

Dry Cooling Technology in Chinese Thermal Power Plants

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Design of efficient dry cooling system is of critical importance for geothermal power conversion technologies. In fact, dry cooling may be the only option for most geothermal power plants planned to be established in areas with limited access to water. The heat exchange performance, flow geometry optimisation and cost are key factors in determining suitability of dry cooling towers for geothermal power plants.

China has made advances in recent years in R&D, manufacturing, and utilisation of dry cooling towers in its coal rich but water scarce Northern provinces. One driver for the surge in applications of dry cooling systems is the government regulation that requires all new coal-fired power plants built in Northern China region to use dry cooling systems. Northern China has plenty of coal but no water for wet cooling in its coal-fired power plants.

A straightforward copying of the technology from coal-fired power industry to geothermal power industry is not expected to deliver a cost-effective solution and should be avoided. Benefits would be gained by reviewing the development of dry cooling technologies in Chinese coal-fired power plants. The Queensland Geothermal Energy Centre of Excellence (QGECE) has supported Dr Zhiqiang Guan to apply for the Queensland International Fellowship aiming to review the advance of the dry cooling technology in China. In this paper a summary of dry cooling technology will be given with a focus on the Chinese practice.

Keywords: Geothermal energy, Cooling tower, natural draft cooling technology, Coal-fired power plants.

Cooling Technology in Thermal Power Plant

Thermal power plants make use of a steam cycle to transport energy from large boilers to turbo-generators. An important part of this steam cycle is the condensation of the steam downstream of the turbine. A Cooling Tower is a heat rejection device that extracts waste heat to the atmosphere by either cooling a stream of hot water from the condenser (indirect wet or dry cooling) or cooling (condensing) the steam downstream of the turbine directly (direct dry cooling). Cooling towers are classified as either wet or dry cooling.

A wet cooling is a recirculation water system that accomplishes cooling by providing intimate mixing of water and air, which results in cooling primarily by evaporation. As shown in Fig.1, the hot water

leaving the condenser is piped to the cooling tower and is pumped and distributed across the distribution deck where it flows through a series of nozzles onto the top of the tower's fill material. Fill material is used in cooling towers to create as much water surface as possible to enhance evaporation and heat transfer. The water, after being cooled by a combination of evaporation and convective heat transfer, is pumped through the condenser to condense the turbine steam in a continuous circuit.

Wet cooling towers are characterised by the means by which air is moved. Mechanical draft cooling towers rely on power-driven fans to draw or force the air through the tower. Natural draft cooling towers use the buoyancy of the exhaust air rising in a tall chimney to provide the draft.

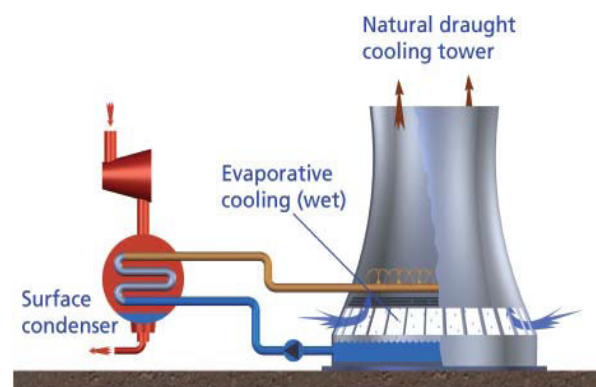


Fig.1 Wet cooling tower [GEA Aircooled Systems (Pty) Ltd]

Dry cooling towers rely on convection heat transfer to reject heat from the working fluid, rather than evaporation. The cooling takes place through air-cooled exchangers similar to radiators. Fig.2 shows configuration of natural draft dry cooling tower used by the thermal power plants.

In natural-draft cooling towers, the volume flow rate of air across the heat exchanger bundle is directly proportional to the height of the cooling tower. There are some options in natural draft cooling tower to use fans to enhance the air flow through the tower.

If fans are used as the mechanism to circulate air, then there is no need for a tall tower as shown in Fig.3. While such systems are cheaper to build, the power needed to drive the fans is significant, especially in low-efficiency cycles where proportionally more heat must be dumped for each MW of electricity generated.

