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ANALYSIS OF VALUES FROM THE CLIMATIC CURVE AND HEAT LOAD ON THE WATER LOSSES IN TPP 'BITOLA'

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Summary: *Heat transfer is conducted through latent heat transfer and is proportional to the change in absolute humidity. Since the input temperature of the dry air thermometer or the relative humidity affect the latent/sensible heat ratio, they also affect the amount of evaporated – lost water.*
Key words: heat, mass, losses, water.

1. INTRODUCTION

Ratio latent/sensible heat is very important in analysis of the water utilization in the cooling tower.

Evaporation in the process AB, $x_B - x_A$, shown in Fig. 1, is smaller in comparison with the process DB, $x_B - x_D$, since the latent heat and mass transfer is smaller for process AB compared to process DB, [1].

The quantity of heat released from the water to the air amounts to:

$$Q_w = m_w \cdot c_w \cdot t_{w1} - (m_w - \Delta m_w) \cdot c_w \cdot t_{w2} = c_w \cdot [m_w \cdot (t_{w1} - t_{w2}) + \Delta m_w \cdot t_{w2}]$$

$$Q_w = c_w \cdot [m_w \cdot (t_{w1} - t_{w2}) + \Delta m_w \cdot t_{w2}] \text{ , (W)} \quad (1)$$

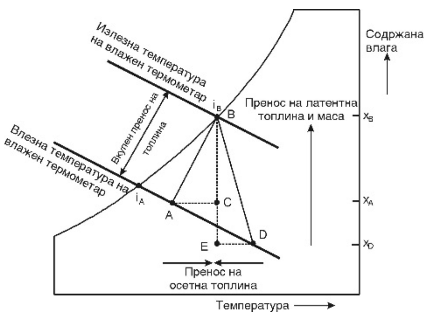

Fig. 1 *Psychrometric analysis of the air passing through the cooling tower*

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The amount of heat accepted by the air is:

$$Q_v = m_v \cdot (i_{v2} - i_{v1}) \text{ , (W)} \quad (2)$$

The amount of evaporated - lost water is:

$$\Delta m_w = m_v \cdot (x_{v2} - x_{v1}) \text{ , (m}^3\text{/h)}$$

The absolute humidity of the air is determined by the equation:

$$x_v = 0{,}62198 \cdot \frac{\varphi_v \cdot p_s}{p_{at} - \varphi_v \cdot p_s} \text{ , (kg/kg)} \quad (3)$$

with atmospheric pressure p_{at} set (or is determined depending on the altitude of the location).

Specific enthalpy of humid air amounts:

$$i_v = 1{,}006 \cdot t_v + x_v \cdot (2501 + 1{,}805 \cdot t_v) \text{ , (kJ/kg)} \quad (4)$$

At the point of saturation (the temperature of the wet thermometer) the enthalpy:

$$i_v = 1{,}006 \cdot t_{vt} + x_s \cdot (2501 + 1{,}805 \cdot t_{vt}) \text{ , (kJ/kg)} \quad (5)$$

The humidity of the air at the same point is:

$$x_s = 0{,}62198 \cdot \frac{p_{s,v}}{p_{at} - p_{s,v}} \text{ , (kg/kg)} \quad (6)$$

Equations (4) and (5) obtain an equation to determine the temperature of a wet thermometer:

$$t_{vt} = \frac{i_v - 2501 \cdot x_s}{1{,}006 + 1{,}805 \cdot x_s} \text{ , (°C)} \quad (7)$$

or:

$$x_{s1} = \frac{i_{v1} - t_{vt}}{2501 + 1{,}805 \cdot t_{vt}} \text{ ; } x_{s2} = 0{,}62198 \cdot \frac{p_{s,v2}}{p_{at} - p_{s,v2}} \text{ , (kg/kg)} \quad (8)$$

On the basis of the equations from (1) to (8), a spreadsheet in MS Excel was created for the determination of the amount of evaporated - lost water.

2. INFLUENCE OF THE CLIMATIC CURVE VALUE ON THE OPERATION OF COOLING TOWER

The analysis, according to the ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) approach, [2] and [3], is made for two groups of values from the climate curve, for both summer and winter periods.

2.1 SUMMER PERIOD

The analysis for the summer period is made for constant inlet temperature of the wet thermometer t_{vt1}=15,9°C, at 100% heat load of the cooling tower Q_0 = 320,927 MW (nominal water flow G_{w0}=30000 m^3/h and nominal cooling range of water Δt_w=9,2 K, according to recommendations from [4] and [5].

