DRY SYSTEMS FOR POWER PLANT COOLING

1. Need for Water Conservation in Power Plant Cooling

Conventional cooling methods of thermal power plants are extremely water intensive processes.

Once-through cooling needs large natural bodies of water (ocean, sea or river) and disposing the waste heat into them causes thermal pollution.

Evaporative (wet) cooling towers require make-up water, emit vapor plumes with the related drawbacks, meanwhile discharge concentrated cooling water blow-down, which may pollute the surroundings.

The use of dry cooling systems completely eliminates the need for cooling make-up water.

Dry cooling systems are emitting only warm and clean air, without adverse environmental effects.

The choice between evaporative and dry cooling systems is very much depending on availability and cost of cooling make-up water.

A realistic water cost shall express that a decision made now is a decision for over three decades - the life-span of the power plant.

In addition, it shall be taken into account that power plants are competing for the limited water resources of these areas with the water need of the growing population, the existing or newly developing industries and that of the agriculture.

Thus deciding for power plant dry cooling may give chance for further development of a whole region by preserving water for future economic expansion.

Dry cooling of a 100 MW_e power plant saves water equivalent with the consumption of a town of fifty thousand inhabitants.

For completely arid inland areas, if a power plant incorporating steam cycle is needed, there is no other practical choice than dry cooling, opening new territories for plant sites.

It is also important to note that, since areas of coal and lignite deposits are often short of water, this freedom of plant location opens up new possibilities for use of important and cheap fuel reserves by setting up mine-mouth generating plants.

Considering the water intensive aspect of conventional power plant cooling methods, it is worthwhile to investigate more thoroughly the economics of non-water cooling solutions.

2. Dry Power Plant Cooling

There are two types of equally proven dry cooling systems - direct and indirect. There are dry cooled power plants in more than 30 countries, capacity-wise most of them operating in semi-arid or in arid sites.

There are plants operating under diverse ambient air temperature conditions ranging from - 50°C to + 50°C. These references provide excellent experience both, technically and economically to develop the adequate system for any unit rating or climatic conditions.

2.1 Dry Cooling Options, Circuitry and Features

In a direct dry system, the steam is condensed directly by air in a heat exchanger (air cooled condenser) and the condensate is returned to the steam cycle in a closed loop (Fig. 1.)

Most part of the condensation takes place in the condenser section at a near constant temperature, however 2-4°C below the saturation temperature corresponding to the turbine backpressure.

Another section of the heat exchanger, approx. 25 % of the surface, serves for condensing the remaining steam with higher air content; therefore it takes place in a gradually decreasing temperature with a significantly lower heat transfer coefficient due to the increasing partial pressure of the air.

Direct air cooled systems need transfer and distribution of huge volumetric steam flows, because of vacuum. Therefore, it is essential to locate the coolers as near to the turbine as possible to reduce cost of ducting and avoid too high steam side pressure loss.

The air flow is induced solely by mechanical draft at all the existing direct air cooled condensers.

Natural draft direct air cooled condensers would need not only significantly higher investment cost than the mechanical draft ones, but would bring in some such operational problems as fluctuation of turbine backpressure, high wind sensitivity, reduced availability due to the fact that at both air and steam side the flow of media is “natural flow", not a forced one by means of a mechanical equipment. Thus, there is a need for further development to evolve a reliable natural draft direct air cooled condenser.

With indirect dry cooling, cooled water from the cooling tower flows through recovery hydraulic turbines connected in parallel and is used in preferably a direct contact jet condenser to condense steam from the steam turbine.

The condensation takes place practically at the temperature corresponding to the turbine backpressure - the terminal temperature difference is not more than 0.3°C, as opposed to approx. 3°C with a surface condenser.

Furthermore, a direct contact (DC) condenser is simpler and less costly than a surface condenser and practically maintenance-free. The mixed cooling water and condensate are then extracted from the bottom (hot-well) of the condenser by circulating water pumps.

About 2-3 % of this flow - corresponding to the amount of steam condensed - is fed to the boiler feed water system by condensate booster pumps. The major part of the flow, discharged by the circulating water pumps, is returned to the tower for cooling.

The cooling deltas (water-to-air heat exchangers) dissipate the heat from the cycle. Since in case of indirect dry cooling, there is an intermediate heat transfer medium, water between the steam and the air, it is not sensitive to the distance of air coolers from the turbine exhaust.

In case of the indirect system, either mechanical or natural draft can be used for providing the required cooling air flow. In Figure 2 TRAKIA 1200MW and 3x770MW Gebze/Adapazari CCGT power plants equipped with natural draft indirect dry cooling systems are shown.