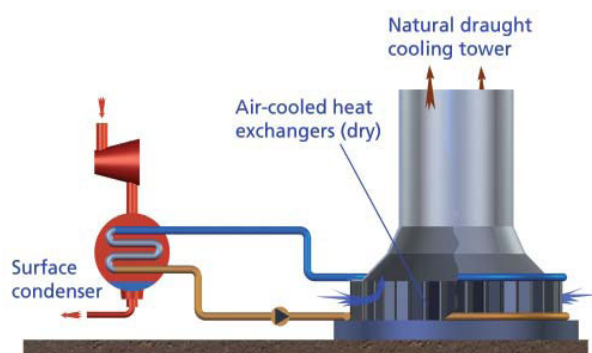


Fig.2 Natural draft dry cooling [GEA Aircooled Systems]



Fig.3 Zhenglan Inner Mongolia Province — ACC for 4 x 600 MW Coal Fired Power Plant

Wet / Dry Cooling Towers

Theoretically a wet cooling tower could cool the water to a temperature approaching the ambient air wet bulb temperature. This cooling system is more efficient, relatively cost effective to install and easy to operate. They are, however, becoming less attractive since they consume large amounts of water through evaporation and high blowdown rates. Dry cooling towers, on the other hand, cools the water to a temperature governed by the ambient air dry bulb temperature. No water is used and therefore the operating costs are lower due to the savings on the cost of water and the water treatment. Since the dry bulb temperature for air is higher than the wet bulb temperature, dry cooling towers require significantly larger heat exchange areas and they are more expensive to build than wet towers.

Water consumption

Coal-fired plant using wet cooling system would require huge amount of water annually to replace cooling tower evaporation, blowdown and drift losses. Under certain conditions, a wet cooling tower plume may present fogging or icing hazards to its surroundings. Fig.4 is a photo of natural draft wet cooling towers at a power plant.

Zhu and Guan (2006) have studied water consumption by comparing the water usage between two wet and dry cooling coal-fired power plants in China. The plants have the same power

generating capacity of 2x600 MW. The study assumed the plants operate 5500 hours yearly and the results are shown in Table 1. It is seen that the water saving is $8.8 \times 10^6 \text{ m}^3$ per year from the dry cooling system. This is based on the factor that the water consumption for other equipments in the plants is the same.



Fig.4 Natural draft wet cooling tower in power plant

Table 1. Comparison of water consumption between wet and dry cooling systems

	Dry cooling	Wet Cooling
Water consumption Index ($\text{m}^3/\text{s.GW}$) (yearly average)	~0.13	~0.5
Water consumption hourly rate (m^3/hrs) (yearly average)	560	2160
Total water consumption in a year (m^3)	3.08×10^6	11.88×10^6
Water saving (m^3)	8.8×10^6	

Coal consumption

Since evaporation process is governed by the ambient air's wet bulb temperature, which is significantly lower than its dry bulb temperature, power plant using a wet cooling system is more efficient than a similar power plant using a dry cooling tower – if the same size of cooling tower is used in both cases. Zhu and Guan (2006) have studied the coal consumption of the above two generators and the results are shown in Table 2. The cooling towers are of the same size but one plant uses a dry cooling tower, the other is wet.

The result shows that, for a 2x600MW power plant operating 5500 hours in a year, the wet cooling plant uses 145200 tonnes less coal than the dry cooling plant.

Table 2. Coal consumption between wet and dry cooling systems

	Dry cooling	Wet cooling
Sub critical generator	332	310
Coal consumption ($\text{g}/(\text{kW} \cdot \text{h})$)		
Super critical generator	317-320	298
Coal consumption ($\text{g}/(\text{kW} \cdot \text{h})$)		

Capital cost

Chai (2006) conducted a cost study on four 2x600MW power plants, one with wet cooling and the other three with dry cooling systems. The result is shown in Table 3.

