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Natural Draught Cooling Tower Operation During Winter

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Abstract: Operation of natural draught cooling towers and its ability to cool water is solely dependent on ambient air parameters (temperature and humidity). During winter period, at low temperatures of external air, circulation of air through the natural draught cooling tower causes greater cooling of the water and appearance of ice on places where air enters into the tower. In such case, with proper operation of the system cooling tower – pump station, and by reducing water's cooling range, temperature of the cold water ought to be maintained at sufficiently high temperature level in order to avoid freezing of the water in the tower and appearance of ice at air entering surfaces.

Keywords: Natural draught, Cooling tower, Winter.

1. Introduction

Thermo power plant (TPP) "Bitola" is the largest coal-fired power plant in North Macedonia that has been operating for more than 40 years. Historically, coal plants have retired at an average lifetime of 46 years globally, [1], but in many cases they can operate for 50–60 years or longer, [2]. In the case of TPP "Bitola", this means that the power plant is already on the end of its operational life. The Strategy for energy development of North Macedonia until 2040"[3] foresees revitalization or deactivation of TPP "Bitola" in the following years, depending on the considered scenario. A particularly radical transition from conventional energy sources to abandoning lignite through the application of new policies is foreseen in the green scenario. However, the lack of investment in this sector, especially in the basic electricity production facilities, gives us the right to expect that this power plant will continue to operate in the near future. Furthermore, in the same context, the construction of district heating system for the city of Bitola is well underway where the power plant is considered as a primary heat source.

Gathered experience from its operation represents valuable basis for further analysis in order to improve its efficiency, especially efficiency of the cold end. This article is based upon the previously developed climatic curve [4], (dependence of temperature and relative humidity of the air), and its influence on the operation of the cooling tower in winter periods.

Air entering areas are the most 'sensitive' surfaces in regards to winter operation of the natural draught cooling tower. Especially this is a case when the cooling tower is of counterflow type.

Temperature regulation of water in winter conditions is performed through three installed technical systems for antifreeze protection. The procedure of regulation is defined according to heat demand of the corresponding plant's block and values from the climatic curve.

Regulation of water temperature in all three systems is done by varying of the water flow. According to defined procedure, application of all three systems reduces the danger of ice appearance for different working modes of the turbine and for different climatic curve values. Control of the systems is individual and their usage is simultaneous or, at least two of them must operate simultaneously.

Under normal working conditions of the cooling tower, the water runs through the water distribution system onto the tower's fill and the protective ring and orbital pipeline are not in operation. Under these conditions, the temperature of water in the basin and at cooling tower's fill exit is equal.

The operating modes and calculations presented in this article refer to design operating values for the power plant before modernization in 2012. Following most recent (in 2022) refurbishment and restoration of the cooling tower of block 2 comprised of complete replacement of asbestos-cement fill and piping system with plastic fill and pipes, together with appropriate valves and fittings, new calculations and proposals for more efficient winter operation of cooling tower in block 2 must be performed followed by newly determined climatic curve for the corresponding period.

2. Normal winter operation of the cooling tower

Different values of climatic curve, for which the temperature of water leaving the cooling tower are determined, are shown on Table 1. These values are calculated for three operating modes in winter conditions.

Table 1. Climatic curve parameters used for determination of exiting water temperature in winter conditions

t_{a1} , °C	-3,0	1,0	5,0	10,0	15,0
φ_{a1} , %	35,0	50,0	35,0	50,0	50,0
t_{wb} , °C	-6,0	-2,0	0,0	5,4	9,5

Values from the climatic curve on Table 1 are used as a basis for calculation of the water temperature leaving the tower. Input parameters and the results from this calculation, determination of t_{w2} for 100% heat load and 100% water flow, are presented on Table 2 for winter operating mode I, whereas 100% heat load corresponds to 225 MW of turbine output and 100% water flow equals 30000 m^3/h (nominal working parameters for thermo power plant's cold end).

