of organohalogens is:

- chloromethane: 5.000.000 t
- bromomethane: 300.000 t
- iodomethane: 300.000 t to 1.200.000 t
- chloroform: 90.000 t to 360.000 t
- bromoform: 500.000 t to 1.000.000 t
- iodoform: not detectable in sea water.

Thus natural concentrations in AOX ranging from 6 to 17 µg Cl/g of sediment in the Gulf of Bothnia and from 50 to 180 µg Cl/g of sediment in the Gulf of Finland were measured. The presence of these organohalogenated molecules has been attributed to biohalogenation reactions.

Chlorination is the anti-fouling chemical treatment method that is the most commonly used to protect the systems of coastal-sited power plants. Another oxidant, chlorine dioxide, has nevertheless been tried with success on thermal power plants.

For a great many years, the choice of the alloy for the pipes of heat exchangers in coastal-sited power plants has gone towards titanuium. Under these conditions, the contribution of corrosion products is insignificant, or even inexistent. However, there are still condensers in copper alloy which are protected by a film of ferric hydroxide produced by adding ferrous sulphate to the cooling water.

For **river-sited** power plants the contribution of chemical reagents will depend to a great extent on the type of cooling system and any biological problems.

Generally, operation with recirculation increases the **risks of scaling**. This often requires setting up a specific treatment of make up water or cooling water. The modes of treatment that may be used are as follows:

- no treatment when the water is not very mineralised,
- lime softening of make up water,
- acid vaccination of circulating water,
- treatment with precipitation retarder,
- combined treatments of the type: acid vaccination and scaling inhibitors or lime softening and acid vaccination.

The choice of the mode of treatment depends on many criteria the following of which are mentioned for example:

- concentration factor,
- chemical composition of the river water,
- design of the cooling system.

The treatment depends on the concentration factor of the cooling system:

- with a low concentration factor (1.05 to 1.2), it is not generally necessary to treat the water of the system,
- with an average concentration factor (1.2 to 2), an acid vaccination of the circulating water is necessary when the hardness of the water is high,
- with a high concentration factor (3 to 7); the lime softening of make up water often becomes the only choice possible, and may be supplemented by a light acid vaccination.

The **acid vaccination** of circulating water can be carried out in three different ways: either by maintaining the pH within a range generally included between 7.5 and 8.2, or by limiting the total alkalinity to 100 mg $CaCO_3$/l (for make up water with low sulfate-content), or by respecting regulation instructions which take into account the alkalinity, calcic hardness and temperature. Sulphuric acid is used in most cases.

The purpose of the **lime softening** of make up water is to raise the pH of the water up to 10 so as to precipitate the calcium and part of the magnesium in the form of carbonate and hydroxide. At the outlet of the decarbonator, the concentration of residual calcium varies between 0.5 and 1 meq. However, it is combined with carbonate, which makes the treated water extremely scaled. To restore the balance of decarbonated water, a post vaccination with sulphuric acid is often carried out. The lime softening results in the production of a large amount of sludge.

In addition, by increasing the pH, lime softening may result in the precipitation of some heavy metals present in the withdrawn water.

The **continuous chlorination** of the circulating systems so as to eliminate the formation of biofilm on the condenser pipes was given up a long time ago in favour of mechanical solutions (Taprogge, Technos systems, etc.). However, in some specific cases and in particular to limit the development of the soft water mussel, *Dreissena polymorpha*, it is sometimes indispensable, on some sites, to make use of this mode of treatment. The concentration at the injection point is low (0,5 mg/l). The time period when periodical chlorination is needed depends on the water temperature. It is limited to a fortnight.

The **massive chlorination** of the circulating system is much less used nowadays. It serves to eliminate fibrous algae which develop in the basins and fills of cooling towers. The concentrations at the injection point vary between 5 and 25 mg Cl2/l. In order to avoid the release of chlorine into the receiving environment, the blowdowns are closed for a few hours. They are open when the concentration of free chlorine in the circulating water is lower than the discharge limit. Depending on the authorisations, this limit varies between 0.1 and 0.5 mg Cl2/l. Some discharge authorisations are expressed in flows. These treatments are not carried out on all the sites.

The frequency of massive treatments depends to a great extent on the quality of the water, the concentration factor and the general state of cleanness of the circulating system. It may be weekly, monthly or quarterly.

