CO_2 Reduction by Cooling Tower Retrofit Measures

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ABSTRACT: In the course of a cooling tower retrofit a cold-end-optimisation should be done. Due to installing best available technology of cooling fills a decrease of cooling water temperature and additional power output can be generated. The following consideration shows options of improvement and takes a look at the economic importance.

1 INTRODUCTION

Increase in efficiency of steam power plants is an ongoing demand, relevant for all components of the thermodynamic cycle. The cooling tower is a significant part for the condensation pressure and therefore has an important influence on the efficiency of the low pressure turbine. Most of the cooling towers are designed as evaporative heat rejection devices, implying an environmental interface by transferring condensation heat to atmosphere. Even a good water treatment and water quality does not guarantee the entire prevention of scaling and biological fouling effects on cooling fills, the core of the heat exchanging and mass transferring surface. Hence the thermal performance will be reduced anyway during a 20 to 30 year operating period. The amount of reduction depends e.g. on air pollutant, make-up water condition and water treatment facilities. A reduced thermal performance entails an increase of cooling water temperature and condensation pressure causing a negative effect on power plant efficiency and it´s CO_2 emission.

Over the last two decades cooling fills made of fibre and asbestos cement have been mostly replaced by plastic film and splash type fills. Changes of moulds and materials into PP and PVC have raised the heat and mass transfer significantly. Hence power plant companies are able to improve thermal performance of out of date cooling towers, even beyond the original design. In this way a regular refurbishment of a cooling tower creates additional benefit of power generation.

Retrofit of cooling towers is limited by constructional and financial boundary conditions. Mostly the pumping head and structural dimensions are fixed, by contrast other influencing variables like cooling fill height are often mutable within some limits. Recalculations of thermal performance demand a close cooperation between power plant and cooling tower companies, in order to define optimized options. With optional thermal cooling tower calculations a power plant operator should be able to evaluate the best available technology with regard to economic aspects. This approach will be shown by means of a thermal and economic analysis of a typical, in the eighties erected, natural draught cooling tower.

2 INITIAL SITUATION

The considered natural draught cooling tower (NDCT) is the heat rejection device of a 500 MW coal fired power plant with a total efficiency of approx. 40 %. During more than 20 years the thermal performance of the cooling tower declined which causes an increase of the temperature level of the exhaust steam by about 0.4 K. Probably this is caused by fouling and scaling effects of the water distribution system and the cooling fills which are virtually not to clean. This increase of cooling water temperature and condensation pressure is to be compensated or overcompensated by the refurbishment. A higher thermal performance of the cooling tower will gain an additional benefit in terms of power output. This effect will be calculated and compared for different retrofit options.

3 RETROFIT MEASURES

A natural draught cooling tower consists of a concrete structure and cooling part. In the cooling part water pipes, sprayers, cooling fill and drift eliminators are summarised which can be replaced with a manageable effort as opposed to the concrete parts. Therefore this consideration pays attention to three options of a cooling technics refurbishment.

3.1 *Technical Options*

The three considered retrofit options differ in fill height (FH) in which the current fill height is represented by option 1, option 2 has approx. 30 % increased height and option 3 has an approx. 50 % increased fill height compared to option 1. Two boundary conditions limit the improvement of thermal performance by increasing the fill height. At first the pressure drop rises with fill height so that a fill height of more than 1.8 m is mostly inefficient. The second limit is the distance between the level of water distribution and top of air inlet, because the fill must not extend into the air inlet. In order to install more cooling fill one layer of fill can be clung under the existing fill in the center of the cooling tower. This entails different fill heights and has to be considered by calculating an average fill height.

All options are to be calculated with different fill types. The suitability of fill types is mainly a question of water quality. The better the cooling water quality the better is the thermal performance of possible cooling fill. In the considered power plant the circulating water analysis shows a good water quality which makes all fill types applicable, even the high performance cross corrugated film fill.

