University of Banja Luka
Faculty of Mechanical Engineering
DEMI 2019
Banja Luka, 24 - 25 May 2019
14th International Conference on Accomplishments in Mechanical and Industrial Engineering

# THERMAL CAPABILITY OF HYPERBOLIC COOLING TOWER

**Filip Mojsovski[1], Vladimir Mijakovski[2]**

***Summary:*** *Operating flexibility of hyperbolic cooling tower, used for large power installation, is examined at various loads and weather conditions. Existing cooling tower theory can't be sufficient for predicting, planning and improving the cooling tower thermal capability. With the actual research, a procedure for evaluation of thermal capability of hyperbolic cooling tower is offered. The analysis is performed in four phases: 1. design of cooling tower, 2. building of unit, 3. field acceptance test, and 4. long term exploitation. Tested cooling towers are used in the field of electric power generation and correspond to thermal power units of 100 and 200 MW. Performance curves, based on long term operation experience, are proposed.*
*Key words: cooling tower, thermal capability, performance curve*

## 1. INTRODUCTION

Thermal power plants in the regions with insufficient natural water resources use cooling towers. This solution provides balance of investments, operating costs and environmental impact with the demands of a cooling system.

Direct-contact, natural draft, hyperbolic cooling towers are designed and manufactured for application to specified heat load amounts, needed in thermal power plants, [1].

The project documentation of cooling tower is always completed with performance curves. They show the predicted cooling tower performance rating at nominal design parameters, as well as performance of cooling tower at other than design conditions.

Using the performance curves, may be identified the feasibility of varying some parameters to meet specific applications. For example, if the cooling tower operates in a region with lower wet-bulb temperature, lower cold water temperature can be reached.

After the building, the thermal capability of cooling tower can be accurately determined only by thermally testing the tower. The range, a cooling tower must accommodate, is provided by taking combinations of flow rate and heat load.

The thermal capability of a cooling tower depends on four factors: tower construction, local weather conditions, water temperature, and water flow rate.

[1] Associate Professor, Filip Mojsovski, Skopje, Faculty of Mechanical Engineering, (filip.mojsovski@mf.edu.mk)
[2] Professor, Vladimir Mijakovski, Bitola, Faculty of Technical Sciences, (vladimir.mijakovski@tfb.uklo.edu.mk)

In the tower construction, the shell form and the fill packing are of primary importance. Some elements of cooling tower construction are replaceable. Complete fill packing, or parts of it, are renewed when designed capability of cooling tower is affected by the actual bad state.The operation of each individual component of cooling tower ought to be under continual inspection and any degradation in performance should be eliminated.

Used materials for cooling tower construction ought to deal with building static, water quality and atmospheric conditions. Usually, reinforced concrete is selected for hyperboloid shell, plastic for film-type fill bundles and metal for hot and cold water pipelines.

Water to be cooled is exposed directly to the atmospheric air and therefore the thermal performance of cooling tower depends strongly on local weather condition. At the large water-air surface area, in the process of simultaneous heat and mass transfer, heat is removed from the water and then dissipated in the environment. Air discharged from a cooling tower is essentially saturated and if the ambient air surrounding the tower cannot absorb all of the moisture, the excess condenses as fog. For that reason, the selection of cooling tower location should be realized with considering the effects of possible fogging. A psychrometric analysis of the air passing through a cooling tower shows that thermal performance of a cooling tower is mainly influenced by the air wet-bulb temperature, [2]. The amount of heat exchanged between the water and the air is proportional to the difference in enthalpy of the air at the entering state and the exit state. Because, in the psychrometric chart, lines of constant enthalpy correspond almost exactly to lines of constant wet-bulb temperature, the change in enthalpy can by analyzed by the change of the wet-bulb temperature in the air.

