POSSIBLE EFFICIENCY IMPROVEMENT BY APPLICATION OF VARIOUS OPERATING REGIMES FOR THE COOLING WATER PUMP STATION AT THERMAL POWER PLANT BITOLA

by

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Thermal power plant Bitola is the largest electricity producer in the Republic of Macedonia with installed capacity of 691 MW. It is a lignite fired power plant, in operation since 1982. Most of the installed equipment is of Russian origin. Power plant's cold end comprised of a condenser, pump station and cooling tower is depicted in the article. Possible way to raise the efficiency of the cold end by changing the operating characteristics of the pumps is presented in the article. Diagramic and tabular presentation of the working characteristics of the pumps (two pumps working in paralel for one block) with the pipeline, as well as engaged power for their operation are also presented in this article.

Key words: *power plant, pump, cold end, operating regime, cooling water*

Introduction

Two pump stations for circulation of cold water from the condensers through cooling towers are used at the plant. One pump station is mutual for blocks 1 and 2, while the other one is for block 3 with the possibility to serve for future enlargement with another block. Block is comprised of steam generator, turbine, electric generator, condenser, and cooling tower. Pumps are of axial type, vertical, with variable geometry of the working blades. Two pumps, working in parallel, are used on each block. There's a third (auxiliary) pump that serves both working pumps whenever needed.

Cold water from the cooling tower basin, through open channel that later transforms into two underground pipes (with DN2400 each) is transported into pump station's open basin (chamber). From this basin, water is taken by the pumps and further transported through one – way valve into main distributive pipeline DN2400. From this pipeline, water flow is divided on two pipes (DN1600) leading to both condenser halves, fig. 1 [1].

Cooling water flows from the condenser, where it is heated up for 9 to 12 °C, through return pipeline (DN1600) and enters the main return pipeline (DN2400). Main pipeline further on, splits on two pipelines (DN1600 each) and enters cooling tower through pipelines DN1800, up to cooling tower's fill.

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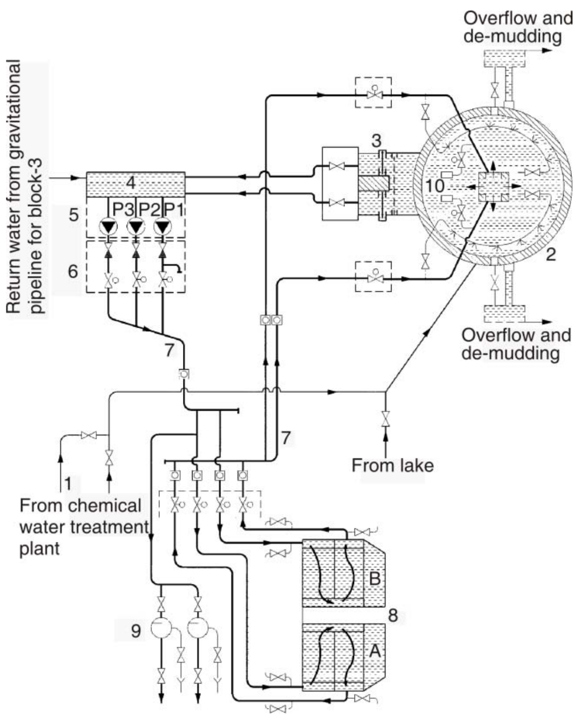

Figure 1. Schematics of the circulation cooling water system for block-3; *(1) – water treatment station, (2) – natural draught cooling tower, (3) – valves with colander, (4) – entering water chamber, (5) – pump station, (6) – pit with valves, (7) – circulation pipelines, (8) – condenser, (9) – mechanical water filters, (10) – unit for winter operation of the cooling tower*

Pump OPV Z-87 MKE is of axial type, one-step, vertical with variable geometry of the blades. It has the following technical characteristics: water volume flow – 3.25 m^3/s, specific energy engaged – 206 J/kg, rotation speed – 730 per minute, maximum engaged power – 880 kW, and optimal pump efficiency (η) – 81.5%.

