INFLUENCE OF CLIMATIC CURVE VALUES ON THE OPERATING REGIME OF THE TURBINE AT TPP "BITOLA"

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Abstract: Several parameters affect the performance of the cooling tower (part of the power plant's cold end): heat load Q, cooling range Δt_w, approach to the wet-bulb temperature Δt_{odd} and wet-bulb temperature t_{vt} (cooling tower's boundary temperature value). An analysis of the influence of climatic curve values (for the months of April, May, June, July, August and September) for a defined size of heat exchanger (cooling tower fill for designed operating regime) on the thermal performance of the cooling tower is presented in this article. This also allows following of the designed operating regimes of the turbine.

Key words: climatic curve, cooling tower, turbine

1. INTRODUCTION

Thermal Power Plant (TPP) – Bitola is the largest electricity producer in the Republic of Macedonia. With an installed capacity of 675 MW and an annual output of around 4,6 GWh this plant provides about 70% of Macedonia’s electricity supply. The plant consists of three blocks. The layout of objects in Thermal Power Plant “Bitola” is shown on Figure 1.

This article deals with the influence of climate on the operation of power plant’s cold end, referring to points 1 – cooling tower for Block-1, 2 – cooling tower for Block-2, 3 – cooling tower for Block-3, 9 – pump station for Blocks 1 and 2, and 25 - pump station for Block-3, shown on Figure 1. Condensers are located in the main building beneath the turbines for each Block respectively, point 6 on Fig.1.

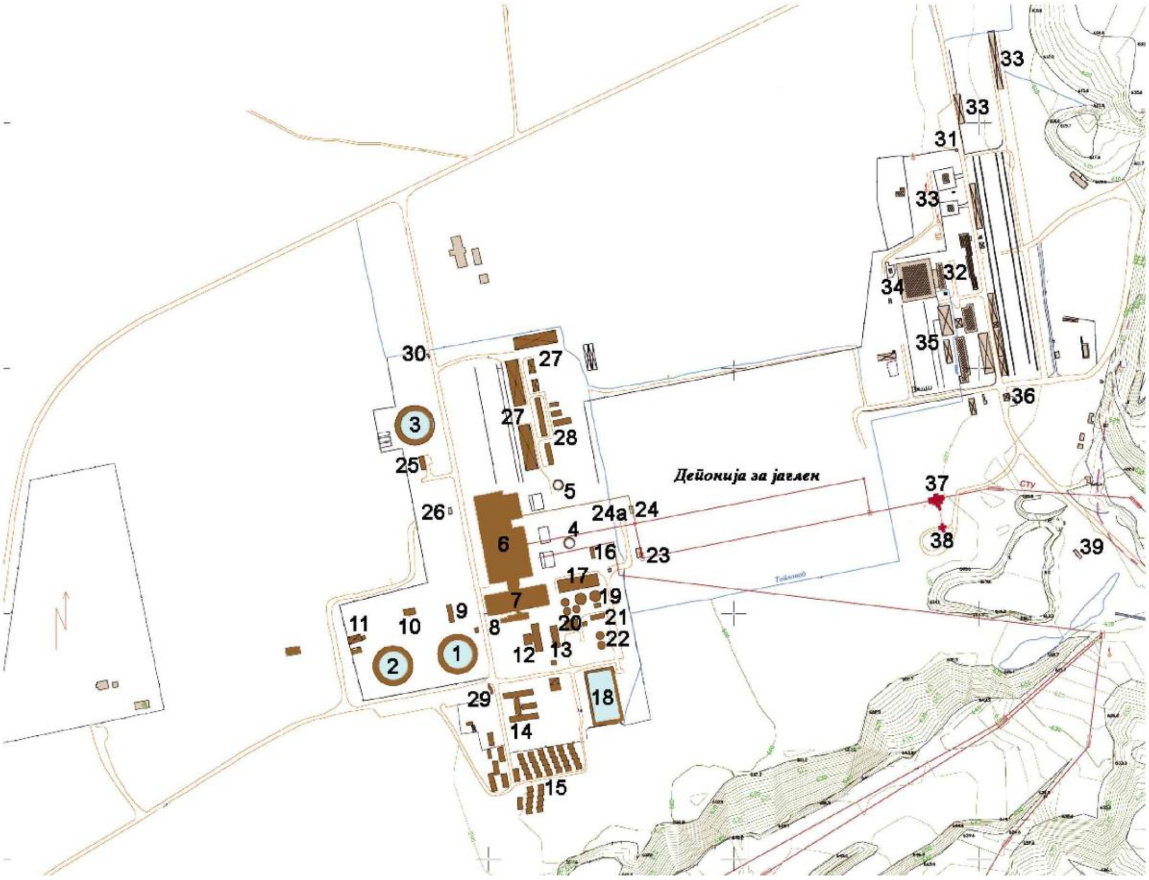

Figure 1. Layout of objects in Thermal Power Plant “Bitola”