With increasing cooling capacity the natural draft becomes more and more attractive by avoiding fan power requirement and thus sharply reducing maintenance care and costs by excluding of moving elements. Whereas the increasing capacity makes the supporting structure of mechanical draft tower more expensive by requiring a high elevation for adequate air access to the heat exchangers, at least when these heat exchangers are arranged horizontally.

Application of natural draft normally is justifiable above 50 MW_e units, under special conditions like strict noise limitation even at smaller units.

Natural draft offers advantages over mechanical draft, including:

- elimination of fan power requirements;
- eliminating noise emission;
- low maintenance due to absence of large number of fans;
- increased availability;
- improved economics.

When comparing natural draft and mechanical draft variants - irrespective of whether both are indirect or the natural draft is indirect and the mechanical draft is direct (since direct is still not available with natural draft) - special attention should be paid to the evaluation of the differences in auxiliary power requirements.

The difference, coming from the auxiliary power, may be 30 % of the investment cost, at the same ITD, in favor of natural draft.

It is important to identify for all individual situations, the most economically viable alternative cooling systems. In general, for larger units, the indirect dry cooling plant tends to be superior especially when natural draft is allowed to use, while for smaller units direct dry cooling may be more advantageous.

2.2 System Characteristics

The cooling system must be analyzed and optimized as an integral part of the water-steam cycle.

The Initial Temperature Difference (ITD=the difference between condenser and ambient temperature; it means that the condenser temperature of an indirect dry cooling system closely follows the ambient temperature profile) is that parameter which determines the size, price and performance of a cooling plant for a certain cooling duty.

In case of an indirect system, it is a near constant value at varying ambient air temperatures.

The dry cooling plant capacity (CPC) can be determined as follows:

$$\mathbf{CPC = Q_{dis} / ITD\ [MW_{th}/°C].}$$

Where Q_{dis} is a heat to be dissipated from cooling tower.

Higher ITD means a higher backpressure (less plant output) but also a smaller (and less expensive) cooling plant.

The optimization of the cold-end means that the ITD value is chosen so that the investment cost and the cost of lost energy produce the lowest cost.

Depending upon the prevailing economic conditions and the requirements of the power system, the optimum overall ITD for an indirect dry cooling with DC condenser can be expected to be between 23 and 33 °C. The optimum ITD range is usually higher for the direct air cooled condensers: 28-38 °C.

Fig. 3 shows the characteristics of the direct and indirect cooling systems (condenser temperature versus ambient air temperature) and that of the steam turbine (turbine output versus backpressure).

By combining the two, "the cold end" can be characterized, illustrated by the plant net output as a function of ambient air temperature. As the curves illustrate, at direct air cooling the "choking phenomenon" may occur from part of the cooling system prior the choking point of the turbine - due to the increased volumetric flow rate at lower ambient temperatures.

Application of dry cooling relative to once-through or wet cooling results in the need of a wider range of turbine backpressure, including the need of higher value for the maximum allowable backpressure to avoid large reductions in output at high ambient temperatures.

3. The Economics of Dry Cooling Relative to Evaporative Cooling

The relative simplicity and lower direct investment cost of wet cooling towers often tempt power plant developers and utilities to prefer evaporative cooling to dry cooling alternates.

The complex evaluation of investments as well as running costs relative to the cooling system may, however, prove, that in many instances the tempting low direct investment with wet cooling is followed by some additional indirect investment costs, or by increased operating costs, and the combination of these results in a total lifetime cost exceeding that incurred with dry cooling.

The reliable analysis, to preclude a costly cooling system selection, is to compare the total costs of the candidate cooling systems in the function of various economic parameters. First, a qualitative comparison of different cooling systems is offered by Table 1.

To exemplify the chosen method, the annual costs of the cooling system options of a 100 MW_e unit are introduced and investigated here. The total annual costs associated with the cooling plant - annual operating costs, annual depreciation of the cooling system - are calculated for all the applicable cooling system candidates, and the lowest annual total cost will identify the optimum selection.

When evaluating the annual operating costs of cooling system variants, besides their own auxiliary power consumption and water requirement, also their effect on the generated electricity is determined on a year-round basis by combining the cold-end characteristic curves (Fig. 3.) with the temperature duration curve.

Table 2 is summarizing the results of the investigation for different cooling systems, assuming an annual depreciation rate of 8%, 3.5 US¢/kWh electricity cost, 15 US¢/m^3 water price and 15 US¢/m^3 for water treatment costs.

Here the differences in maintenance costs (except water treatment costs) and cooling systems' effect on the availability of the power plant are not considered, though, both would benefit the dry cooling.

With the above assumptions, the wet cooling ranks behind the front-runner dry cooling. Since, during the life-time of the power plant, a more than proportional water price increase can be foreseen, the break-even water price is also determined considering a 3% p.a. relative water price increase.