Natural draught cross-flow hyperbolic cooling tower with fill made of asbestos plates is part of the cold end. Numerical calculation of moist air properties [2], and cooling tower theory and performance [3], are partly used in the analysis performed in this article.

Operating regimes should match the recommended operating area of the pump, which is shown with bold line on fig. 2.

Six working blades are mounted on pump's rotor. The angle of the blades can be changed according to needs, mostly to meet variations in heat load. Change of the angle of working blades can be made manually, while the pump is not in function, or from distance (control room for each block). There are five different angle possitions of the blades. This means that each pump has five different working characteristics. Blade angles are: –4°, –2°, 0°, +1°30', and +4°. Parallel work of two pumps gives the possibility of 15 achievable operating points for each block.

Operating characteristics

Operating characteristics for every pump (according to the angle of the blades) are:

– angle of blades: –4°

$$e_{p,-4^\circ} = -1731.76 + 1498.49712\, q_\mathrm{v} - 289.422 q_\mathrm{v}^2; \quad \eta_{p,-4^\circ} = -0.3165 q_\mathrm{v}^2 + 1.7404 q_\mathrm{v} - 1.5983 \tag{1}$$

– angle of blades: –2°

$$e_{p,-2^\circ} = -363.568 + 472.116\, q_\mathrm{v} - 95.1688 q_\mathrm{v}^2; \quad \eta_{p,-2^\circ} = -0.1754 q_\mathrm{v}^2 + 1.0823 q_\mathrm{v} - 0.8595 \tag{2}$$

– angle of blades: 0°

$$e_{p,0^\circ} = -148.17 + 309.6428\, q_\mathrm{v} - 62.54856 q_\mathrm{v}^2; \quad \eta_{p,-0^\circ} = -0.164 q_\mathrm{v}^2 + 1.0539 q_\mathrm{v} - 0.8792 \tag{3}$$

– angle of blades: +1° 30'

$$e_{p,1°30'} = -472.469 + 510.08\,q_\mathrm{v} - 90.7424\,q_\mathrm{v}^2; \quad \eta_{p,1°30'} = -0.1482\,q_\mathrm{v}^2 + 0.9957\,q_\mathrm{v} - 0.8513 \quad (4)$$

– angle of blades: +4°

$$e_{p,+4°} = -385.1995 + 435.54438\,q_\mathrm{v} - 74.069424\,q_\mathrm{v}^2; \quad \eta_{p,+4°} = -0.1782\,q_\mathrm{v}^2 + 1.2181\,q_\mathrm{v} - 1.2584 \quad (5)$$

where e_p is the specific engaged energy, q_v – the volume flow of water, and η_p – the optimal utility pump efficiency.