2. ANALYSIS OF THE CLIMATE’S INFLUENCE ON THE OPERATING PARAMETERS OF THE COLD END

Design parameters of the turbine are given in Table hereafter, [1].

Table 1. Design operating parameters of each Block in TPP-Bitola

Electric power N , MW	Mass flow of flash steam m_{sp} , kg/s	Mass flow of steam through condenser m_k , kg/s	Parameters of steam in condenser	
			p_k, kPa	t_k , °C
225	190,362	129,300	6,600	37,933
222	187,252	127,576	6,500	37,651
220	169,260	126,429	6,469	37,563
218	183,157	125,285	6,475	37,580
215	180,123	123,574	6,380	37,308
210	174,440	120,640	6,294	37,057
205	170,231	117,905	6,194	36,765
200	165,270	116,190	6,102	36,500
195	160,650	112,295	5,986	36,140
175	141,940	101,000	5,602	34,900
150	120,550	87,830	5,179	33,500
100	81,110	61,530	4,145	30,700

Volume flow of cooling water required through the condenser for part of the designed operating regimes of the turbine (Table 1) is determined with the following equation:

$$q_{m,w} = \frac{m_k \cdot \left(i_k - i_k^{'}\right)}{c_{p,w} \cdot \left(t_{w1} - t_{w2}\right)} \cdot 3{,}6 \quad , \qquad m^3/h$$

where:

m_k , kg/s – mass flow of steam in the condenser;

$i_k^{'}$, kJ/kg – specific enthalpy of steam at condensation temperature with water content x = 0,925;

$i_k^{''}$, kJ/kg – specific enthalpy of steam at condensation temperature on saturation line;

$c_{p,w}$, kJ/kgK – isobaric specific heat of water.

An example of calculation for electrical output of N = 225 MW is presented below:

$$p_k = 0{,}0066\,\text{bar} \;;\; t_k = 37{,}933\,°\text{C} \;;\; i^{'} = 158{,}814\,\text{kJ/kg} \;;\; i_k^{''} = 2570{,}657\,\text{kJ/kg} \;;\; x=0{,}952$$

$$i_k = i_k^{'} + x \cdot \left(i_k^{''} - i_k^{'}\right) = 158{,}814 + 0{,}952 \cdot (2570{,}657-158{,}814) = 2454{,}888 \text{ kJ/kg}$$

$$q_{m,w} = \frac{129{,}3 \cdot \left(2454{,}888 - 158{,}814\right)}{4{,}19 \cdot 7} \cdot 3{,}6 = 36439 \text{ m}^3/\text{h}$$

Results of calculation for operating regimes different than designed are shown in Table 2.

Table 2. Results of cooling water flow calculation for different values of electric power output - N and different values of cooling range - Δt_w, of the cooling tower (designed cooling range – 9,2 K)

N	m_k	p_k	t_k	$q_{v,w}$, m^3/h for Δt_w, K			
MW	kg/s	kPa	°C	7 K	8 K	9,2 K	11 K
225	129,300	6,600	37,933	36439	31880	28342	25507
220	126,429	6,469	37,563	35644	31188	27120	24950
215	123,574	6,380	37,308	34847	30492	26514	24393
210	120,640	6,294	37,057	34017	29765	25883	23812
200	116,190	6,102	36,500	32710	28620	24887	22892

An excerpt of microclimate conditions of Bitola, [2] and [3], in a form of climate curve, is used in order to present the condition of air entering natural draught cooling tower during its operation in "hard conditions" for the months april, may, june, july, august and september, for the years 1992 to 2003, Table 3.

Table 3. Excerpt from the climate curve of Bitola for summer months, period 1992-2003

t_v	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
φ	54	51	49	47	44	41	39	38	36	34	32	31	28	26	24	30	22	20	14
t_{vt}	14	15	15	15	16	16	17	17	17	18	18	19	18	19	18	21	20	20	18

where:

t_v, °C – dry-bulb temperature of ambient air;

φ_v, % – relative humidity of ambient air;

t_{vt}, °C – wet-bulb temperature of ambient air.

