EXERGY ANALYSIS OF WET COOLING TOWER AT VARIOUS LOADS AND AMBIENT TEMPERATURES

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Abstract: *This paper presents an exergy analysis of wet cooling tower at three different loads and in a range of the ambient temperatures. Increase in cooling tower load increases its exergy destruction and simultaneously decreases cooling tower exergy efficiency, while an increase in the ambient temperature causes a decrease in cooling tower exergy destruction and simultaneously decreases its exergy efficiency. The lowest cooling tower exergy destructions (between 1417.54 kW and 2925.65 kW) are obtained at low load. The highest cooling tower exergy efficiencies are calculated at the lowest observed ambient temperature of 5 °C - they amount 64.31 % at low load, 54.80 % at middle load and 53.94 % at high load. The change in ambient temperature for 5 °C resulted with a change in cooling tower exergy efficiency of 4 % or more on average.*

KEYWORDS: EXERGY ANALYSIS, WET COOLING TOWER, VARIOUS LOADS, CHANGE IN AMBIENT TEMPERATURE

1. Introduction

Steam condenser is one of the essential elements of any steam power plant [1]. Its operation significantly influences steam turbine and steam expansion process through the turbine. For adequate steam condensation in the condenser a proper cooling medium is required, which is, in most cases, water [2] (or in some situations air [3]).

Cooling water which passes through the condenser tubes (in the most used water cooled steam condensers) must be cooled and returned back to condenser (with decreased temperature) so that it could take the heat from steam again.

Cooling of water which takes heat from the steam in steam condenser can be performed in several ways. It can be used wet or dry cooling tower with natural air circulation or with air circulation caused by fans (forced air circulation). In the cooling towers in general, the ambient air is used for cooling the water, which is delivered from steam condenser or more of them [4].

This paper presents an exergy analysis of wet cooling tower with natural air circulation from cogeneration power plant. Exergy analysis is performed at three cooling tower loads and in a range of ambient temperatures. Calculations show that the highest cooling tower exergy efficiencies and the lowest exergy power losses will be obtained at low cooling tower load. Cooling tower has the lowest exergy power losses at the highest observed ambient temperature, while the highest cooling tower exergy efficiencies are obtained for the lowest observed ambient temperature.

2. Description and operating characteristics of the analyzed wet cooling tower

General scheme of the analyzed wet cooling tower along with marked operating points of each fluid flow stream (water and air) necessary for the exergy analysis is presented in Fig. 1.

Wet cooling towers operate on the principle of evaporative cooling. The hot water flow stream from the steam condenser is sprayed into the air flow stream (operating point 2, Fig. 1), which allows both sensible and latent heat transfer. In such cooling towers the water flow stream is cooled to near the wet-bulb temperature of air. Such heat transfer makes wet cooling tower more efficient (when compared to dry cooling towers).

Analyzed wet cooling tower has natural air circulation. Therefore, air fans for increasing air velocity (and thus improving heat transfer between water and air) are not used.

Inside the cooling tower, the flow arrangement between air and water flow streams can be crossflow, counterflow and parallelflow. Cooling towers with counterflow arrangement, as the one analyzed in this paper, where the air flow is opposite to the water flow, in general achieves the best efficiencies during its operation.

As presented in Fig. 1, cooled water is collected in a water pool at the cooling tower bottom and delivered again (by a pump) into the steam condenser.

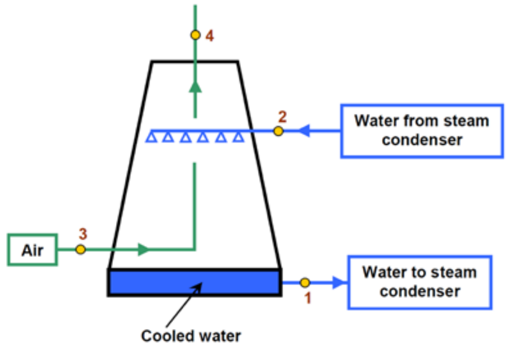

Fig. 1. *Cooling tower scheme with marked operating points necessary for the analysis*