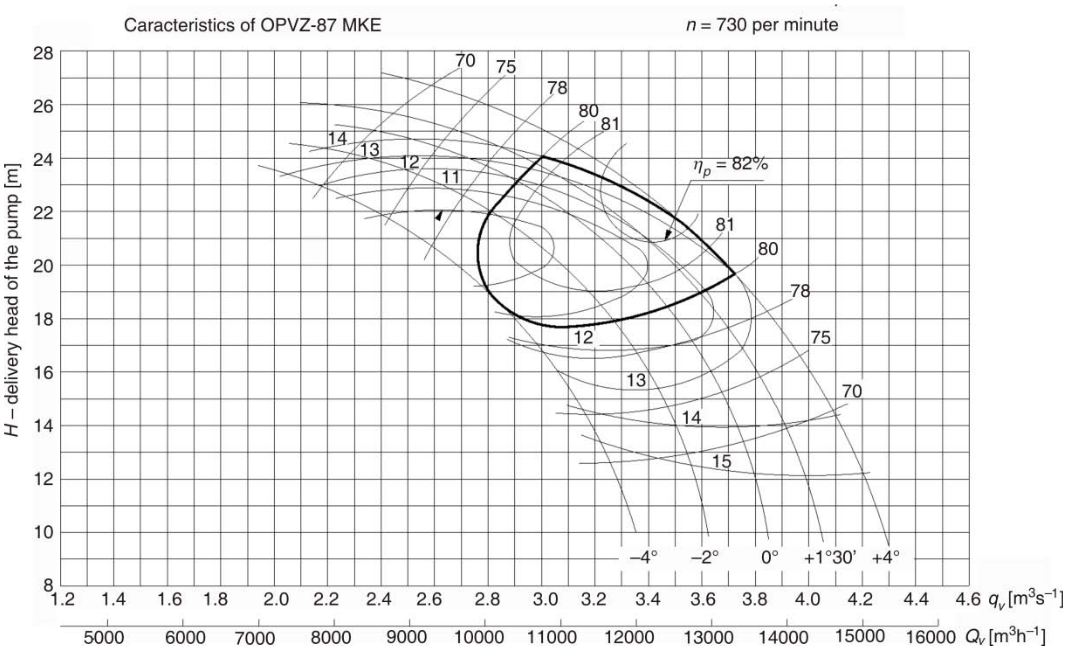

Figure 2. Operating characteristics of axial pump OPVZ-87 MKE operating at TPP-Bitola

Operating characteristics of the pipeline cooling tower – circulation pump station – condenser – cooling tower equals [4]:

$$E = 256.49226 - 42.183\,q_\mathrm{v} + 4.598928\,q_\mathrm{v}^2 \quad (6)$$

Two pumps working in parallel with same angle of the blades

Operating characteristics of two pumps working in parallel and with same angle of the blades on both pumps:

$$-4°\;(2\,e_{p,-4°})_\mathrm{par} = -1731.76 + 749.248\,q_\mathrm{v} - 72.355617\,q_\mathrm{v}^2 \quad (7)$$

$$-2°\;(2\,e_{p,-2°})_\mathrm{par} = -363.568 + 236.058\,q_\mathrm{v} - 23.7922\,q_\mathrm{v}^2 \quad (8)$$

$$0^\circ\ (2\, e_{p,0^\circ})_{\text{par}} = -148.17 + 154.82\, q_{\text{v}} - 15.637\, q_{\text{v}}^2 \tag{9}$$

$$+1^\circ 30'\ (2\, e_{p,1^\circ 30'})_{\text{par}} = -472.469 + 255.04\, q_{\text{v}} - 22.6856\, q_{\text{v}}^2 \tag{10}$$

$$+4^\circ\ (2\, e_{p,+4^\circ})_{\text{par}} = -385.1995 + 217.77219\, q_{\text{v}} - 18.517356\, q_{\text{v}}^2 \tag{11}$$

The resulting intersection point between the pipeline characteristic and operating characteristics of both pumps working in parallel is the operational characteristics of equivalent pump.

Operational characteristics of the pumps and operational characteristic of the pipeline along with intersections are shown in fig. 3.

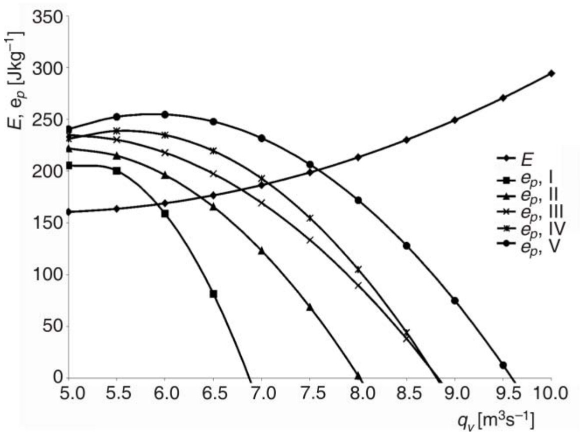

Figure 3. Operating characteristics of two pumps with equal angle of the blades, working in parallel and operating characteristic of the pipeline cooling tower – circulation pump station – condenser – cooling tower

Parameters for the operating points of both pumps in parallel connection and with equal angle of the blades are given in tab. 1.