Local weather conditions are provided by national weather service. Thermal engineers predict the states of atmospheric air by the use of climatic curves, [3]. To obtain these curves, long term hourly observations for air temperature and relative humidity are exploited. The examination and interpretation of long term weather conditions in the layers of air, adjacent to the earth surface, usually are conducted for annual or summer period. Three steps action is needed in development of climatic curve for new location: 1. providing long term observations for air temperature and relative humidity, 2. statistical elaborating of collected data and 3. transferring the values with maximum frequency of occurrence, into psychrometric chart. In North Macedonia, climatic curves are published for Skopje, and prepared for Bitola.

Water temperature and water flow rate should be within the range of normal operating level for power plant thermal cycle. Regarding to cooling towers, tested in the actual research, which are with decades in exploitation, of great importance was to take into account the possibility for increasing the capacity of thermal power unit. For example, Tower 1 is located in thermal power plant which worked long time as 600 MW unit, but now has reached 700 MW, without adding new cooling tower.

## 2. IMPROVING THE THERMAL CAPABILITY BY THE USE OF COLLECTED DATA AND EXPERIENCE FROM LONG TERM OPERATING OF COOLING TOWER

Cooling tower theory, developed by Baker and Shryock, [4], explains the process of energy and mass transfer, and after half century is still cited, but the equations are not self-sufficient and are not subject to direct mathematical solution. In cooling tower practice, predicting, planning and improving of thermal capability is needed.

With the actual research, a procedure for evaluation of thermal capability of hyperbolic cooling tower is proposed. The analysis is performed through four phases: 1. design of cooling tower, 2. building of unit, 3. field acceptance test, and 4. long term exploitation, which means evaluation of thermal performance at changeable operating and weather conditions. Finally, all the experience was introduced into, so-called, real performance curve.

Tested cooling towers, are used in the field of electric power generation, and correspond to thermal power units of 200 MW, ("Tower 1") and 100 MW, ("Tower 2"). Tower 1 is designed by Marley, England and is located in Bitola region, Tower 2 is designed by Chlodnie Kominowe, Poland and is located in Kicevo region.

## 2.1. FIRST PHASE - DESIGN OF COOLING TOWER

In the design phase, the thermal capability of cooling tower can be increased: 1. with optimization of shell form, and 2. with maximization of the contact surface water-air.

Shell form should follow the air flow shape, dictated by heating, humidification and acceleration of air, during its vertical movement inside the cooling tower. In correctly designed shell, air flow stream does not suffer of excessive compression, neither it is separated from the shell inner side.

The main question, for the designer of cooling tower fill, is "How to maximize the contact surface water-air, for given flow of water and air". A larger contact surface water-air provides more intense heat transfer and so, the improvement of cooling tower thermal capability or colder leaving water. Therefore, more efficient cooling tower fill packing or larger cooling tower produces closer approach, for the given heat load, flow rate and entering air condition.

In the project documentation, the manufacturer is trying to express the thermal capability of the cooling tower as a water flow rate at a specific operating temperature conditions: entering and leaving water temperatures, entering air wet-bulb temperature, and entering air dry-bulb temperature. In the Marley project documentation, the designed thermal performance capability of actual cooling tower, is expressed as cold water temperature at two specific operating conditions, wet-bulb temperature and range. In the Chlodnie Kominowe project documentation, the designed performance capability of cooling tower, is expressed as cold water temperature at two specific operating conditions, wet-bulb temperature and temperature difference between dry-bulb temperature and wet-bulb temperature.

Nominal design parameters for both cooling towers are shown in Table 1.

In the performance curves of Tower 1 and Tower 2, the nominal design parameters, from Table 1, are used to represent the design point, for 100% design flow. The charts, covering 70 % and 110 % of design flow are also provided.

When the ambient temperature is off-design or when heat load or water flow rate varies from the design conditions, a cooling tower will operate at other temperature levels.