Sensible heat is:

$$Q_{os1} = m_v \cdot c_{pv} \cdot (t_{v5} - t_{v1}) \text{ , kW}$$

or:

$$Q_{os1} = m_v \cdot \left(i_{v1'} - i_{v1} \right),\ \text{kW}$$

Latent heat is:

$$Q_{lat1} = m_v \cdot \left(i_{v5} - i_{v1'} \right)\ ,\ \text{kW}$$

Amount of evaporated – lost water equals:

$$\Delta m_1 = m_v \cdot \left(x_{v5} - x_{v1} \right),\ \text{m}^3/\text{h}$$

where:

m_v , kg/s – mass flow of air through the cooling tower;

c_{pv} , kJ/kgK – isobaric specific heat of the air;

t_{v5}, °C – output temperature of the air from the fill (heat exchanger) of the cooling tower at φ_{v5}≈100%;

t_{v1}, °C – air temperature entering in the fill (given values of the climatic curve, in this particular case t_{v1} = 17,5°C and φ_{v1} = 85%);

$i_{vi'}$, kJ/kg – enthalpy of the air at temperature t_{v5}, is used to determine the values of the latent and sensible heat;

i_{v1} , kJ/kg – enthalpy of the air entering the fill (given values from the climatic curve, in this particular case t_{v1} = 17,5°C and φ_{v1} = 85%);

i_{v5}, kJ/kg – enthalpy of the air exiting the fill at temperature t_{v5} and at relative humidity φ_{v5}≈100%;

x_{v1} , kg/kg – absolute humidity of the air entering the fill (given values from the climatic curve, in this particular case t_{v1} = 17,5°C and φ_{v1} = 85%);

x_{v5} , kg/kg – absolute humidity of the air exiting the fill at temperature t_{v5} and at relative humidity φ_{v2}≈100%.

Table 1 *Input data and results from the calculation for the summer period*

t_{v1} °C	φ_{v1} %	$x_{v1} \cdot 10^3$ kg/kg	t_{v2} °C	$x_{v2} \cdot 10^3$ kg/kg	$\Delta x_v \cdot 10^3$ kg/kg	Δt_v °C	t_{w1} °C	t_{w2} °C
17,5	85	11,57	31,73	32,60	22,03	14,23	35,37	26,17
20,0	67	10,65	31,62	32,75	22,10	11,62	35,41	26,21
25,0	40	8,59	31,22	32,86	24,27	6,22	35,38	26,18
27,4	31	7,66	31,06	32,95	25,29	3,66	35,40	26,20

Q_{oset} kW	Q_{lat} kW	$0{,}8 \cdot \Delta W$ m³/h	$1{,}0 \cdot \Delta W$ m³/h	$1{,}1 \cdot \Delta W$ m³/h
69663	251264	294	367	404
56839	264088	310	387	426
30519	290408	341	427	469
17975	302952	356	445	490

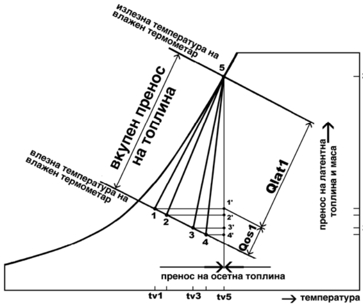

Fig. 2 *Psychrometric analysis of the air passing through the cooling tower, summer period*

2.2 WINTER PERIOD

The analysis for the winter period is made for constant inlet temperature of the wet thermometer t_{vt1}=-6,0°C, at 100% heat load of the cooling tower Q_0 = 320,927 MW (nominal water flow G_{w0}=30000 m^3/h and nominal cooling range of water Δt_w=9,2 K), according to recommendations from [4] and [5].

Sensible heat, in this case, is:

$$Q_{os2} = m_v \cdot c_{pv} \cdot \left(t_{v5} - t_{v2}\right),\ \text{kW}$$

or:

$$Q_{os2} = m_v \cdot \left(i_{v2'} - i_{v1}\right),\ \text{kW}$$

Latent heat is:

$$Q_{lat2} = m_v \cdot \left(i_{v5} - i_{v2'}\right)\ ,\ \text{kW}$$

Amount of evaporated – lost water equals:

$$\Delta m_2 = m_v \cdot \left(x_{v5} - x_{v2}\right)\ ,\ \text{m}^3/\text{h}$$

where:

m_v , kg/s – mass flow of air through the cooling tower;

c_{pv} , kJ/kgK – isobaric specific heat of the air;

t_{v5}, °C – output temperature of the air from the fill (heat exchanger) of the cooling tower at $\varphi_{v5}\approx$100%;

t_{v2}, °C – air temperature entering in the fill (given values of the climatic curve, in this particular case t_{v2} = -4,4°C and φ_{v2} = 61%);