Table 1. Operating parameters of both pumps working with equal blade angles

Combination	Volume flow		Specific energy usage		η_p [%]	Power usage N [kW]
	q_{v} [m^{3}s^{-1}]	Q_{v} [m^{3}h^{-1}]	e_{p} [Jkg^{-1}]	H [m]		
$(2 \times e_{p,-4^\circ})_{\text{par}}$	5.92	21310	167.984	17.12	78	1274.96
$(2 \times e_{p,-2^\circ})_{\text{par}}$	6.37	22940	174.506	17.79	81	1372.97
$(2 \times e_{p,0^\circ})_{\text{par}}$	6.79	24450	182.109	18.56	81	1562.68
$(2 \times e_{p,1^\circ 30'})_{\text{par}}$	7.16	25790	190.350	19.40	81	1683.54
$(2 \times e_{p,+4^\circ})_{\text{par}}$	7.59	27310	201.195	20.51	80	1907.83

Two pumps working in parallel with different blade's angle

In this case, the combination of two pumps working in parallel, with different angle of the blades on every pump, results in 10 different operating characteristics [5]. The operating characteristic of the pipeline remains unchanged.

Pump 1 angle	Pump 2 angle	Operating characteristics (q_{v} [m^{3}s^{-1}]; e_p [Jkg^{-1}]

–4°	–2°	$(e_{p,-4^\circ}+e_{p,-2^\circ})_{\mathrm{par}} = -802.09 + 399.13\,q_{\mathrm{v}} - 39.165\,q_{\mathrm{v}}^2$	(12)
–4°	0°	$(e_{p,-4^\circ}+e_{p,0^\circ})_{\mathrm{par}} = -581.86 + 312.24\,q_{\mathrm{v}} - 30.358\,q_{\mathrm{v}}^2$	(13)
–4°	+1°30'	$(e_{p,-4^\circ}+e_{p,1^\circ 30'})_{\mathrm{par}} = -985.51 + 437.82\,q_{\mathrm{v}} - 39.69\cdot q_{\mathrm{v}}^2$	(14)
–4°	+4°	$(e_{p,-4^\circ}+e_{p,+4^\circ})_{\mathrm{par}} = -837.96 + 397.34\,q_{\mathrm{v}} - 33.716\,q_{\mathrm{v}}^2$	(15)
–2°	0°	$(e_{p,-2^\circ}+e_{p,0^\circ})_{\mathrm{par}} = -257.22 + 194.34\,q_{\mathrm{v}} - 19.476\,q_{\mathrm{v}}^2$	(16)
–2°	+1°30'	$(e_{p,-2^\circ}+e_{\mathrm{p},1^\circ 30'})_{\mathrm{par}} = -458.75 + 257.05\,q_{\mathrm{v}} - 24.001\,q_{\mathrm{v}}^2$	(17)
–2°	4°	$(e_{p,-2^\circ}+e_{p,+4^\circ})_{\mathrm{par}} = -377.66 + 226.37\,q_{\mathrm{v}} - 20.847\,q_{\mathrm{v}}^2$	(18)
0°	+1°30'	$(e_{p,0^\circ}+e_{p,1^\circ 30'})_{\mathrm{par}} = -299.91 + 202.29\,q_{\mathrm{v}} - 19.024\,q_{\mathrm{v}}^2$	(19)
0°	+4°	$(e_{p,0^\circ}+e_{p,+4^\circ})_{\mathrm{par}} = -227.02 + 177.06\,q_{\mathrm{v}} - 16.554\,q_{\mathrm{v}}^2$	(20)
+1°30'	+4°	$(e_{p,1^\circ 30'}+e_{p,+4^\circ})_{\mathrm{par}} = -379.17 + 223.35\,q_{\mathrm{v}} - 19.721\,q_{\mathrm{v}}^2$	(21)

Operating characteristics of both pumps, working in parallel with different angle of the blades together with pipeline characteristic are presented on fig. 4.