The reaction of chlorine with humic and fulvic matter leads to the formation of organochlorinated compounds. In fact, bromide ion concentrations in river water are generally insignificant. Under these conditions, only organochlorinated compounds can be formed. Volatile compounds such as chloroform, dichloromethane, (POX) and adsorbable compounds (AOX) can be distinguished.

However, as is the case for sea water, the presence of organohalogenated compounds in internal surface waters is not solely due to the chlorination of the cooling systems. Among the other possible sources, particular mention should be made of agriculture and natural production. In unpolluted lakes - for example in Sweden - AOX concentrations ranging from 10 to 190 µg Cl/l. The highest concentrations were measured in highly eutrophicated lakes.

Among the parameters which affect the reactions resulting in the formation of organochlorinated compounds during the disinfection of cooling water, the following should be mentioned:

- humic or fulvic concentration,
- free chlorine concentration,
- reaction time,
- pH of the environment,
- reaction temperature,
- presence of ammonium ions.

These complex reactions can be modelled and validated by measurements carried out on the sites.

The chlorination of the once-through systems does not result in significant increases of organochlorinated compounds. Indeed, the contact times are short, about 10 minutes at most, and the concentrations of free chlorine are low.

According to the chlorination procedures used, the POX and AOX concentrations measured at the peak vary between 0 and 10 µg Cl/l and between 20 and 150 µg Cl/l, respevtively. These values correspond to free chlorine concentrations at the injection included between 0.5 and 10 mg/l.

The chlorination in a closed loop of circulating systems may lead to higher concentrations of organochlorinated compounds. The following factors play an infavourable role here:

- the contact time is longer,
- the recirculation increases the concentration of precursors.

It should nevertheless be mentioned that the increase of pH linked to the degassing of CO_2 is favourable to the formation of POX. The latter are easily transferred to the atmosphere via the cooling tower.

Under these conditions, the concentrations of POX are included between 0 and 10 µg Cl/l and the concentrations of AOX between 200 and 2 500 µg Cl/l. For concentrations of free chlorine at the injection included between 5 and 25 mg/l and stay times varying between 2 and 70 hours.

One should note, however, that the presence of low concentrations of ammonium ion in natural water may considerably reduce POX and AOX concentrations. Actually, the kinetics of the chlorine-NH_4^+ reaction is more rapid than those of the reactions taking place between the chlorine and aromatic compounds.

3.5 OTHER POSSIBLE HARMFUL EFFECTS RESULTING FROM THE CHOICE OF SOME COOLING SYSTEMS

Although the use of natural draught, forced draught and hybrid cooling towers, or also dry condensers and cooling towers, makes it possible to considerably reduce the water flow requirements of a power plant and, consequently, to limit the possible impact on the aquatic environment, the presence of cooling systems on a site may pose other problems. They concern in particular problems of aesthetics and noise for wet cooling towers. For dry cooling towers and condensers, in addition to the two previously-mentioned aspects, there is also the possible dissemination into the air of corrosion products from the heat exchange surface area, in particular, when the heat exchangers consist of finned tubes made of galvanised steel.

Natural draught wet cooling towers, the sober form of which is generally not unpleasant, are nevertheless structures that can be seen from afar and that cannot be concealed in a fairly flat landscape.

On the other hand, **mechanical draught wet cooling towers or hybrid cooling towers,** the aesthetics of which is itself much more debatable, present the advantage of generally being lower than the main part of the power plant.

Nevertheless beyond that it is required to quote comparative factors between different technologies since a lot may depend on the assumptions made by manufacturers in giving cost data.

Similar remarks may be made for **dry cooling towers and** condensers. The size effect is nevertheless much more considerable. This is because the low exchange properties of air require much larger structures. In addition, in the case of mechanical draught systems, the power necessary for air supply is about 2 % of the unit's net electrical output. For the same thermal power to be dissipated, it is therefore three times higher than that required for wet cooling towers and combined systems.