$i_{v2'}$, kJ/kg – enthalpy of the air at temperature t_{v5}, is used to determine the value of sensible and latent heat;

i_{v2} , kJ/kg – enthalpy of the air entering the fill (given values from the climatic curve, in this particular case t_{v2} = -4,4°C and φ_{v2} = 61%);

i_{v5} , kJ/kg – enthalpy of the air exiting the fill at temperature t_{v5} and at relative humidity $\varphi_{v5}\approx$100%;

x_{v2} , kg/kg – absolute humidity of the air entering the fill (given values from the climatic curve, in this particular case t_{v2} = -4,4°C and φ_{v2} = 61%);

x_{v5} , kg/kg – absolute humidity of the air exiting the fill at temperature t_{v5} and at relative humidity $\varphi_{v5}\approx$100%.

Table 2 *Input data and results from the calculation for the winter period*

t_{v1} °C	φ_{v1} %	$x_{v1}\cdot10^3$ kg/kg	t_{v2} °C	$x_{v2}\cdot10^3$ kg/kg	$\Delta x_v\cdot10^3$ kg/kg	Δt_v °C	t_{w1} °C	t_{w2} °C
-5,3	80	2,097	22,00	17,75	15,653	27,30	25,82	16,62
-4,4	61	1,726	21,96	17,76	16,034	26,36	25,82	16,62
-3,7	49	1,471	21,96	17,78	16,309	25,66	25,83	16,63
-2,9	35	1,124	21,92	17,77	16,646	24,82	25,82	16,62

Q_{oset} kW	Q_{lat} kW	$0,8\cdot\Delta W$ m³/h	$1,0\cdot\Delta W$ m³/h	$1,1\cdot\Delta W$ m³/h
133227	187700	219	274	301
128714	192213	224	280	308
125339	195588	228	285	314
121259	199668	233	291	320

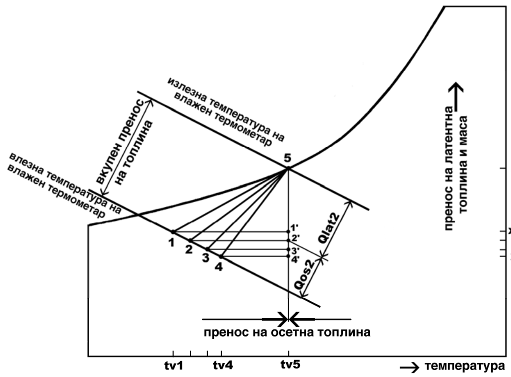

Fig. 3 *Psychrometric analysis of the air passing through the cooling tower, winter period*

From the values in Table 1 and Table 2, the following can be concluded: by increasing the outside air temperature, at a constant inlet temperature of a wet thermometer, the difference between the air temperatures entering and exiting the fill ($\Delta t_v = t_{v,izlez} - t_{v,vlez}$) is reduced. The ratio latent/sensible heat increases, thereby increasing the amount of evaporated – lost water. The amount of evaporated water is proportionally dependent upon heat load, 80%, 100% and 110% of the nominal value.

3. CONCLUSION

By reducing the difference in the air temperature at the exit and the entrance to/from the cooling tower ($\Delta t_v = t_{v,izlez} - t_{v,vlez}$), the latent heat transfer is increased (sensible heat transfer is reduced), thus, the absolute humidity increases proportionally. By increasing the value of absolute humidity, the amount of evaporated water is also increasing proportionally, i.e.:

$$\Delta m = m_v\cdot(x_{v,izlez} - x_{v,vlez})$$

In the summer period, with the decrease in the air temperature difference ($\Delta t_v = t_{v,izlez} - t_{v,vlez}$), the ratio of latent and sensitive heat (251264/69663 = 3,6: 1; 264088/56839

= 4,6: 1; 290408/30519 = 9.5: 1; 302952/17975 = 16.85: 1) significantly increases, thereby increasing the amount of evaporated water.

In the winter period, with the decrease in the air temperature difference (Δt_v = $t_{v,izlez}$ - $t_{v,vlez}$), the ratio of latent and sensitive heat (187700/133227 = 1,41:1 ; 192213/128714 = 1,49:1 ; 195588/125339 = 1,56:1 ; 199668/121259 = 1,65:1) increases at lower rate, correspondingly increasing the amount of evaporated water.

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