Table 3. Capital cost comparison (10⁶ Chinese Yuan)

	Stand wet cooling plant	Datong power plant	Toketo power plant	Yang Chen power plant
Equipment cost	135.66	492.11	346.40	420.70
Construction cost	58.98	69.80	122.16	145.29
Installation	58.98	68.66	96.68	68.11
Total	256.82	630.57	565.24	634.10

Results of a similar analysis conducted for US plants was presented by Maulbetsch (2008) in an Advanced Cooling Workshop in Charlotte, NC and the US results according to this study are presented in Fig.5. Based on these limited samples, in US, the capital costs of dry cooling systems appear to be about 3.0 - 3.6 times higher than wet cooling systems and, in China 2.0 - 2.5. It should be noted that the operating cost will vary depending the cost of water and water treatment.

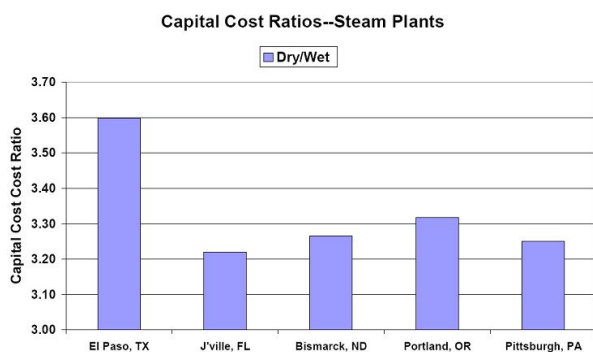


Fig.5 Cost comparison by Maulbetsch (2008)

Market Potential of Dry Cooling in China

Based on the current GDP growth rate in China, the demand for electrical power is significant. It has been predicted that the increase of the electricity must be at least 7% to maintain the country's GDP growth. Reportedly using conservative assumptions, Liu (2007) predicts the total electric energy demand for 2010 and 2020 to be 818 GW and 1186 GW, respectively, as shown in Table 4.

Chen (2008) predicts the demand for dry cooling systems for heat exchanger manufactures as shown in Table 5. Based on his prediction, there will be about 30 new dry cooling power plants in 2007, 40 in 2008, 45 in 2009 and 45 in 2010 with average capacities equivalent to 600MW, to be requiring heat exchangers for their dry cooling

systems. The market is expected to get even bigger if water becomes more expensive.

Table 4. Electricity demand predicted by Liu

Year	2006	2010	2020
Total power (GW)	622	818	1186
Coal Power (GW)	484.05	624.5	780
Hydraulic (GW)	128.57	180	320
Nuclear (GW)	6.7	8	40
Wind (GW)	2.589	5	40
Other (GW)	0.091	0.5	6

Table 5. Air cooling power plant potential

Year	2007	2008	2009	2010
New installed air cooling plant (GW)	18	24	27	27

Heat Exchanger Manufacturers

Heat exchangers are the most expensive and the most critical components in dry cooling systems of thermal power plants.

Due to the attractive market potential for heat exchangers, international and local Chinese companies are competing to produce high performance and cost-effective heat exchangers and cooling towers. Two leading international companies, SPX and GEA, have set up production lines and factories inside China. There are four major Chinese local manufactures that have emerged in recent years in competition to SPX and GEA.

Finned tube bundle design shown in Fig.6 is the only heat exchanger element used in thermal power plants. In this figure, extended surfaces or fins are used to increase the heat transfer surface area. The challenges for the manufacturers are to produce low-cost finned surfaces that must resist corrosion, be lightweight but have adequate mechanical strength.

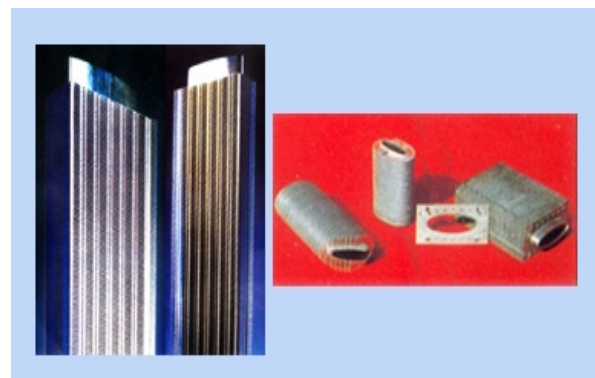


Fig.6 Finned tube heat exchanger

SPX Cooling Technologies is the leading full-line, full-service cooling tower and air-cooled

condenser/heat exchanger manufacturer. SPX has set up finned tube heat exchanger plants in Zhang Jia Kou and Tianjing respectively. Their market share is almost 35% in Chinese coal-fired power plants.