Parameters of the operating point for both pumps working in parallel while with different blades angle is given in tab. 2.

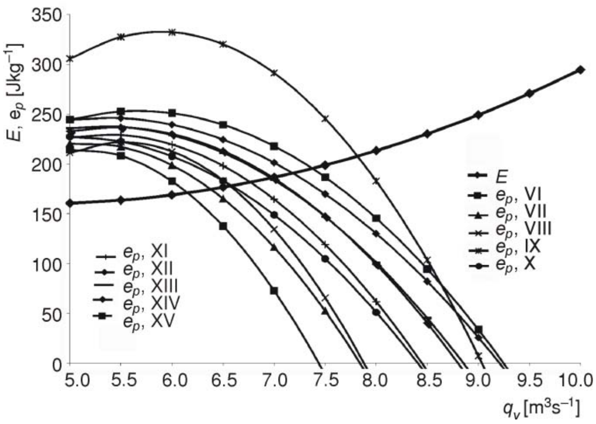

Figure 4. Operating characteristics of both pumps working in parallel with different angle of the blades together with pipeline operating characteristic

Relation power plant cold end – climatic curve

From the values of the climatic curve for Bitola [6], for the months of October, November, December, January, February, and March and for a volume flow of water to/from the cooling tower of 27310 m^3/h (2 pumps operating in parallel with +4° angle of the blades – maximum power-maximum flow) for certain values of cooling range, dependence of water temperature leaving the cooling tower and wet-bulb air temperature is presented, $t_{\mathrm{w2}} = \mathrm{f}(t_{\mathrm{vt}})$. These values are shown in tab. 3.

Values of water temperature leaving the tower indicate that the cooling tower performance is correct. Having in mind that the projected cooling range (temperature difference of water entering and leaving the cooling tower) is 9.2 K [6], we count the number of appearances of cooling range values presented in tab. 3 (10-13 K, respectively) for the cold months of the year (from October till March) and for three values of electric power on the power plant's generator (215, 220, and 225 MW, respectively). Number of appearances shows how many times certain cooling range matched certain power output, for months October--March and for years 1999-2001 [7-9]. Engaged time in hours shows the operation time of the pumps for each pair "cooling range – power". Number of appearances, sorted by power and range are shown in tab. 4.

Table 2. Operating parameters of both pumps working with different blade angles

Combination	Volume flow		Specific energy usage		η_{p1} [%]	η_{p2} [%]	Power usage N [kW]
	q_v [m^{3}s^{-1}]	Q_v [m^{3}h^{-1}]	e_p [Jkg^{-1}]	H [m]			
$(e_{p,-4°} + e_{p,-2°})_{par}$	6.15	22150	171.076	17.44	78	82	1315.00
$(e_{p,-4°} + e_{p,0°})_{par}$	6.38	22970	174.547	17.79	78	80	1408.39
$(e_{p,-4°} + e_{p,1°30'})_{par}$	6.57	23650	177.753	18.12	78	81	1466.49
$(e_{p,-4°} + e_{p,+4°})_{par}$	7.82	28150	207.424	21.14	79	30	4279.83*
$(e_{p,-2°} + e_{p,0°})_{par}$	6.58	23700	178.296	18.18	81	81	1448.38
$(e_{p,-2°} + e_{p,1°30'})_{par}$	6.77	24370	181.443	18.49	81	81	1516.51
$(e_{p,-2°} + e_{p,+4°})_{par}$	6.99	25130	186.275	18.99	81	78	1612.97
$(e_{p,0°} + e_{p,1°30'})_{par}$	6.97	25090	185.848	18.95	81	81	1599.19
$(e_{p,0°} + e_{p,+4°})_{par}$	7.18	25850	190.750	19.44	81	79	1714.34
$(e_{p,1°30'} + e_{p,+4°})_{par}$	7.37	26550	195.466	19.93	82	77	1819.43