Table 2. Input parameters and calculation results from the determination of water temperature leaving the tower during winter operating mode I

t_{a1} = 5,0	°C	dry-bulb air temperature entering the cooling tower
φ_{a1} = 35,0	%	relative humidity of air entering the cooling tower
t_{wb} = 0,0	°C	wet-bulb temperature of air entering the cooling tower
x_{a1} = 0,002	kg/kg	humidity ratio of air entering the cooling tower
t_{w1} = 28,8	°C	temperature of water entering the cooling tower
p_{at} = 94152	Pa	barometric pressure of ambient air
g_{w1} = 6632	kg/m^{2}h	specific mass flow of water entering the cooling tower
g_a = 3603	kg/m^{2}h	specific mass flow of air in the tower
σ_V = 3531	kg/m^{3}h	volume coefficient of evaporation
t_{a2} = 11,3	°C	dry-bulb air temperature exiting the cooling tower
φ_{a2} = 91,4	%	relative humidity of air exiting the cooling tower
x_{a2} = 0,008	kg/kg	humidity ratio of air exiting the cooling tower
t_{w2} = 17,2	°C	temperature of water exiting the cooling tower

Input data from the climatic curve and results from calculation of exiting water temperature, t_{w2}, for 100% heat load and 80% water flow through the tower – winter operating mode II, are shown on Table 3.

Table 3. Input data and results from calculation of water temperature leaving the tower during winter operating mode II

t_{a1} = 5,0	°C
φ_{a1} = 35,0	%
t_{wb} = 0,0	°C
x_{a1} = 0,002	kg/kg
t_{w1} = 29,6	°C
p_{at} = 94152	Pa
g_{w1} = 6632	kg/m^{2}h
g_a = 3603	kg/m^{2}h
σ_V = 3531	kg/m^{3}h
t_{a2} = 12,9	°C

φ_{a2} = 97,2	%
X_{a2} = 0,009	kg/kg
t_{w2} = 15,2	°C

Input data from the climatic curve on Table 1 and the results from calculation of exiting water temperature, t_{w2}, for 50% heat load and 100% water flow through the tower – winter operating mode III, are shown on Table 4.

Table 4. Input parameters and resulting value for water temperature, t_{w2}, determination during winter operating mode III

t_{a1} = 5,0	°C
φ_{a1} = 35,0	%
t_{wb} = 0,0	°C
x_{a1} = 0,002	kg/kg
t_{w1} = 17,6	°C
p_{at} = 94152	Pa
g_{w1} = 6632	kg/m^{2}h
g_a = 11938	kg/m^{2}h
σ_V = 3531	kg/m^{3}h
t_{a2} = 5,04	°C
φ_{a2} = 83,9	%
x_{a2} = 0,005	kg/kg
t_{w2} = 13,0	°C

Values of water temperature leaving the tower depending on the climatic curve values and for three different winter operating modes: mode I – 100% heat load and 100% water flow through tower; mode II: 100% heat load and 80% water flow and mode III: 50% heat load and 100% water flow through the tower, are presented on Table 5.

Table 5. Values of water temperature leaving the tower depending on values from the climatic curve

t_{wb}, °C		-6,0	-2,0	0,0	5,4	9,5
t_{w2}, °C	Mode I	14,4	16,2	17,2	19,6	21,4
	Mode II	12,0	14,2	15,2	18,1	20,3
	Mode III	8,9	11,6	13,0	16,6	19,3

The dependence between the water temperature leaving the tower, t_{w2}, and climatic curve for all three winter operating modes of the cooling tower is shown on Fig.1.

It is obvious from the diagram that for the conditions of nominal water flow and nominal heat load, that is winter operating mode I, there is no possibility of water freezing in the cooling tower's basin and at tower fill's exit until extremely low air temperatures occur.

Since there are different values for water gradient between central and external sections of the cooling tower's fill, temperatures of water in the basin lower than 4,5°C poses danger for water freezing, [5], [6], [7]. Decreasing of water flow running through the tower significantly increases the possibility of local ice occurrence inside cooling tower's fill (Fig. 1).