GEA has also set up a subsidiary in Longfan to manufacture finned tube heat exchangers. It also has two joint ventures with local Chinese partners in Shang Xi and Changshu. The market share of GEA is about 30%.

Harbin air conditioning Co., Ltd. is the largest local heat exchanger manufacturer in China. Their dry cooling products cover about 20% in coal-fired power plants and about 50% in the petroleum and chemistry processing plants.

Other heat exchanger manufacturers in China include Beijing Longyuan Cooling Technology Co., Ltd., Shouhang IHW Cooling Technology (Beijing) Co., Ltd. and Jiangsu ShuangLiang Air-conditioning Equipment Co., Ltd.

Dry Cooling Research and Cooling Tower Design

While most large heat exchange manufacturers can provide design, manufacture and installation for the entire cooling system including heat exchangers and the cooling tower, most of the natural draft cooling tower design and installation are done by power design and research institutes in China.

The China Institute of Water Resources and Hydropower Research (IWHR) is a comprehensive research organization in thermal and nuclear power. The institute has a division specializing in cooling tower design, cooling processing optimization, efficiency improvement of heat exchange and the cooling tower simulation.

IWHR has conducted intensive studies on the optimisation of the natural drafting cooling towers to improve the cooling efficiency.

Beijing University and Tsinghua University play a leading role in CFD, heat exchanger research and natural draft cooling tower optimisation.

Other universities specialised in heat exchange and cooling tower related research include North China Electric Power University, Chongqing University, Harbin Institute of Technology, and Xi'an Jiaotong University.

Cooling Tower in Geothermal Power Plant

The heat rejection per kWh(e) of net generation from geothermal power plants will be four or more times as great as from fossil-fuelled plants (Kroger, 2004). This will require larger cooling towers at higher costs.

Water shortage exists in most proposed Australian geothermal sites. The dry cooling will be the only option for these geothermal power plants. Mechanical draft consumes a large amount of power for driving fans so natural draft cooling system may be more attractive, provided the capital cost is acceptable.

Surrounding environment conditions have also a significant impact on the performance of power plants with dry cooling systems. Most proposed geothermal sites experience large daily temperature differences. An excessive rise in cooling water temperature during periods of peak ambient temperature will result in a loss of efficiency. In this case, hybrid cooling tower combining dry and wet cooling system (such as the system shown in Fig.7) may prove more cost-effective. In this design, both dry and wet sections are operated at the peak ambient temperature while only the dry section is used for the rest of time.

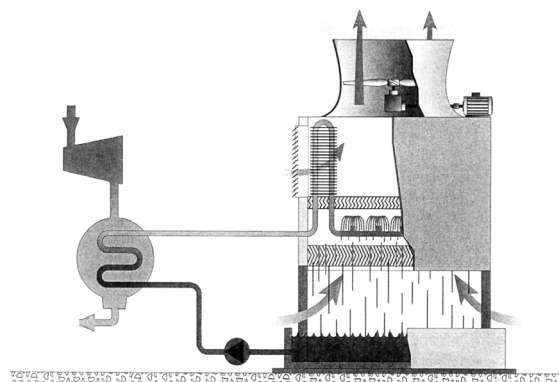


Fig. 7 Natural draft hybrid cooling system

Other options for geothermal plant cooling include precooling the entering air by humidification or deluging the air side of the heat transfer surface with water during the high cooling demand.

Fans may also be used to enhance the natural cooling during high ambient temperature.

Summary

An appropriate and well-designed cooling system can have a very significant positive impact on geothermal power plant performance and profitability.

The combination of theoretical and experimental studies as well as extensive practical experience in dry cooling technology in Chinese coal-fired power industry may offer good examples towards a cost-effective design and operation of such cooling systems for Australian geothermal power industry.

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