Tower 1 has two pipes inlet connection and operates with hot water at temperatures between 35 and 50 °C, and cold water at temperatures between 25 and 35 °C. The inlet piping to the cooling tower is realized by two 1620 mm diameter pipes. A concrete distribution basin receives all the hot water and directs it in every tower quarter by 2350 × 1000 mm channel. The hot water continues its way through 250 mm, 200 mm and 150 mm pipes to the 2920 sprayers. Small amount of hot water can by send to the cold water basin by two bypass pipes. Cold water outlet uses two 1620 mm pipes.

Table 1 *Nominal design parameters of cooling towers*

| Subject | Tower 1 | Tower 2 |
|---|---|---|
| Shell | | |
| - Basement diameter, m | 81 | 58 |
| - Top diameter, m | 51 | 32 |
| - Height, m | 108 | 65 |
| Water | | |
| - Hot water temperature, °C | 38,2 | 35 |
| - Cold water temperature, °C | 29 | 26 |
| - Flow rate, t/s | 8,3 | 4,7 |
| - Range, °C | 9,2 | 9 |
| Air | | |
| - Wet-bulb temperature, °C | 20 | 12 |
| - Dry-bulb temperature, °C | 25 | 15 |
| Water-Air | | |
| - Approach, °C | 9 | 14 |

Tower 2 has one pipe inlet connection and operates with hot water at temperatures between 30 and 40 °C, and cold water at temperatures between 20 and 33° C. The inlet piping to the cooling tower is realized by 1620 mm diameter pipe. A concrete distribution basin receives all the hot water and directs it in 32 radially placed pipes DN 350, than 64 DN 250 and finally 128 DN 200 pipes.

### 2.2. SECOND PHASE – BUILDING OF COOLING TOWER

Building operations and materials were inspected and reported during the construction period. Disagreements with the project documentation were analyzed, regarding to their influence on correct functioning of cooling process.

In the building phase, of one of the three cooling towers located in the same thermal power plant as Tower 1, concrete shell construction was stopped at height of 83 m, instead of 108 m, because of static error in the process of constructing. So, the profile of cooling tower has lost the hyperbolic character, and has become a simple chimney. With this cutback the cooling function of this unit was essentially reduced. Exactly, damaged cooling tower remained more as a memento of bad mistake in building process, than as a relevant element of a cooling system. Later, the manufacturer has tried to install additional cooling tower capacity, in the neighboring cooling tower, Tower 1, located at 50 meters of ruined unit.

In the building phase of Tower 2, the manufacturer, failed in the attempt to find hot water circulating pump with correct capacity, and has built a vast size pump. At these conditions the function of cooling tower was impossible, and until the purchase of new pump, the thermal power plant worked using water flow damper installed behind the pump. Technically, that was the period of undesirable state, to produce energy and then to destroy the excess of energy by damper.

## 2.3. THIRD PHASE – FIELD ACCEPTANCE TEST

Seeking assurance that a cooling tower will work in accordance with the project requirements, purchaser has conducted test procedure. After the building and the tentative period, the function of the actual cooling towers was tested by guarantee and normative tests, [5], [6], [7], [8]. In either procedure, the tests consisted of collecting the data, evaluating the data, calculating the test result and preparing the test report. During the test period, the cooling tower was running under a steady heat load, as near as possible to the design state. Selection of weather conditions was also practiced. Reasonably stable weather states were used. Horizontal wind speeds, at the top of the cooling tower, over 5 m/s, were not permitted, to ensure correct test procedure.

In the first version, acceptance tests for Tower 2 negatived the guaranty. The problem was occurrence of water flow rate for 20 % over the nominal value. As result of this state, the hot water, after entrance in the cooling tower, overflowed the edge of distributive basin and fell as large jets in the cold-water basin. With this bypass effect of water flow, the function of cooling tower was destroyed. The owner of the cooling tower was disappointed to discover that the purchased tower does not perform as it should, and the penalty for non-performance of contract was activated. The manufacturer has exchanged the main circulating pump with a smaller one, in an effort to improve cooling system performance and has refunded a percentage of the contract price proportional to the provoked temporary loss in the power of thermal power plant.