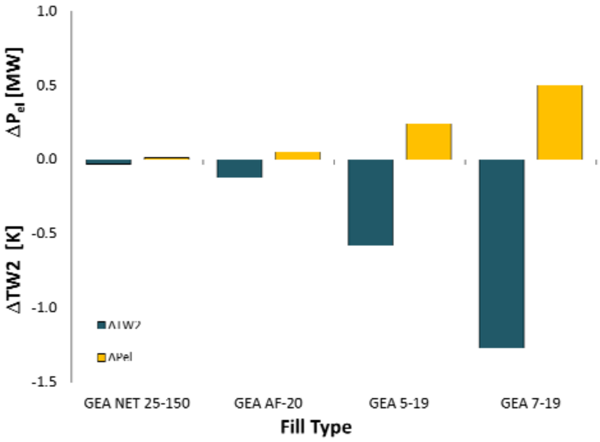

Figure 1: Thermal performance and power output
for option 1 and different fill types

Figure 1 shows the feasible cooling water temperature improvement of different cooling fills (cf. Figure 2) and the resulting additional power generation for a retrofit with an identical construction of the cooling part in terms of fill height FH = 100 % (option 1). As the reference value of temperature the former design values are used. Even the trickle grid (GEA NET 25-150) and vertical flow film fill with offset (GEA AF-20) who are designed for poor cooling water quality lead to a small decrease of the condensation temperature. With cross corrugated film fills (GEA 5-19 and GEA 7-19) a temperature decrease of 0.58 K up to 1.27 K and a corresponding increase of power generation of 0.24 MW till 0.50 MW are feasible. The GEA 7-19 is the successor of the GEA 5-19 and is equipped with an improved substructure. For the sake of clarity and because of the best thermal performance only the GEA 7-19 will be considered in the following considerations.

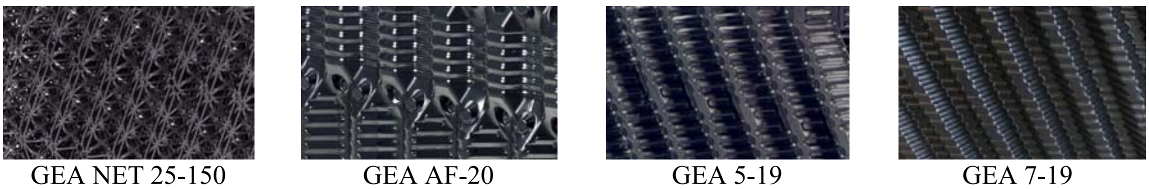

Figure 2: Considered film and splash type fills

3.2 *Definition of characteristic Load Cases*

In order to find an optimal compromise of costs and increased power output a calculation on an annual basis is to be considered. Therefore the operating company defined relevant load cases and associated hours of operation. Parameters to be considered during the definition of load cases are environmental conditions and process parameters of the power plant. Hence the definition of load cases comprises dry and wet bulb temperature (DBT and WBT) and process parameters like water mass flow and heat.

Figure 3 shows the cumulative curve of the ambient conditions in the site region with different load cases. Besides the primary design condition (DBT = 8.5 and WBT = 6.6 °C) two additional load cases have been defined by operator. Both of them are higher while the lower one represents transitional season and the higher one summer operation. It becomes obvious that the original design point is an average of the whole year (8760 h). Allowing for winter operation and cold ambient temperatures the neglecting of temperatures below approx.

4 °C is reasonable which leads to the lower one of new defined load cases. The higher load case represents summer operation in which the cooling tower capability is most important.

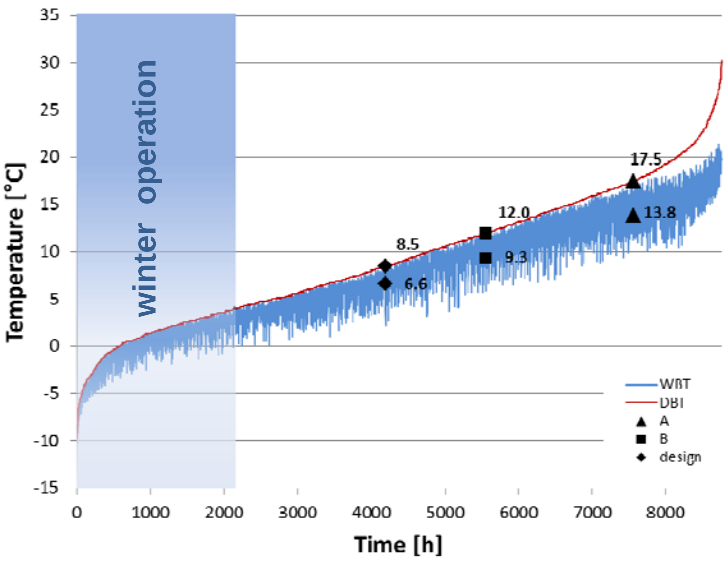

Figure 3: Environmental data with design data and load cases A and B

The two load cases are subdivided into six load cases with different boiler load and heat extraction given in Table 1. For every load case a number of 500 full load hours a year is realistic. This low utilization of the power plant which was former used as a base load power plant has been effected by the change in German energy policy for the last 12 years. The deviation in cooling water mass flow of 6.8 % between primary design and additional load cases is often a result of safety margins during design phase.