A certain detrimental effect that can be caused by a cooling system resides in the emission of noise at the air inlet and outlet. Even for a **natural draught wet cooling tower**, the sound level may reach 60 dBA at 100 m. For a **mechanical draught wet cooling tower and hybrid cooling tower**, the noise level comes to about 70 dBA under the same conditions. It is close to 80 dBA for **dry condensers.**

4. PRIOR STUDY OF THE SITES: INDISPENSABLE TOOL FOR THE EVALUATION OF THEIR RECEIVING CAPACITY, IMPACT CONTROL AND PREVENTION OF HARMFUL EFFECTS

4.1 ANALYSIS OF THE SITUATION

The cold source is one of the determining elements in the choice of a site. That's why great care is taken at a very early stage with regard to the environmental problems posed by the cooling of a power plant. As mentioned earlier on, these problems may be of several kinds:

- water heating by once-through systems,
- effect on the quality of water and on aquatic organisms, in the case of wet cooling towers,
- effect on the quality of air, in the case of dry cooling towers,
- meteorological effects, discharges of chemical substances and problems of noise regardless of the mode of cooling adopted.

The designer is not powerless in the face of the problems posed. The knowledge acquired through a great many observations made in the vicinity of existing power plants constitutes a solid experimental basis serving to effectively orient the studies to be undertaken prior to the installation of a new power plant.

4.2 MATHEMATICAL MODELLINGS, SIMULATIONS ON MODELS AND TESTS ON PILOT LOOPS, FIRST INDISPENSABLE TOOLS

The interest of **numerical models** has been mentioned for forecasting thermal changes in the near field as in the far field.

In the near field, fairly sophisticated tools serve to describe the dilution conditions of thermal discharges. They are used at the local discharge level. These models serve to dimension the outfall structures to the best possible extent so as to ensure the optimum dispersion of the hot plume in the receiving environment as quickly as possible and thus limit its impact to a minimum (meteorological and hydrobiological data).

In the far field, the parameters that have to be taken into account are much more complex. They concern not only the characteristics specific to the receiving environment, but also discharges originating from other companies. Much more complex models have been developed to this effect. They take into account biological parameters of water quality and take into account the presence of chemical pollutants. They integrate various pollution sources and provide an assessment of response of waterways or lakes to thermal and chemical disturbances or the excessive contribution of nutriments (eutrophisation phenomenon).

There are also other models used to simulate the accumulative impact of several wet cooling towers installed on the same site.

The forecast making use of numerical models must rely on field data and experimental knowledge. These **in situ and laboratory studies** are required to define and optimise the anti-fouling treatment or systems cleaning periods.

Biological studies make it possible to know the periods of reproduction and fixation of larvae, as well as the rate of growth of the main biological species. These field and laboratory studies are long. Indeed, in the ecological field, forecast analytical tools have not yet been wholly validated.

To determine the mode of treatment of the recirculating systems, systematic tests on pilot loops are carried out. The purpose of these tests is to grasp the **scaling risks** on the one hand, and, on the other hand, to define the optimum mode of treatment, as well as the operating instructions. Among the laboratory studies are to be found model simulations for the understanding and visualisation of steam and hot water plumes phenomena, etc..

5. DESIGN OF COMPONENTS AND CHOICE OF MATERIALS

5.1 WET COOLING

As mentioned previously the problems encountered in wet cooling systems may be of three types:

- corrosion,
- scaling,
- biological developments.

For many years now, and almost naturally, the choice of materials used in the cooling systems of power plants has been oriented towards corrosion resistant materials. It must be mentioned that the pressure within the condenser of a power plant is about 35 mbar but can be lower in units optimised to achieve higher efficiency - in particular when climatic conditions are suitable or may be even higher when climatic conditions are unfavourable. Under these conditions, the slightest leak in the pipes leads to the ingress of impurities into the water-steam cycle. The damage incurred by these intrusions may be substantial and reduce the efficiency of the unit, or even lead to its shutdown.

In order to avoid the ingress of raw water into the water-steam cycle, the choice of materials went to highly resistant alloys. Titanium is thus almost always used in sea water and brackish water. For river water, condensers are equipped with 316L (or even higher Mo-content) stainless steel pipes most often or brass or sometimes made of titanium. In order to limit the formation of deposits (sediments and biological developments) in the pipes, the velocity is fixed between 1.8 and 2.5 m/s, depending on the choice of the alloy.

The tube plates are often made of carbon steel. The side in contact with the circulating water is protected by appropriate painting (epoxy or ebonite coating). In some particular cases, cathodic protection devices have been installed to solve galvanic corrosion problems among others.