This assumption, at 3.5 US¢/kWh electricity cost, results in a smaller break-even water price (incl. treatment costs) by 15-20 US¢/m^3. Here the make-up water price of the wet cooling tower was assumed to cover all possible water related cost items, including such as primary fee of the raw water, a reservoir (if it is needed), the conducting costs (piping and power) from the primary source to a possible reservoir and from the reservoir to the wet cooling system, the investment and operating costs of the cooling tower make-up water treatment plant (including chemicals) as well as, costs or fees related to rejection of cooling water blow-down.

The break-even cost may be further reduced by considering other evaluation criteria, such as the maintenance cost difference in favor of dry cooling tower; the investment cost difference arising from the possibility that the flue gas desulphurization plant could be located inside the dry cooling tower; and finally if the power plant, served by a wet cooling tower, is penalized by 0.5 % annual generation loss due to the reduced availability caused by the surface condenser and the open water circuit. When all these factors are evaluated, the result will in favor of dry cooling system.

4. Conclusions

- There are proven dry cooling technologies, which have successfully demonstrated their technical qualities and effectiveness in power plant heat rejection.
- Dry cooling offers major benefits:
    - by conserving significant amount of water (each 100 MW_e dry cooled capacity saves water for 50,000 inhabitants),
    - by providing sitting flexibility for power plants and minimizing their environmental impact.
- Even economics of dry cooling evaluated with the present economic conditions would justify a higher level of application, if all cost items and aspects are considered.

- A decision on a power plant cooling system made now is a decision for 2-3 decades.
- A correct evaluation shall consider, that a more than proportional water price increase can be foreseen, justifying a wider application of dry cooling.

References

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	Dry System Natural draft	Dry System Mech. draft	Air Cooled Condenser	Wet system
Power consumption	low	high	medium-high	medium
Noise	no	medium	medium	medium
Wind effect	medium	medium	medium	medium
Recirculation	no	low-medium	medium	medium
Visible plum	no	no	no	yes
Polluted water discharge	no	no	no	yes
Maintenance	low	medium	low-medium	high
Plot area	medium-high	medium	medium-high	low
Flexibility in site arrangement	good	good	medium	good
Lifespan of heat exchanger / cooling fill	high (>30 years)	high (>30 years)	high (>30 years)	low (~10 years)
Special features, options:				
Chimney inside the tower	yes	no	no	no
Integrating part of the power plant or FGD inside the tower	yes	no	no	no

Table 1 Qualitative Comparison of Different Dry and Wet Cooling Systems

	Dry System Natural draft	Mechanical Draft Dry Cooling Tower	Wet system
Total Investment (USD)	6'500'000	6'450'000	4'000'000
Annual Depreciation over Power Plant Lifetime (USD/year)	520'000	516'000	320,000
Average Turbine Net Output (MW)	101	99	103
Annual Net Energy (GWh/year) –LPF 80%	708	694	722
Annual Energy Loss (GWh/year)- LPF 80%	14	28	0
Cost of Annual Energy Loss (USD/year)	490'000	980'000	0
Average Water Consumption (m^3/h)	-	-	350
Annual Water Consumption (m^3/year)	-	-	2'460'000
Annual Water Price (USD/year)	-	-	738'000
TOTAL ANNUAL COST	1'010'000	1'496'000	1'058'000