For these values of climatic curve (t_v - φ curve), and defined values of the cooling tower according to designed operating regime ($q_{v,w} = 30000$ m^3/h ; $t_{v1} = 25\,°$C ; $t_{vt} = 20\,°$C ; $t_{w1} = 38{,}2\,°$C ; $t_{w2} = 29\,°$C), values for water temperature entering the cooling tower – t_{w1} and water temperature leaving the cooling tower – t_{w2} are presented in Table 4. In order to speed up the calculations, a computer programme in C+, named "POLNEZ" was made for 4 cooling ranges (Δt_w = 7; 8; 9,2 and 11 K).

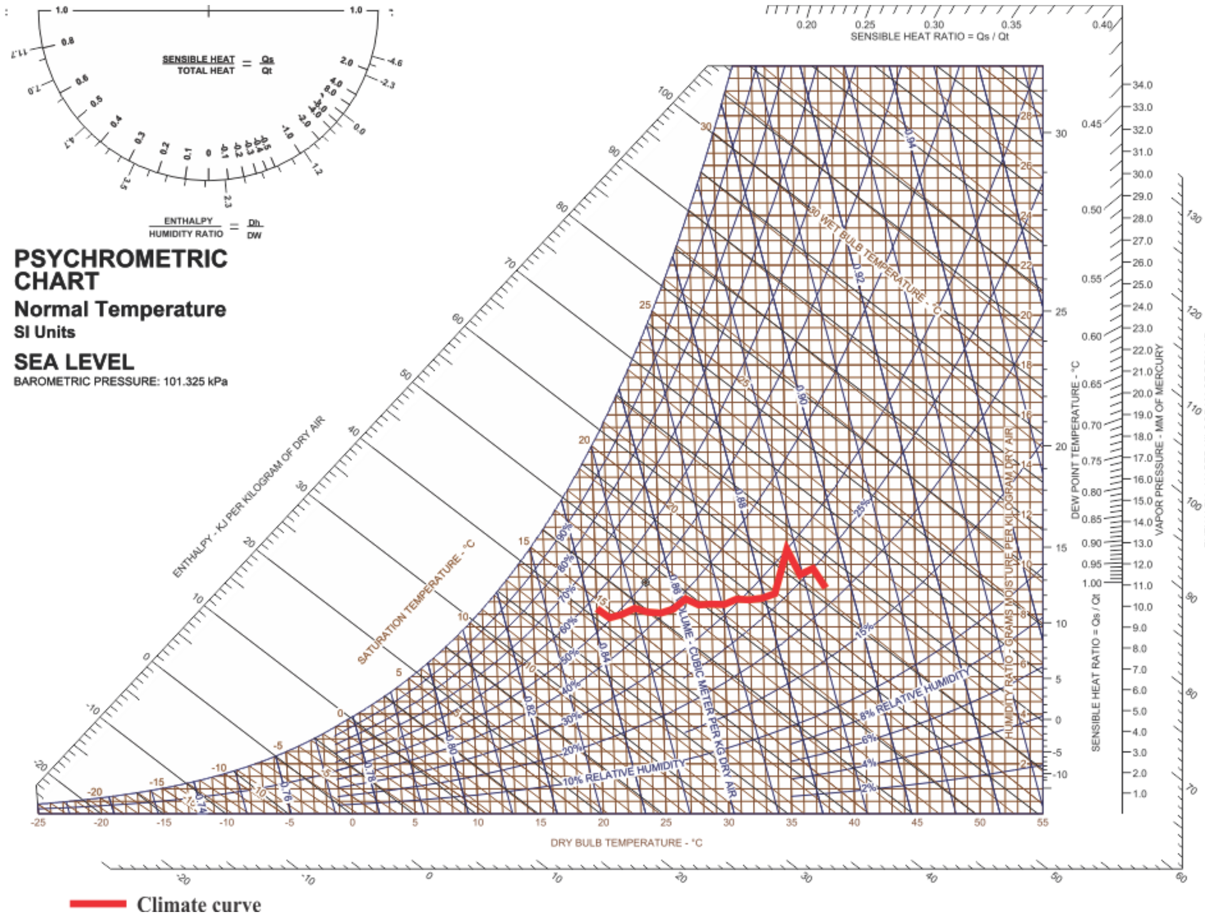

Figure 2. “Summer” climate curve for Bitola, period 1992-2003

Table 4. Calculated values of water entering and leaving the cooling tower for various ambient air parameters and cooling ranges