3. Exergy analysis equations

3.1. General exergy analysis equations valid for any volume or system

The second law of thermodynamics defines exergy analysis of a system or volume, [5] and [6]. For a volume or system in steady state, the main exergy balance equation can be defined as [7]:

$$\dot{X}_{\text{heat}} - P = \sum \dot{m}_{\text{OUT}} \cdot \varepsilon_{\text{OUT}} - \sum \dot{m}_{\text{IN}} \cdot \varepsilon_{\text{IN}} + \dot{E}_{\text{ex,D}} \tag{1}$$

Specific exergy of any flow stream is defined, according to [8], as:

$$\varepsilon = (h - h_0) - T_0 \cdot (s - s_0) \tag{2}$$

The exergy power of any flow stream can be defined by an equation [9]:

$$\dot{E}_{\text{ex}} = \dot{m} \cdot \varepsilon = \dot{m} \cdot \left[(h - h_0) - T_0 \cdot (s - s_0) \right] \tag{3}$$

At temperature T, the exergy transfer by heat ($\dot{X}_{\text{heat}}$) can be defined, according to [10], as:

$$\dot{X}_{\text{heat}} = \sum (1 - \frac{T_0}{T}) \cdot \dot{Q} \tag{4}$$

The exergy efficiency of any system or a volume has an overall definition which can be found in [11]:

$$\eta_{\text{ex}} = \frac{\text{Exergy output}}{\text{Exergy input}} \tag{5}$$

In the exergy analysis of any volume or a system in steady state it is usually assumed that leakage of any flow stream does not occur (or if does, it should be measured and included in the exergy balance). Following such assumption, as described also in [12] and [13], the mass balance equation is:

$$\sum \dot{m}_{\mathrm{IN}} = \sum \dot{m}_{\mathrm{OUT}} \tag{6}$$

3.2. Equations for the exergy analysis of investigated wet cooling tower

Investigated cooling tower exergy analysis (as well as exergy analysis of any other control volume or system) depends on ambient conditions (the ambient pressure and temperature). The base ambient conditions (base ambient state) for the cooling tower exergy analysis are the ambient pressure of 1 bar and the ambient temperature of 15 °C.

During the exergy analysis of any steam system or any of its components, numerical change in the ambient temperature can be performed in order to investigate the ambient temperature influence on the system or component exergy losses and exergy efficiencies, [14] and [15]. The change in ambient pressure, in most cases, is not significant and it cannot have a notable influence on any steam system or component exergy losses and exergy efficiencies.

The exergy analysis equations of wet cooling tower investigated in this paper are presented according to cooling tower operating points from Fig. 1:

Mass flow balance

- Water mass flow balance:

$$\dot{m}_1 = \dot{m}_2 \tag{7}$$

- Air mass flow balance:

$$\dot{m}_3 = \dot{m}_4 \tag{8}$$

Exergy balance

- Cooling tower exergy power input:

$$\dot{E}_{\mathrm{ex,IN}} = \dot{m}_2 \cdot \varepsilon_2 + \dot{m}_3 \cdot \varepsilon_3 \tag{9}$$

- Cooling tower exergy power output:

$$\dot{E}_{\mathrm{ex,OUT}} = \dot{m}_1 \cdot \varepsilon_1 + \dot{m}_4 \cdot \varepsilon_4 \tag{10}$$

- Cooling tower exergy destruction:

$$\dot{E}_{\mathrm{ex,D}} = \dot{E}_{\mathrm{ex,IN}} - \dot{E}_{\mathrm{ex,OUT}} = \dot{m}_2 \cdot \varepsilon_2 + \dot{m}_3 \cdot \varepsilon_3 - \dot{m}_1 \cdot \varepsilon_1 - \dot{m}_4 \cdot \varepsilon_4 \tag{11}$$

- Cooling tower exergy efficiency:

$$\eta_{\mathrm{ex}} = \frac{\dot{E}_{\mathrm{ex,OUT}}}{\dot{E}_{\mathrm{ex,IN}}} = \frac{\dot{m}_1 \cdot \varepsilon_1 + \dot{m}_4 \cdot \varepsilon_4}{\dot{m}_2 \cdot \varepsilon_2 + \dot{m}_3 \cdot \varepsilon_3} \tag{12}$$

4. The operating parameters of cooling tower necessary for the exergy analysis

Wet cooling tower exergy analysis is performed by using temperatures, pressures and mass flows of each cooling tower fluid stream (in each operating point from Fig. 1). Those operating parameters were found in [16].