Even if rich, alloys such as stainless steels may be the subject of particular corrosion, like corrosion beneath deposits. To avoid these phenomena, the pipes must remain clean under all circumstances. This objective may be met in two ways:

- either by a continuous injection of rapid-action biocides, generally an oxidising biocide, such as chlorine;
- or by a continuous mechanical cleaning process. There are various processes in existence. They consist in the injection of brushes or foam balls which are recovered and reused in a continuous basis.

The desire to reduce the use of chemical reagents imposed the second solution.

The main heat exchangers of auxiliary cooling systems generally consist of coolers made of steel or stainless steel. The distance between the plates is relatively short, which sometimes leads to silting up. However, these systems operate according to the one of two or two of three principle. In other words, the operation of one or two systems is sufficient to carry out the cooling of the auxiliaries, with the additional train playing the security role. This design choice serves to schedule periodic cleaning operations. These operations consist in dismounting the unused heat exchanger and in cleaning the plates with pressurised water.

The make up and outfall structures, main circulating water pipes and cooling towers are made of reinforced concrete. The choice of cement used depends on the mode of treatment to be adopted for the circulating water. Thus, in the case of sulphuric acid vaccination, it is sometimes indispensable to use special cements. The addition of fly ash is recommended. In the case of higher sulfur acid concentration the use of special coatings ist required.

The **fill** of cooling towers is usually made of thermoplastic materials. Specific loads are often added during fabrication so as to make them fire resistant. The risk of fire in the fills is particularly high during the maintenance operations. This choice avoids the problems of asbestos encountered with the packings of the previous generations. In addition, recent developments have made it possible to substantially increase the thermodynamic properties of the fill. The choice of lighter synthetic materials and enhanced performances have served, for an identical thermal load, to appreciably reduce the size of cooling towers. However, some present profiles show a larger sensitivity to (bio)fouling and scaling. These phenomena have been studied by several researchers.

As can be seen, the choice of a fill depends on several factors. More than the performances sought, it is rather the quality of water (presence of suspended matter, scaling tendency) which imposes the choice of the profile. The manufacturers still have a great deal of progress to make with regard to this particular point. The ideal profile is, of course, the one which guarantees high performances while being not very sensitive to (bio)fouling and scaling.

The standard **droplet separators** currently used make it possible to limit the amount of water drawn in by priming to 0,01 % or even less of the total flowrate. For facilities built near major trunk roads, these values can be further reduced. A compensation of loss of capacity is necessary in this case. Separators are also made of plastics.

Part of the **pumping energy** can be recovered by installing cooling towers equipped with recuperators located under the fill. However, these cooling towers are extremely sensitive to frost. Before opting for this solution, a study of local climatic conditions is absolutely necessary.

5.2 HYBRID COOLING

Hybrid cooling towers are recommended for special site conditions and in the need of low tower hights.

By their design, hybrid cooling towers combine an evaporative process with a non-evaporative process. This results in a decrease of relative humidity and therefore the almost complete disappearance of the plume at the outlet of the cooling tower. The investment costs are higher than for a wet cooling tower.

In general the energy consumption related to the operation of fans and the higher temperature of the cold source, result in lower cycle efficiencies and higher fuel consumption.

5.3 DRY COOLING

Dry cooling is mainly used in regions with unsufficient water supply.

5.3.1 Forced Draught Air Cooled Condenser (Figure 8, see Annex II)

In a dry condenser arrangement the exhaust steam from the steam turbine is ducted to the air cooled condenser (ACC) where the steam is distributed through a large number of finned tubes. Cooling air is forced over these tube bundles by fans. The steam rejects heat directly to the atmosphere via the finned tubes, condenses and flows by gravity into a condensate tank. From the condensate tank it is returned to the boiler. A typical design for the heat exchanger is the „A“ frame condenser (other framework designs are also possible to accommodate the tube elements, fans, and steel structure).

Large dry condensers tend to have long and complex steam pipe systems which may cause siting and pressure drop problems. To minimise pressure losses in the steam ductwork the cooling bundles are generally located immediately adjacent to the turbine hall. Depending on site conditions, the ACC concept is technically feasible to cover a wide range of power plant unit sizes.