* Combination is not possible since η_p of the second pump is outside of recommended operating area

Table 3. Dependence of $t_{w2} = f(t_{vt})$ for Q_v = 27310 m^3/h

t_{vt} [°C] →	–15	–10	–5	0	5	10
Δt_w [K]	t_{w2} [°C]					
10	21.8	23.2	24.6	26.0	27.4	28.8
11	23.2	24.4	25.5	26.7	27.9	29.0
12	24.1	25.4	26.6	27.8	29.0	30.2
13	25.1	26.2	27.4	28.5	29.6	30.7

Table 4. Number of appearances/pump's engaged time in hours, for six months of the year and for corresponding power on the generator shaft

□t_w [K] →	10	11	12	13
N [MW]	No. of appearances/ /engaged time in hours			
215	10/132	30/397	30/397	0
220	4/53	55/728	50/662	10/132
225	0	62/423	37/490	30/397

Required volume flow of cold water for reaching the mentioned power of the plant and cooling ranges is presented in tab. 5.

In order to achieve the required volume flow of water to match the electricity production, we propose using of one combination (out of 15 possible combinations) for parallel connection of pumps. To cover the entire range of values for volume flow of water presented in tab. 5, possible combinations of pump's connections are shown on tab. 6 with the corresponding electricity consumption of the pumps (engaged power).

Table 5. Required volume flow for three values of installed power at certain cooling range

Δt_w [K] →	10	11	12	13
N [MW]	Q_v [m^{3}h^{-1}]			
215	24300	22090	20250	18690
220	24880	22620	20735	19140
225	25450	23134	21210	19575

Results and discussions

From the values presented in tab. 4 and tab. 6, we can determine the consumption of electricity in the period of 6 months.

Table 6. Combinations of pump's connection and engaged power

Δt_w [K] →	10	11	12	13
N [MW]	q_w [m^{3}h^{-1}]/N_p [kW]			
215	$e_{p,0°} + e_{p,1°30'}$ 25090/1599	$e_{p,-4°} + e_{p,-2°}$ 22150/1315	$2 \times e_{p,-4°}$ 21310/1275	–
220	$e_{p,-2°} + e_{p,1°30'}$ 25130/1516	$e_{p,-4°} + e_{p,0°}$ 22970/1408	$2 \times e_{p,-4°}$ 21310/1275	$2 \times e_{p,-4°}$ 21310/1275
225	–	$e_{p,-4°} + e_{p,1°30'}$ 23650/1466	$2 \times e_{p,-4°}$ 21310/1275	$2 \times e_{p,-4°}$ 21310/1275

$$E = 132 \times 1599 + 397 \times 1315 + 397 \times 1275 + 53 \times 1516 + 728 \times 1408 + 662 \times 1275 + 132 \times 1275 + 423 \times 1466 + 490 \times 1275 + 397 \times 1275 = 5108.063 \text{ MWh per year}$$

The pumps work approximately 3811 hours on average in the period of 6 months of the year (average is calculated according to available data for three consecutive years [7-9]), for the power range between 215 to 225 MW, shown in tab. 4. For this period of time, the consumption of electricity for two pumps working in parallel with maximum engaged power-volume flow ($2 \times e_{p+4°}$) reaches:

$$E\,(2 \times e_{p+4°}) = 3811 \times 1908 = 7271.388 \text{ MWh per year}$$

Possible savings of electricity by matching the required volume flow, through matching of appropriate angle of blades is:

$$\Delta E = 7271.388 - 5108.063 = 2163.325 \text{ MWh per year}$$

Possible improvements of energy efficiency are obvious and easily achievable since, from technical point of view, it is very easy to change the angle of the blades even when the pumps are in operation.