Table 2 Annual Cost Comparison for Different Cooling Systems

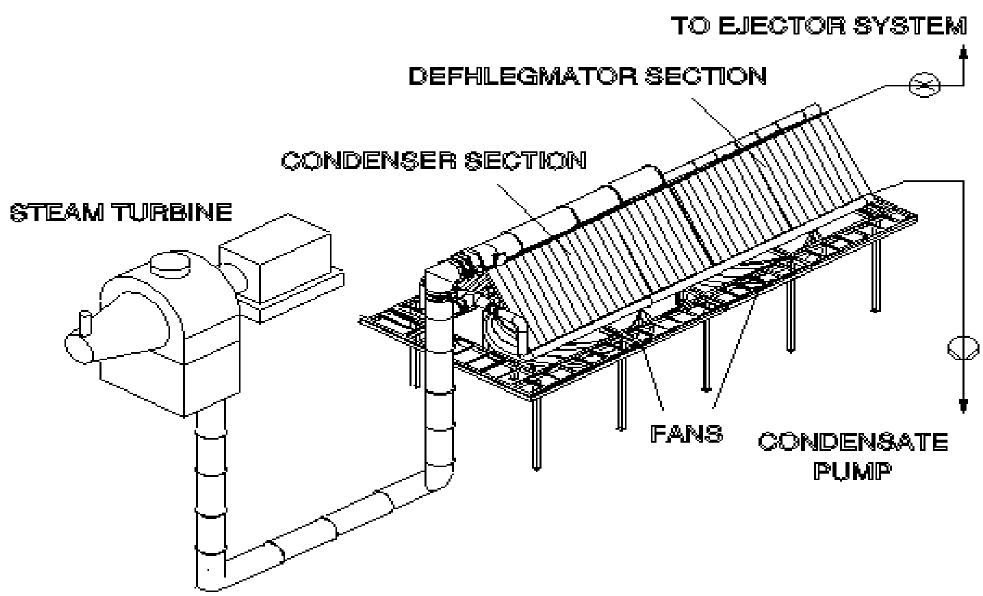
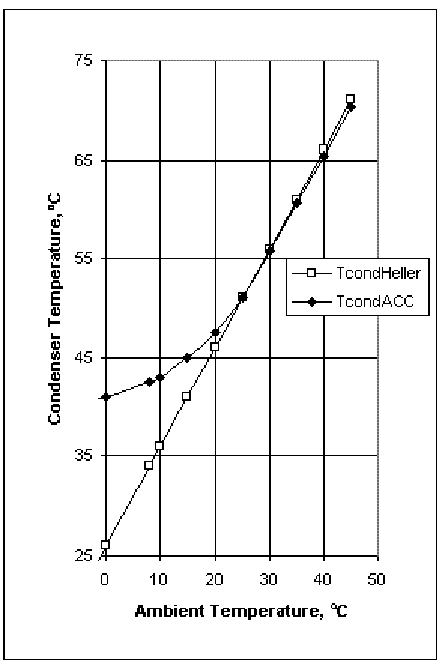
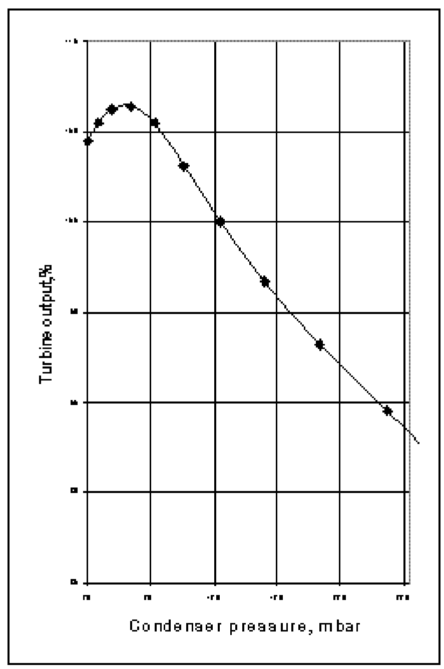


Fig. 1 Direct Air Cooled Condenser

1200MW Trakya **3x770MW Gebze/Adapazari**

Fig. 2 Worldwide Largest Dry Cooled CCGT Power Plants





Turbine **Cold-End**

Fig.3 Characteristics of Dry Cooling Systems, the Turbine and the "Cold-End"

SUMMARY

Given the problems with the availability and the price of water, plus the concerns relating to negative environmental effects of traditional wet and once-through cooling systems, the need for water conserving cooling systems has been increasing.

Dry cooling and dry/wet combinations offer technically sound and economically feasible alternatives to once-through or all evaporating type cooling systems. Emitting only warm and clean air, they have no adverse environmental effects, while making power plants practically independent from water sources.

Therefore, dry cooling and dry/wet combinations open new possibilities for power generation in areas of water shortage or locations highly sensitive on environmental issues.

Presently, there are dry cooled power plants in more than 30 countries. These references provide excellent experience both, technically and economically to develop the adequate system for any unit rating or climatic conditions.

A short review is given of the cooling system features and characteristics. A special emphasis is made on introducing natural draft indirect cooling systems, which offer technical advantages over mechanical draft (including major reduction of auxiliary power requirement, eliminating noise emission, low maintenance due to absence of air moving equipment) - thus resulting in improved economics depending on site conditions and economic factors.

The conditions of the economic application of dry cooling systems are evaluated in comparison to the all evaporative cooling systems. It is important to take into account both, the investment and operations costs, based on a year-round analysis to provide a comprehensive and realistic investigation.

By combining the characteristics of the turbine cycle with those of the dry and wet cooling systems, the year-round electricity productions (and in case of wet cooling system the water consumption, too) can be determined. As a result a break-even water price analysis is provided, showing the effect of a number of economic and technical factors, and giving orientation to the conditions of economic feasibility.

Whenever a decision is made, it is a decision for at least 2-3 decades. Considering the 20-30-year life-span of power plants and the growing problems with water availability, a more than proportional water price increase can be foreseen related to other cost items It justifies application of dry cooling even in areas presently without water shortage.

Applying dry cooling means saving water for fifty thousand inhabitants per each 100 MW_e capacity.