Compared to wet cooling systems, the ACC´s efficiency of heat transfer to the atmosphere is relatively low with the recooled water temperature being determined by the dry bulb air temperature. The system needs to be designed to exclude formation of dead zones by non-condensable gases and thus eliminate the danger of undercooled condensate or freezing.
The design of tube bundles also needs to be robust to allow for periodic high pressure water cleaning of the external surfaces to maintain efficiency and plant output. However, this method of dry cooling with an ACC avoids the need for large cooling towers, eliminates the vapour plume and greatly reduces the consumption of cooling water. In particular using low noise fans and drives can meet stringent noise restrictions.

In comparison to indirect dry cooling systems, then the ACC provides a greater temperature difference between the condensing steam and the cooling air, and consequently the ACC system will have a relatively smaller heat transfer surface. The indirect dry cooling system, which has two heat transfer processes (i.e. steam condenser and air cooled heat exchanger) would need to compensate by either adopting a larger cooling surface and/or by increasing its cooling air flow. The investment costs for an ACC will be smaller than an indirect dry cooling system as the latter will have to include the costs of the cooling water recirculation pumps and surface condenser. On the other hand, the auxiliary power consumption and maintenance requirements for the mechanically forced draught ACC will be significantly greater than the natural draught dry tower.

5.3.2 Natural Draught Air Cooled Condenser (Figure 8, see Annex II)

Although the characteristics of placing a direct air-cooled condenser inside a natural drought tower make it as feasible as the forced draught air cooled condenser, the disadvantages are that the height of the natural draught tower structure will of cource be greater and so will its investment costs (i.e. the cost of the tower itself, the routing of the large steam exhaust ducts to the cooling tower, and the larger heat transfer surface required as the natural air draught may be only half of the forced air draught).

The advantages of this natural draught ACC system would include

- reduced/no sound emissions
- reduced/no air recirculation due to high tower structure
- no maintenance for fans, drives or circulation water pumps
- no auxiliary power consumption for steam condensation.

5.3.3 DRY COOLING TOWERS

In dry-type cooling towers, water flows through the cooling elements in a closed system. Waste heat is exclusively transmitted by convection. The missing vapour leads to a significant increase of the temperature of the cool water and thus a low efficiency compared to wet-type cooling.

In case of dry cooling two flow arrangements are possible:

- closed circuit cooling with dry-type cooling towers as direct cooling in connection with a surface condenser and
- closed circuit cooling with dry-type cooling tower as direct cooling in connection with injection condenser.

Advantages of dry cooling are as follows:

- no visible plume formation,
- simple set-in and examination of chemical parameters of the circulating cooling water,
- no need to make up water during operation, only replacement of possible leakage losses.

Compared to wet cooling, dry cooling has the following disadvantages:

- considerably higher investment and operation costs,
- larger dimensions of the building,
- stronger influence of the ambient air temperatures (summer/winter) on cooling performance,
- operation in winter requires special ice prevention measures during standstills,
- the tendancy to fouling of the cooling elements requires an efficient stationary cleaning device.

5.4 COOLING TOWERS WITH DISCHARGE OF CLEANED FLUE GAS
(Figure 10, see Annex II)

During the last years the emission of desulphurized flue gas via cooling towers (as an alternative to the emission via chimneys) in fossil-fired plants has proved to be favourable regarding environmental and economical aspects. The effect of the transport of flue gas to higher atmosphere areas is achieved in this case by differences in density between the flue gas/vapour mixture inside the cooling tower and the relatively cold ambient air, and not by the high temperature of the flue gas itself. Using this method an increase of the efficiency of the power plant is obtained.

Flue gas desulphurization plants of coal-fired power plants often work according to the principle of wet desulphurization. Wet cleaning cools down hot flue gases to between 50 ^{o}C and 70 ^{o}C. For environmentally-compatible and troublefree emission of these cleaned flue gases via a chemney a heating under additional utilization of energy is necessary. An alternative for reheating is the clean gas emission via a natural draught cooling tower: up to now this principle has been exclusively used for wet cooling. The clean gases are led into the cooling tower above the packing and thus emitted into the atmosphere together with the cooling tower plumes.

Coating and Corrosion Protection

During the inlet of clean flue gases into the cooling tower, condensate can flow down the cooling tower shell, which is, compared to concrete, heavily aggressive due to the low pH value. This is the reason why the inner side of the cooling tower shell including the upper ring beam must be completely coated.

Concrete parts of the internal structure, e.g. the top framing of the fill supporting structure of channel segments and riser heads respectively, must also be coated like the inner side of the shell.