No.	t_v	φ_v	t_{vt}	$\Delta t_w = 7$ K		$\Delta t_w = 8$ K		$\Delta t_w = 9{,}2$ K		$\Delta t_w = 11$ K	
				t_{w1}	t_{w2}	t_{w1}	t_{w2}	t_{w1}	t_{w2}	t_{w1}	t_{w2}
	°C	%	°C	°C	°C	°C	°C	°C	°C	°C	°C
1	20	54	14,1	29,8	22,8	21,6	23,6	33,6	24,4	36,5	25,5
2	21	51	14,5	30,0	23,0	31,8	23,8	33,8	24,6	36,7	25,7
3	22	49	15,0	30,3	23,3	32,0	24,0	34,1	24,9	36,9	25,9
4	23	47	15,5	30,6	23,6	32,4	24,4	34,5	25,2	37,2	26,2
5	24	44	15,8	30,8	23,8	32,5	24,5	34,5	25,2	37,4	26,4
6	25	41	16,1	31,0	24,0	32,7	24,7	34,7	25,5	37,5	26,5
7	26	39	16,5	31,2	24,2	32,9	24,9	34,9	25,7	37,7	26,7
8	27	38	17,0	31,6	24,6	33,3	25,3	35,2	26,0	38,0	27,0
9	28	36	17,4	31,8	24,8	33,5	25,5	35,4	26,2	38,4	27,4
10	29	34	17,7	32,0	25,0	33,7	25,7	35,6	26,4	38,4	27,4
11	30	32	18,0	32,2	25,2	33,8	25,6	35,7	26,5	38,5	27,5
12	31	31	18,5	32,5	25,5	34,1	26,1	36.0	26,8	38,7	27,7
13	32	28	18,4	32,5	25,5	34,1	26,1	36.0	26,8	38,7	27,7
14	33	26	18,6	32,6	25,6	34,2	26,2	36,1	26,9	38,8	27,8
15	34	24	18,8	32,7	25,7	34,3	26,3	36,2	27,0	38,9	27,9
16	45	30	21,0	34,0	27,0	35,7	27,7	37,6	28,4	40,2	29,8
17	36	22	19,5	33,0	26,0	34,8	26,8	36,6	27,4	39,3	28,3
18	37	20	19,5	33,0	26,0	34,8	26,8	36,6	27,4	39,3	28,3
19	38	14	18,1	32,3	25,3	33,9	25,9	35,8	26,6	38,6	27,6

Thermal resistance of the water is the difference between the temperature of the condensate and the temperature of “hot” cooling water leaving the condenser:

$$\Delta t_{kond} = t_k - t_{w1}$$

In practice, [4], this value is in the range $\Delta t_{kond} = (2 \div 4)$ °C.

Approach to cooling range is the difference between temperature of water leaving the cooling tower and wet-bulb temperature of ambient air - t_v:

$$\Delta t_{odd} = t_{w2} - t_{vt}$$

In practice [5], this value is $\Delta t_{odd} > 4\,°C$

Values for temperature of steam – condensate in the condenser for design operating regimes of the turbine are used from Table 1, and values of t_v, t_{w1} and t_{w2} for different values of climatic curve are used from Table 4.

Values for thermal resistance temperature - Δt_{kond} and approach to the cooling range - Δt_{odd}, for electrical output of N = 225 MW and optimal operating parameters of the turbine are shown in Table 5.

Table 5. Values for thermal resistance temperature and approach to the cooling range for N = 225 MW