Table 1: Load cases

Load Case		Design*	A1	A2	A3	A4	B1	B2
T_{dry}	°C	8.50	17.5				12.0	
T_{wet}	°C	6.60	13.8				9.3	
TW1 (hot water)	°C	33.68	38.1	37.4	34.4	33.7	32.6	28.5
TW2 (cold water)	°C	19.85	25.0	24.9	24.4	24.3	21.5	20.4
Water Mass Flow	kg/s	10300	11000					
Heat Load	%	100	100	100	75	75	100	75
Heat Extraction	MWth	0	0	30	0	30	100	100

*) former design values

3.3 *Potential for additional Power Generation*

The amount of additional power generation is to be calculated with a detailed model of the power plant and cooling tower. Thus the operating company and GEA Energietechnik GmbH worked closely together in order to get significant results. A calculation of the potentials for the three different fill heights represented by option 1-3 with fill type GEA 7-19 leads to the results summarised in Figure 4 and Figure 5.

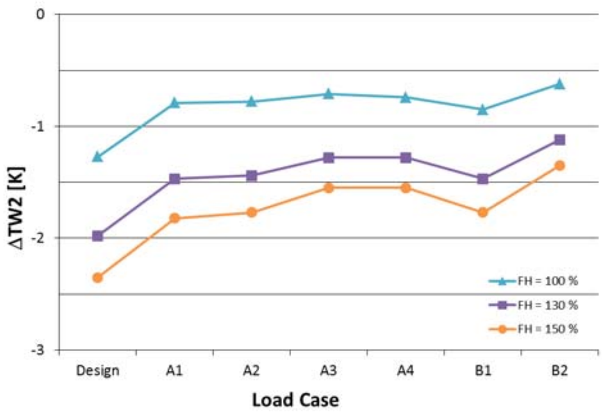

Figure 4: Cooling improvement

The highest improvement of thermal performance shows option 3, option 1 and 2 are less efficient with a minimum ΔT of -0.62 K. The strong distinctions between the different load cases are mainly a result of ambient conditions and heat load. Heat extraction for district heat and deviations in cooling water mass flow cause only deviations of approx. 0.2 K. With a improvement of -2.35 K the design case is dominant because of the low ambient temperatures, deviating water mass flow and zero heat extraction. Here the focus is yet on the load cases A1-B2 because they are defined on the basis of operational experience by operator.

Looking at the corresponding increase of power output, shown in Figure 5, it is remarkable that the additional power generation is not close-coupled to the improvement of cooling performance. Reason for this is an increased flow loss in the low-pressure turbine when condensation temperature level decreases. It becomes most visible under design condition where the condensation temperature decreases by 2.35 K but the corresponding increase of power generation is only 0.79 MW. In contrast the smaller improvement of cooling water temperature in load case A1 causes a higher additional power generation (1.82 K, 1.54 MW). A low-pressure turbine, optimised for lower condensation pressure, may halve the flow loss but entails much higher costs compared to cooling tower improvements.

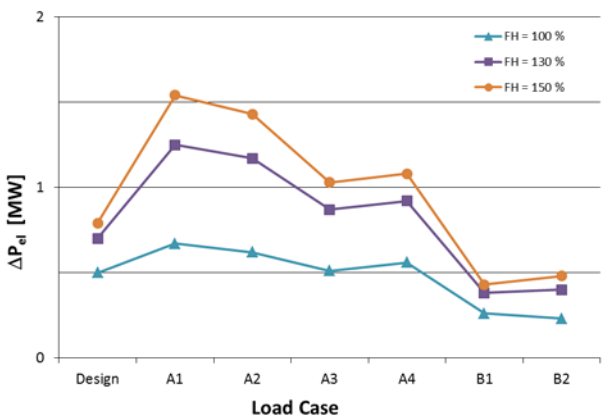

Figure 5: Additional power generation

The corresponding average annual additional power output is about 0.48 MW, 0.83 MW and 1.00 MW for the options 1-3.