Steel parts, e.g. slides or handrails that might get into contact with acid condensate from the plumes must be made out of special stainless steel.

Clean Gas Channel

The clean gas channel conducts the clean gases from the FGD[3] building to the middle of the cooling tower. It can be inserted into the cooling tower at the height of the FGD outlet or above the internal tower fill. The maximum channel diameter is 8 m.

The clean gas channel should be made out of glass fibre reinforced vinylester or equivalent. To this end, especially chemical-resistant moulding materials on the basis of penacryl resins and, as textile processing, especially acid-resistant fibres out of ECR glass are to be used.

Due to the condensate formation inside the channel, it should have a slight inclination against the cooling tower. For the outlet of the condensate, an outlet facility at the clean gas channel inside the cooling tower is to be provided, leading into the cooling tower basin.

6. COST COMPARISON BETWEEN THE VARIOUS TYPES OF COOLING TOWERS

The costs of cooling facilities are mainly of three kinds:

- investment,
- costs related to energy consumption,
- maintenance costs.

In the case of mechanical draught cooling towers, one may suppose that the maintenance costs are very similar because they are mainly linked to the maintenance of the fans. By taking into account the first two criteria and by selecting the least expensive solution as the reference, in other words wet cooling, one can establish the comparison set out in table 3.

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3 Flue gas desulphurisation

	Mechanical draught wet cooling	**Mechanical draught dry systems (dry cooling towers and air-cooled condensers)**	**Mechanical draught hybrid cooling tower**
Investment	1	2 to 3	1.8
Energy consumption	1	2.5	1.6
Total	1	2.5	1.7

Table 3: Mechanical draught cooling towers - Comparison of the investment and operating cost

The results of a similar study for the purpose of comparing wet cooling towers only are set out in table 4. The comparison basis is the natural draught wet cooling tower.

	Natural draught wet cooling tower	**Mechanical draught cooling tower**
Investment	1	0.7
Operation	1	1.7
Maintenance	1	2.3

Table 4: Wet cooling towers - Comparison of costs

From the two previous tables, it is shown that the least costly investment solution is the natural draught wet cooling tower.

The mechanical draught dry cooling is the most expensive both at the investment level and the energy consumption level.

7. CHOICE OF THE TREATMENT OF CIRCULATING WATER ALTERNATIVE METHODS - MONITORING

As mentioned previously, problems of corrosion seldom arise in the cooling systems of power plants. The use of corrosion inhibiter products is therefore unnecessary for cooling systems cooled by raw water.

7.1 ANTI-SCALE TREATMENT

With a wet cooling system, the only way of reducing heat discharges into the aquatic environment consists in the recirculation of the cooling water. This practice results in increasing the concentration factor (table 5). It is often applied for power plants located on **inland waterways and in estuaries.**

This concentration tends to result in the precipitation of calcium salts that are not very soluble: carbonate, sulphate, phosphate. The scale most commonly encountered is calcium carbonate. It settles on the pipes of condensers and in the fill of cooling towers, which leads to a reduction in efficiency. Two prevention techniques are generally used to avoid the precipitation of calcium carbonate in the cooling systems of power plants. One is the lime softening of make up water and the other is the vaccination of circulating water with sulphuric or hydrochloric acid.

Concentration factor	**Withdrawn water flowrates (m^3/h)**	**Energy discharged into the receiving waterway (%)**
1	36 000	100
1.2	3 600	7.8
1.3	2 600	5.1
1.4	2 100	3.5
1.5	1 800	3.1
2.0	1 200	1.6
3.0	900	0.8
4.0	800	0.5
5.0	750	0.4
6.0	720	0.3

Table 5: Relationship between the concentration factor, the withdrawn water flowrate and the energy discharged into the receiving waterway (individual example)

Only organic scaling inhibitors for which there are ecotoxicological data are used within the limits laid down by regulations. Their use is extremely limited. Indeed, current ecotoxicological data are often insufficient. Furthermore, these substances released into the receiving waterway may disturb the water treatment operations of industries situated downstream of the discharge point.

Coastal-sited power plants are generally cooled by a once-through system. Cooling towers operating on an after cooling basis can be installed in order to reduce the thermal load. This choice will mainly depend on local conditions (tides, mixture, etc.).