## 2.4. FOURTH PHASE – LONG TERM EXPLOITATION

Performance curves, prepared by the producer of typical cooling tower, can offer only estimated value of thermal capability, because the location of cooling tower is usually not known yet, and the operating experience don't exist, [9]. Real performance curve may be available only after long period of cooling tower operation. In those circumstances, corrected performance curve can be used as some form of capacity control tool, offering support during the normal operating season, when cooling tower encounters substantial changes in ambient wet-bulb temperature and load.

A true performance level for the cooling tower can be followed and registered in practice. Systematic documentation of operating functions and reached results is important for long term operating analysis. Efficient operation and thermal capability of cooling tower depend on correct functional state of each individual component and both working media, atmospheric air and cooled water. Water quality is extremely important for the intensity of the process of heat transfer at the water-air surface area. An oily film, excessive foaming or scum, at the water-air surface, inhibits heat transfer. The water cleanliness, of both cooling towers, was many times threatened with birds feathers collected at the exit grating from the cold water basin. In the case, when the heated and humidified air, at the top of the cooling tower, forms air stream separated from the shell, outside air enters in the pocket between the inside surface of shell and the air stream, pulling down the birds.

Tested cooling towers are in the fourth decade of their use. They started operating in 1981 and 1984. Tower 1, is one of three identical, located at the same thermal power plant. Tower 2 is unique at the location. Their long term exploitation provided enough data and experience for analysis of tower thermal capability and for making the real performance curve.

All in the day's work of cooling tower is registered in the document: "Cooling tower - daily report". Collected data, in those reports, shows that cooling capability in some tropical days of summer period or in the cases of damaged uniformity of air and water distribution throughout the fill pack, is critically endangered. At hot ambient conditions, the reduced water flow or heat load is usually one enforced solution. With the use of real performance curve, expected cooling tower range can be disclosed. That is the recorded value, already reached in the past, under similar operating conditions.

The performance curves for Tower 1 and Tower 2, shown in Figure 1 and Figure 2, are not the predicted performance curves supplied by manufacturers of cooling towers. The diagrams in Figure 1 and 2, brackets the acceptable tolerance range of required parameters, collected in long term operating conditions, and may be considered as safe and verified tool for thermal engineers, from the both thermal power plants.