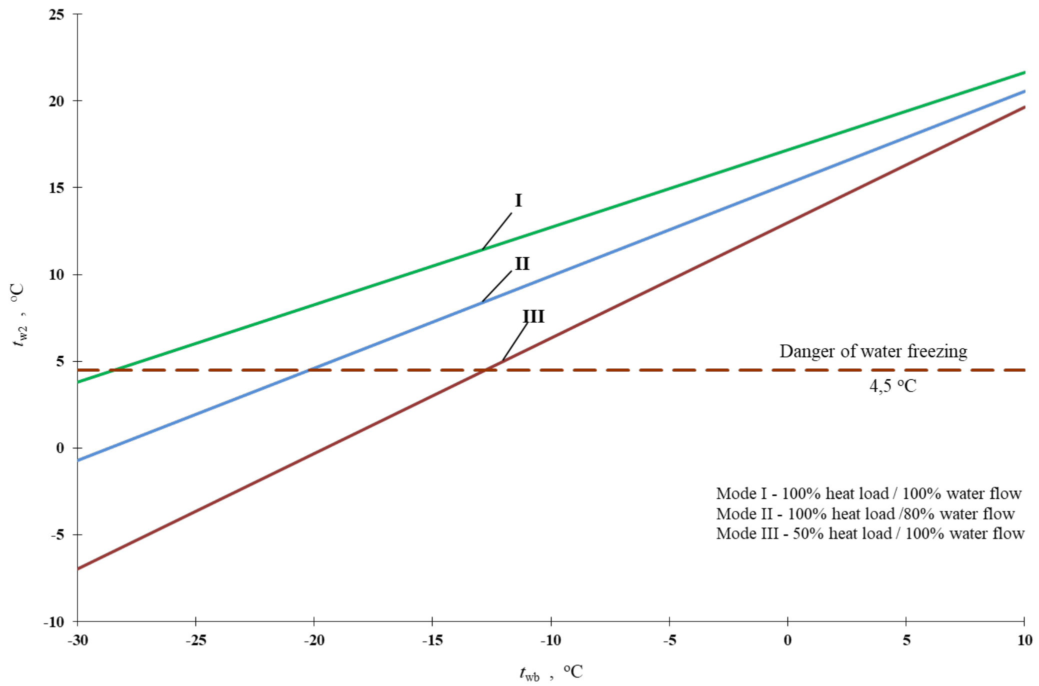

Fig. 1. Dependence of cooling water temperature exiting the tower and wet-bulb temperature of air entering the tower

3. Antifreeze systems (protection from water freezing)

There are three available systems for effective protection of water freezing for this type of cooling tower:

System 1 – Water circulation through sequinned pipeline

Usage of this system implies partial or total water flow redirection from the condenser straight to the cooling tower's basin. During the start - up of the system, in winter operating conditions, the complete circulation of the water is done through the sequinned pipeline (pipeline directed into cooling tower's basin), and this operational mode is kept on until the water temperature is raised to a degree that would enable anti-freezing protection for the cooling tower's fill. Fill sections are engaged gradually, depending on the block's requirements.

For a certain air temperature, if a larger quantity of water is transported through the orbital pipeline, temperature of water in the basin rises, while temperature of water at fill's exit drops. This decline in water temperature is a result of a water flow decrease, further resulting in decrease of the heat extraction capability of the cooling tower. Under stationary operating conditions it is possible to regulate water temperature by orbital pipeline even at lower external air temperatures.

System 2 – Protective pipeline ring against freezing

Efficient protection from freezing, in natural draught cooling towers is achieved by orbital pipeline and protective ring and eventually, by installing a system for zone distribution of cooling water through the tower.

Protective ring is installed in the inner side of the cooling tower under its fill. The pipeline of the protective ring has orifices on the bottom side that enables formation of water curtain at air entrance into the tower.

Essence of this solution is that at any wet-bulb temperature of the air, increase in water flow through the protective ring results in increase of water temperature in the basin. Protective ring is designed to enable 20% of total water flow through the tower. Its function is to pre-heat the air entering the tower and by doing so, to prevent the occurrence of ice in the external sections of the fill. Water curtain on the top side of the air entrance has higher density and causes change in the direction of air flow towards lower parts of the air entrance. External sections of the entrance and of cooling tower's fill remain protected from direct influence of entering cold air.

Increase in water flow quantity through the circulation pipeline, increases the water temperature in the protective ring and in the basin causing decrease in water temperature in the fill. During extremely low air temperatures and operating mode with lower than designed power output of the turbine, the valve on the circulation pipeline opens and enables the level of water in the vertical square-shaped pipeline to decrease below the level of water distributing system pipeline. By doing so, the whole water flow is transported through the protective ring and it does not affect the fill.