However, the analysis presented in the chapter *Relation pover plant cold end – climate curve* showed that one combination of pump's parallel operation ($e_{p,-4°}+ e_{p,+4°}$) is not possible since the optimal pump efficiency of the pump with angle of blades +4° is far outside recommended operating area of the pump and hence will require greater engaged power.

Conclusions

Two axial pumps, working in parallel transport cooling water for each block's cold end at TPP Bitola. By varying the angle of the blades on any of the pumps, a total of 15 different operating characteristics are possible. This means 15 different operating points (cross points between the curves of pump's operating characteristics an characteristic of the pipeline) can be achieved. As a result, water flow can range from 5.92 m^3/s to 7.59 m^3/s, while the power consumption varies from 1274.96 kW to 1907.83 kW, respectively. Since TPP Bitola became fully operational (more than 25 years ago), the only working combination of the pumps is the one with same angle of the blades (+4°), with maximum volume flow and maximum power consumption. As a logical conclusion of everything said above, there is a space for efficiency improvements at plant's cold end, related to pump station's optimal operating regime, mainly by matching the required volume flow through adjustments of the angle of the pump's blades. That would lead to substantial savings in own electricity consumption, especially in "colder" months of the year.

Nomenclature

E	– pipeline characteristics, [Jkg^{-1}]	Δt_w	– temperature difference between of water entering/leaving the cooling tower, [K]
e_p	– specific engaged energy	t_{w1}	– temperature of water entering the cooling tower, [°C]
N	– engaged power, [kW], [MW]	t_{w2}	– temperature of water leaving the cooling tower, [°C]
N_p	– electricity usage of the pump, [kW]	η_p	– optimal pump efficiency, [%]
n	– rotation speed of pump, [min^{-1}]		
q_v, Q_v	– volume flow of water, [m^{3}s^{-1}], [m^{3}h^{-1}]		
t_{vt}	– wet bulb temperature of the ambient air, [°C]		

References

[1] Pecakov, S., Petreski, T., Hristov, T., Local Instruction for Exploatation of Circulational Pump Stations and Technical Water Systems (in Macedonian), Public Enterprise Electric Power Company of Macedonia, Bitola, Republic of Macedonia, 1999

[2] ***, ASHRAE Handbook of Fundamentals, Chapter 1 – Psychrometrics, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, Geo., USA, 2009

[3] ***, ASHRAE Handbook of HVAC Systems and Equipment, Chapter 39 – Cooling towers, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, Geo., USA, 2008

[4] Mijakovski, I., *et al*., Savings of Energy and Environmental Protection Around Thermal Power Plants, Final Report from Scientfic-Research Project 2001-2004 (in Macedonian), Funded by the Ministry of Education and Science of the Republic of Macedonia, Skopje, 2005

[5] ***, Guarantee and Normative Measurements of the Cooling Towers for Block-I and Block-II of TPP Bitola (in Macedonian), Faculty of Mechanical Engineering, Skopje, 1985

[6] Mijakovski, V., Influence of the Climatic Curve on Cooling Tower Operation (in Macedonian), Ph. D. thessis, University "Sv. Kiril i Metodij", Faculty of Mechanical Engineering, Skopje, 2009

[7] ***, Daily Report for the Work of Turbine and Cold-End of TPP "Bitola" for Year 1999, Hourly Values, Public Enterprise Electric Power Company of Macedonia, Bitola, Republic of Macedonia, 2000

[8] ***, Daily Report for the Work of Turbine and Cold-End of TPP "Bitola" for Year 2000, Hourly Values, Public Enterprise Electric Power Company of Macedonia, Bitola, Republic of Macedonia, 2001

[9] ***, Daily Report for the Work of Turbine and Cold-End of TPP "Bitola" for Year 2001, Hourly Values, Public Enterprise Electric Power Company of Macedonia, Bitola, Republic of Macedonia, 2002

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