On the other hand, operation with sea water recirculation is exceptional. Indeed, high concentration factors may cause the precipitation of a great many salts (calcium carbonate, calcium sulphate, barium sulphate, etc.). Although the formation of calcium carbonate may be avoided by adding acid, the same does not hold true for the other salts which can only be stabilised by organic inhibitors (phosphonates, polyacrylates, copolymers, etc.).

7.2 ANTI-FOULING TREATMENTS (BIOCIDES)

A recent review of the experience acquired in EUROPE in methods to reduce biological fouling enables to draw the following conclusions:

> The **mechanical cleaning** of the systems and **water filtration** are the most commonly used processes. They involve the continuous cleaning of the pipes of condensers by foam balls or brushes, manual cleaning, use of trash rakes, filters with meshes of different widths.

Three other physical methods are also regularly used for the anti-fouling treatment of industrial systems. They concern the following:

- maintaining of velocities high enough to avoid the fixation of organic organisms ($v > 2$ m/s), this recommendation is applied to a large extent today;
- temperature increase which consists in raising the temperature of the cooling water beyond 40 ^{O}C for some dozens of minutes; this technique eliminates the fixed organisms (mussels), but nevertheless requires an appropriate design of the cooling systems;

- non-toxic coatings and paints, which reduce the fixation of the organisms, reinforce the velocity effect and facilitate cleaning; these coatings are nevertheless expensive and are not generally applicable under water and must be renewed every 4 to 5 years.

Other techniques are sometimes used, the following in particular:

- dryout;
- installation of specific filters (mussel filters).

The physical methods can be applied both in sea water and soft water.

Chemical treatment can be applied in cases where physical methods are not appropriate or show insufficient results. There are two biocide products, chlorine, ClO_2 and ozone, which can be used for antifouling treatments.

Finally degradable organic compounds applicable intermittently and non toxic in the receiving environment, might be an alternative to chlorination. Among these, some amine filminducing polymers appear to be promising.

7.3 MONITORING

Given the flowrates of power plant cooling systems, one cannot conceivably operate them without an advanced monitoring and control system. This reasoning is applicable both for problems concerning scale and biological development.

To avoid **scaling**, the regulation of acid injection into the circulating water is generally subject to the continuous monitoring of physico-chemical parameters such as: alkalinity, calcic hardness, conductivity, temperature at the condenser outlet. A computer uses these various parameters as a basis to calculate a specific scaling index and compares it with the operating instructions. If necessary, the regulator adapts the injection pump flowrate. Finer control methods are also implemented in high-risk sites. They concern in particular the measurement of the critical pH 4 and other scaling monitors.

As concerns the follow-up of **biological developments,** many types of sensors exist and are implemented. Among these should be mentioned biomonitors, and electrochemical sensors.
A control of the quality of drainage water is desirable in order to monitor parameters like temperature, oxygen concentration, pH, conductivity etc.

8. DESIGN OF THE COOLING SYSTEM

As a non-neglecting requirement it should be recognised that the adoption of cooling water systems at a particular site can be the collaboration of many different factors. The most obvious one is the site specific characteristics**.**

8.1 DESIGN AND ENERGY RECOVERY

In conventional thermal power plants, the thermodynamic cycle imposes the overall efficiency of the facility. The economiser, superheater and reheater optimise the operation of the boiler. The low and high pressure superheaters raise the temperature of feedwater by recovering part of the energy withdrawn by means of steam extractions. In order to reduce the electrical consumption of the auxiliaries, turbine-driven feedwater pumps are also used, these being also supplied by steam extractions. Combustion air is also heated by air heaters prior to entering the boiler. All of these devices have one objective: **reduce the energy losses of the cycle.**

The energy loss in the condenser is governed by **thermodynamic laws.**

If energy gains can be obtained in the cooling systems, it is mainly at the level of design and the resulting choices that it is possible to do so. Some golden rules may be applied:

- limit the number of pumps,
- avoid mechanical draught cooling towers,
- if cooling tower is needed, prefer wet cooling tower to recovery systems (recuperators),
- if deconcentration flowrates are sufficient, install a hydraulic recovery turbine on the deconcentration blowdown;
- where flowrates must not be constant, use frequency variators on the pumps or fans.