System 3 – Distribution of cooling water by zones (zonal distribution)

When the external temperature is extremely low, zonal distribution of cooling water is used as an additional protection against freezing. The essence of this solution is to divert the water flow of hot water from the central to the outer parts of the fill while the central part remains dry.

4. Operating modes for antifreeze protection

Cooling towers of TPP „Bitola" can implement four operating modes in order to protect its fill from freezing. They are used depending on the values from the climatic curve and the heat load of the appropriate block.

Operating mode I – Nominal operation of the cooling tower with 100% water flow. Protective ring is not in function. Circulation pipeline is in function, if the temperature of water in the basin is to be kept at optimal values, while keeping the turbine at most economical - design parameters.

Operating mode II – Operation with protective ring, aimed at protecting the external parts of the fill at air entrance in the cooling tower. Operation of the protective ring is foreseen to maintain certain water temperature in the tower's basin.

Operating mode III – Protective ring is in full operation and zone distribution of water is also applied. Circulation pipeline is also in operation, but not with full capacity.

Operating mode IV – Total quantity of water is transported through the circulation pipeline and protective ring. Areas of cooling tower's different operating modes, depending on the climatic curve values and heat load are presented on Fig. 2.

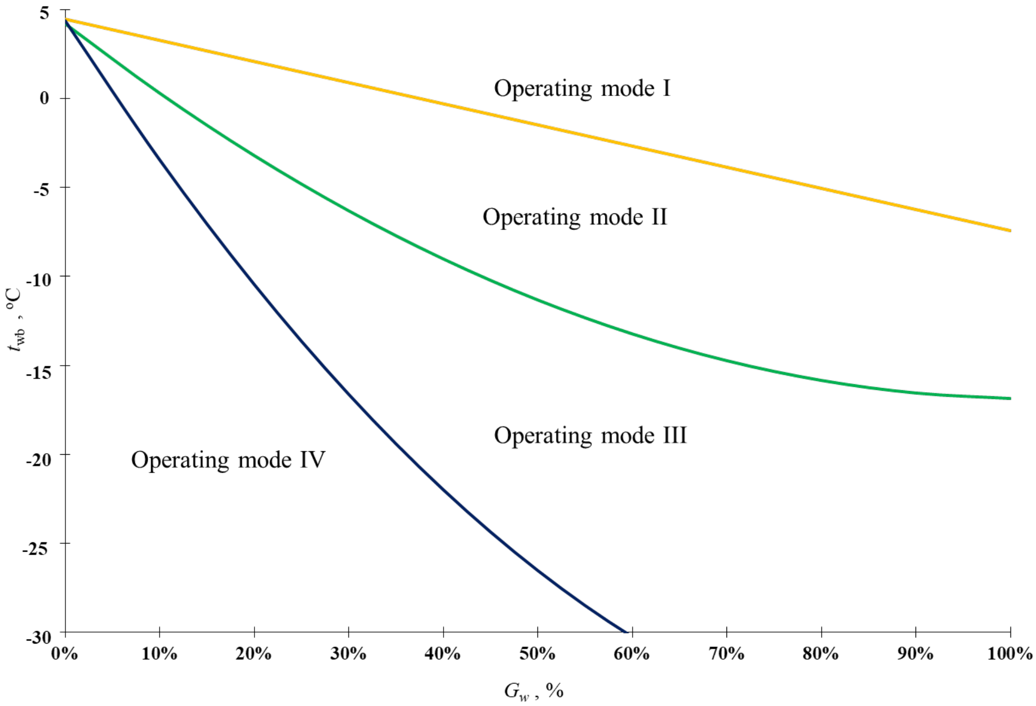

Fig. 2. Operating modes for antifreeze protection of the cooling tower

5. Conclusion

During winter, air circulation through the natural draught cooling tower can induce greater cooling of the water and appearance of ice at air entering areas, [8], [9]. Three systems for protection from freezing are used for natural draught cooling towers.

Determination of cooling water temperature at tower's exit – t_{w2} depending on climatic curve values and for three winter operating modes are presented in this article.

The diagram developed from this calculation shows that under nominal water flow and nominal heat load, operating mode I, there is no possibility for freezing of the water in the basin and at cooling tower fill's exit, as long as extremely low external air temperatures occur. By reducing the water flow, the danger for freezing of water in the tower is increasing.

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