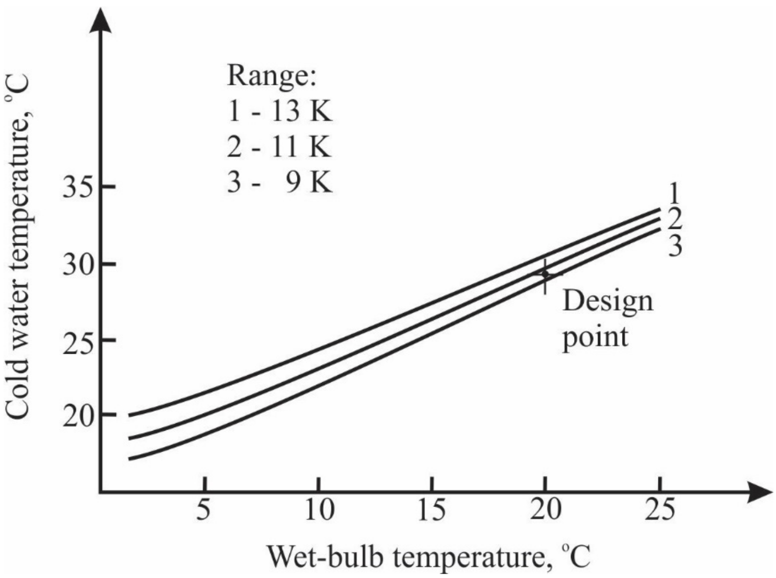


Fig. 1 *Performance curve for Tower 1*

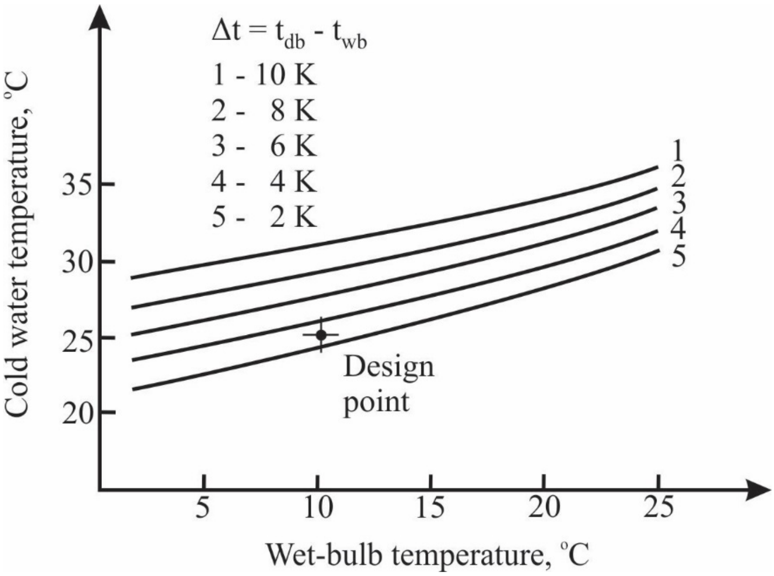


Fig. 2 *Performance curve for Tower 2*

## 3. CONCLUSION

Thermal capability of hyperbolic cooling tower is analyzed for towers with long term operating experience. In the industrial environment, in which this research was conducted, the exploitation regime of cooling tower depends on weather conditions and correct state of its functional elements. Therefore, the proposed real performance curves are important for thermal power station process managing. The procedure presented for transforming the predicted performance curves supplied by manufacturer, into real performance curves, appeared applicable to evaluate the right thermal capability. This method is based upon the use of all relevant data, from the design period of cooling tower to the period of actual exploitation.

## REFERENCES

[1] Harte, R., Wittek, U. (2009). Recent developments of cooling tower design, *Proceedings of the International Association for Shell and Spatial Structures (IASS) Symposium*, Valencia.

[2] ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) (2012). Cooling towers, *Handbook HVAC Systems and Equipment*, Atlanta, Georgia.

[3] Mojsovski, F. (2016). Entering air state influence on thermal performance of hyperbolic cooling tower, *Acta Technica Corviniensis*, Tome IX, Fascicule 1, p. 113-116.

[4] Baker, D. R., Shryock, H. A. (2016). A comprehensive approach to the analysis of cooling tower performance, ASME Transactions, *Journal of Heat Transfer*, Volume 83, Issue 3, p. 339-349.

[5] Andrejevski, B., Mojsovski, A., Serafimov, M. (1985). Expert report for the certification of cooling tower performance 1784-10-84, Faculty of Mechanical Engineering, Skopje (in Macedonian).
[6] Andrejevski, B., Mojsovski, A., Serafimov, M. (1985). Guarantee and normative test of cooling tower for block I and block II at Thermal Power Plant Bitola, Faculty of Mechanical Engineering, Skopje (in Macedonian).
[7] DIN EN 14705 :2005-10 (2005). *Heat exchangers-Method of measuring and evaluation of thermal performance of wet cooling towers*, Beuth Verlag GmbH, Berlin.
[8] Mojsovski, A., Serafimov, M. (1982). Guarantee and normative test of cooling tower at Thermal Power Plant Oslomej, Faculty of Mechanical Engineering, Skopje (in Macedonian).
[9] Hensley, J. C. (Editor) (2009). *Cooling Tower Fundamentals*, SPX Cooling Technologies, Inc., Kansas, USA.