The following conclusions therefore emerge from these observations:

- two sets of pumps are sufficient, one for the supply of the auxiliary cooling system, the other for the main cooling system;
- if once-through cooling is not possible, natural draught wet cooling towers should be preferred to other cooling systems;
- two schemes are therefore conceivable (figures 11 and 12, see Annex II) and make it possible to eliminate the heat from the auxiliary system via the cooling tower.

8.2 DESIGN AND NOISE REDUCTION MEASURES

The reduction of noise of the cooling systems can be carried out in different ways:

- installation of anti-noise walls around cooling towers,
- modification of the relief of the site (wooded slopes),
- choice of "low noise" fans,
- utilisation of anti-noise panels.

These various solutions generally make it possible to meet stringent noise restrictions.

8.3 IMPLEMENTATION OF PHYSICAL METHODS

Right from the design stage, it is absolutely necessary to reflect on the possibilities of implementing physical methods, particularly so as to avoid biological developments. It concerns the following in particular:

- guarantee an adequate velocity in all the portions of the system;
- install continuous cleaning systems on all heat exchangers whenever this is technically possible;
- provide for mussel filters on sites at risk;
- design the systems so as to be able to carry out manual cleaning operations under normal operating conditions (alternate heat exchanger operation);

- design the systems so that temperature increase is possible (recirculation with cooling tower in by-pass);
- in natural draught wet cooling towers prefer anti-fouling fill that is not very sensitive to scale.

8.4 MODELLING AND PILOT TESTS

The purpose of **modelling** is to study any physico-chemical impacts and adapt to the facilities so as to reduce these impacts to the greatest extent possible. It is particularly important to study:

- water withdrawals and discharges,
- the visual aspect of the site,
- the evolution of plumes,
- the thermal and chemical impacts on the receiving environment.

The objective of the **pilot loop tests** is to define the optimum treatment of cooling water both with regard to scaling and to any biological developments. To do so, pilot facilities representative of real commercial operating conditions are installed on the site for up to one year. This makes it possible to integrate the variations of the quality of the waterway in the course of the seasons. This also serves to assess the opportunity of some choices on a representative scale (examples: choice of cooling tower fill, choice of alloys, etc.).

8.5 CHOICE OF THE COOLING SYSTEM

As can be seen in the examination of the precious analysis, the choice of the type of cooling system essentially depends on local site-specific conditions. It is therefore extremely difficult and may not be appropriate to offer a unique recommendation. The decision-making logic diagram shown in figure 13 (see Annex II) gives an idea of all the conceivable cases involved.

From the energy standpoint, wet cooling (once-trough cooling if necessary with wet cooling tower) is by far the most economical solution - combined with the ecological advantage of saving energy and avoid flue gas emissions. Whether it is carried out using the once-through technique or via a circulating system with wet cooling tower, the energy balances are favourable to this solution.

Of course, such wet cooling can only be envisaged if the receiving waterway is able to accomodate it. Within the scope of the sustainable management of water resources, it is absolutely essential that this point has to be examined carefully, particularly by taking into account future developments. A long-term modelling, integrating statistical data, is a necessary tool for estimation and assessment of the environmental impacts. It is in the basis of this essential approach that the choice of the cooling mode, concentration factor and any treatments must be made.

9. CONCLUSIONS

A BAT approach for the cooling systems of new thermal power plants requires a series of reflection points:

- the need to carry out prior studies concerning site conditions;
- the choice of corrosion-resistant materials for the heat exchange surface of condensers and cooling towers;
- the implementation of local protection (paints, cathodic protection, etc.):
- the reduction of energy consumers (fans, pumps);
- the installation of anti-noise systems (walls, panels, modification of the site relief, etc.) or the choice of solutions resulting in lower emissions (low noise fans);
- the optimisation of the use of treatment reagents and the setting up of (bio)monitors and chemical monitoring and control devices;
- the study of systems so as to be able to carry out temperatur increase operations;
- the design of water intakes to limit the drawing in of living organisms;
- a control of the quality of water discharges by the drain (temperature, oxygen, etc.).

No single solution seems to have emerged. Each case is a specific one and depends, for example, on the cycle of the power plant. In the case of units with recirculating systems, the choice of the water treatment will depend on the concentration factor selected, maximum temperatures and the quality of the water withdrawn. The same holds true for the fight against biological developments. Although macroorganisms can generally be eliminated by thermal shocks, this solution cannot be applied to eliminate biofilm.

Annex I

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