3.4 *Additional parameters for Optimisation*

During this consideration additional interesting aspects related to the cooling water mass flow where found. At first it is remarkable that a reduction of cooling water mass flow does not cause a lower power output. Normally it causes a higher cooling range and due to that a higher condensation temperature. But in this particular case the increase of thermal performance in the cooling tower and the resulting additional power output (cf. Figure 6) compensates the effect of the higher cooling range.

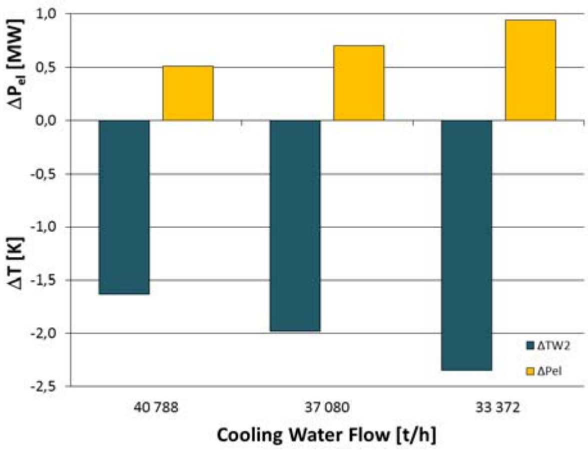

Figure 6: Effect of variation of cooling water mass flow
on temperature level and power output

Secondary cooling positions like oil coolers and the cooling of the generator need also cooling water. Normally this cooling circuit is arranged parallel to the condenser and the downstream is mixed in to the water of cooling tower intake. If this partial stream is high and his warming-up low the mixing temperature decreases with a negative influence on the plant efficiency. With a bypass flow of about 15 % the mixing temperature in the specific case is 0.97 K lower than condenser outlet. That entails a power loss of approx. 0.4 MW. Limited by the maximum allowable temperature of the secondary heat exchangers and plant design the partial stream mass flow is to be adjusted that his temperature gets close to these of the condenser outlet. By doing this an optimal exploitation of the cooling circuit is ensured.

4 RESULTS

The economic evaluation and feasible emission saving are described in the following two sections.

4.1 *Feasible CO_2 Emission Savings*

Feasible savings in terms of CO_2 and other pollutions can be calculated on basis of the additional power output. The increase of power plant efficiency leads with a assumed CO_2 emission of 898 kg/MWh [Krewitt & Mayerhofer 1997] to a saving of more than 2690 t/a for option 3. Option 1 and 2 are saving more than 1280 respectively 2240 t/a. For lignite fired power plants this amount may increase for the same cooling tower retrofit by approx. 20 % [Wagner & Koch 2007].

4.2 *Amortisation and Opportunity Cost*

With applicable options of cooling tower refurbishment an additional power generation of about 3000 MWh/a is possible. This benefit is limited by different parameters like few full load hours, heat extraction and flow losses in the low-pressure turbine. Refurbishment measures in other power plants thus can have much higher effect.
The economic feasibility is to be shown in dependence of investment volume, electricity rate and calculated plant improvements. Based on the investment volume of a simple replacement of the current configuration the additional power output is to check against greater investment for option 2 and 3. By doing this it can be shown that option 2 is more efficient than option 3. This option needs additional supporting structures and thus the investment increases more than the cooling capability, compared to option 2. With an estimated electricity price of 50 €/MWh [EEX 2012] and costs for CO_2 certificates of 9 €/t the amortisation for option 2 comprises 1.5 years and approx. 3 years for option 3. These short payback periods are possible because drift eliminators and water distribution are already included in the simple replacement. If the drift eliminators and water distribution are in good condition it is possible to waive the replacement of them. It reduces the investment by approximately 50 %.

5 CONCLUSION AND OUTLOOK

Concluding we may say that a cooling tower retrofit is to be used for an improvement of plant efficiency. This can be achieved by using state of the art cooling fill and the feasible improvement is approx. 0.15 percentage points or 0.37 %. Even the considered power plant that meets the European standard offers the possibility to save more than 2690 t of CO_2 a year. With use of opportunity costs in the amount of up to 180 000 €/a the amortisation periods are short.
Furthermore additional parameters may be taken into account like circulating water mass flow, water quality and the secondary cooling positions. If their downstream temperature is too low it decreases the cooling tower capability. The rule of thumb is that the downstream temperature should be about the same like condenser outlet temperature.
Other optimisation potential, especially the reduction of a.m. flow loss in low-pressure turbine, may double the increase of power output but causes much more investment costs than the cooling tower retrofit.

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