No.	Δt_{kond} for $\Delta t_w = t_{w1} - t_{w2}$				Δt_{odd} for $\Delta t_w = t_{w1} - t_{w2}$, K			
	7 K	8 K	9,2 K	11 K	7 K	8 K	9,2 K	11 K
1	8,133	6,333	4,333	1,433	8,7	9,5	10,3	11,4
2	7,933	6,133	4,133	1,233	8,5	9,3	10,1	11,2
3	7,633	5,933	3,833	1,033	8,3	9,0	9,9	10,9
4	7,333	5,533	3,633	0,733	8,1	8,9	9,7	10,7
5	7,133	5,433	3,433	0,533	8,0	8,7	9,4	10,6
6	6,933	5,233	3,233	0,433	7,9	8,6	9,4	10,4
7	6,733	5,033	3,033	0,233	7,7	8,4	9,2	10,2
8	6,333	4,633	2,733	-	7,6	8,3	9,0	10,0
9	6,133	4,433	2,533	-	7,4	8,1	8,8	10,0
10	5,933	4,233	2,333	-	7,3	8,0	8,7	9,7
11	5,733	4,133	2,333	-	7,2	7,8	8,5	9,5
12	5,433	3,833	1,933	-	7,0	7,6	8,3	9,2
13	5,433	3,833	1,933	-	7,1	7,7	8,4	9,3
14	5,333	3,733	1,833	-	7,0	7,6	8,3	9,2
15	5,233	3,633	1,733	-	6,9	7,5	8,2	9,1
16	3,933	2,233	0,333	-	6,0	6,7	7,4	8,2
17	4,933	3,133	1,333	-	6,5	7,3	7,9	8,8
18	4,933	3,133	1,333	-	6,5	7,3	7,9	8,8
19	5,633	4,033	2,133	-	7,2	7,8	8,5	9,5

Same values as in Table 5 are shown in Table 6, with the difference that electrical output in this case is N = 200 MW.

Table 6. Values for thermal resistance temperature and approach to the cooling range for N = 200 MW

No.	Δt_{kond} for $\Delta t_w = t_{w1} - t_{w2}$				Δt_{odd} for $\Delta t_w = t_{w1} - t_{w2}$, K			
	7 K	8 K	9,2 K	11 K	7 K	8 K	9,2 K	11 K
1	6,7	4,9	2,9	0,0	8,7	9,5	10,3	11,4
2	6,5	4,7	2,7	-	8,5	9,3	10,1	11,2
3	6,2	4,5	2,4	-	8,3	9,0	9,9	10,9
4	5,9	4,1	2,2	-	8,1	8,9	9,7	10,7
5	5,7	4,0	1,8	-	8,0	8,7	9,4	10,6
6	5,5	3,8	1,6	-	7,9	8,6	9,4	10,4
7	5,3	3,6	1,3	-	7,7	8,4	9,2	10,2
8	4,9	3,2	1,1	-	7,6	8,3	9,0	10,0
9	4,7	3,0	0,9	-	7,4	8,1	8,8	10,0
10	4,5	2,8	0,8	-	7,3	8,0	8,7	9,7
11	4,3	2,7	0,5	-	7,2	7,8	8,5	9,5
12	4,0	2,4	0,5	-	7,0	7,6	8,3	9,2
13	4,0	2,1	0,4	-	7,1	7,7	8,4	9,3

14	3,9	2,3	0,3	-	7,0	7,6	8,3	9,2
15	3,8	2,2	-	-	6,9	7,5	8,2	9,1
16	2,5	0,8	-	-	6,0	6,7	7,4	8,2
17	3,5	1,7	-	-	6,5	7,3	7,9	8,8
18	3,5	1,7	-	-	6,5	7,3	7,9	8,8
19	4,2	2,6	-	-	7,2	7,8	8,5	9,5

4. CONCLUSION

From the calculations for parameters of power plant's cold end (condenser – cooling tower) and values of climate curve in a period of "hard" operating conditions for summer months, years 1992 to 2003 (Table 3), the following can be concluded:

- For all values of wet-bulb temperature t_{vt}, the cooling tower cools the water with approach ranging from 6 to 11,4 K. Temperature of steam condensation in the condenser, in just a few cases provides real temperature of thermal resistance Δt_{kond}, and in some cases has negative value which is impossible. This means that temperatures of steam condensation in the condenser must be higher than the designed ones, shown on Table 1. Temperatures of "hot" water leaving the condenser would be higher than water temperatures entering and leaving the cooling tower (Table 5 and Table 6). Higher water temperatures at cooling tower entrance cause increased heat seizure from the water and its transfer to the air thus raise in enthalpy is proportional to increase of "hot" water temperature entering the cooling tower. By increasing the 'driving force' (difference between enthalpies of water and air), heat transfer between water and air is facilitated.
- With higher water temperatures leaving the condenser, cooling tower is able to cool bigger volume flow of water compared to designed values;
- Increase of condensation temperature above the designed operating regime of the turbine (Table 1) causes increased specific fuel consumption in g/kWh.

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