The cooling tower load is defined by a temperature of cooling water that enters from steam condenser into the cooling tower (operating point 2, Fig. 1). At low cooling tower load cooling water temperature at the cooling tower inlet is equal to 38.84 °C, at middle load is equal to 44.82 °C and at high cooling tower load is equal to 45.44 °C. Temperature of cooling water and thus cooling tower load is proportional to steam condenser load - higher steam mass flow at the steam condenser inlet denotes a higher condenser load [17]. Steam mass flows at the condenser inlet at low, middle and high cooling tower loads are 14.750 kg/s, 22.361 kg/s and 23.417 kg/s, respectively.

In the analyzed wet cooling tower heat is transferred from hot water (operating point 2, Fig. 1) to air (operating point 3, Fig. 1). Each cooling tower load, at each ambient temperature, required calculation of air specific exergies (operating points 3 and 4, Fig. 1), that are necessary for cooling tower exergy analysis. From NIST REFPROP 9.0 software [18] air is selected with characteristics and specifications presented in Table 1.

Table 1. *Characteristics and specifications of air used in cooling tower exergy analysis*

Air mass fractions	Nitrogen	75.57 %
	Oxygen	23.16 %
	Argon	1.27 %
Critical properties	Temperature	-140.32 °C
	Pressure	38.508 bar
	Density	344.76 kg/m^3
Air molar mass	28.959 kg/kmol	

The operating parameters of each fluid flow stream required for the cooling tower exergy analysis are presented in Table 2 for low cooling tower load, in Table 3 for middle cooling tower load and finally in Table 4 for high cooling tower load.

Specific enthalpies and specific exergies of each fluid flow stream are also presented in Table 2, Table 3 and Table 4. They were calculated by using NIST REFPROP 9.0 software [18]. Specific exergies of any fluid stream presented in all three tables are calculated for the base ambient state (the ambient pressure of 1 bar and the ambient temperature of 15 °C).

Table 2. *Operating parameters of the analyzed cooling tower - low cooling tower load*

OP*	Temperature (°C)	Pressure (bar)	Mass flow (kg/s)	Specific enthalpy (kJ/kg)	Specific exergy (kJ/kg)
1	29.41	5.00	826.389	123.70	1.857
2	38.84	5.00	826.389	163.10	4.306
3	32.70	1.01	613.333	306.20	1.349
4	35.40	1.01	613.333	308.92	1.517

* OP = Operating Point (according to Fig. 1)

Table 3. *Operating parameters of the analyzed cooling tower - middle cooling tower load*

OP*	Temperature (°C)	Pressure (bar)	Mass flow (kg/s)	Specific enthalpy (kJ/kg)	Specific exergy (kJ/kg)
1	30.48	5.00	826.389	128.20	2.079
2	44.82	5.00	826.389	188.10	6.435
3	32.70	1.01	613.333	306.20	1.349
4	39.10	1.01	613.333	312.64	1.784

* OP = Operating Point (according to Fig. 1)

Table 4. *Operating parameters of the analyzed cooling tower - high cooling tower load*

OP*	Temperature (°C)	Pressure (bar)	Mass flow (kg/s)	Specific enthalpy (kJ/kg)	Specific exergy (kJ/kg)
1	30.58	5.00	826.389	128.60	2.100
2	45.44	5.00	826.389	190.70	6.681
3	32.70	1.01	613.333	306.20	1.349
4	39.50	1.01	613.333	313.05	1.816

* OP = Operating Point (according to Fig. 1)

5. Cooling tower exergy analysis results and discussion

In the investigated cooling tower exergy analysis, each calculated operating parameter, regardless of the current cooling tower load, is presented for the various ambient temperatures. Throughout the complete analysis, the ambient temperature was varied in a range from 5 °C to 20 °C, with a step of 5 °C.

Exergy power input of the analyzed cooling tower at each observed load and at each ambient temperature is calculated by using Eq. 9.

Fig. 2 presents that the highest cooling tower exergy power input is at high cooling tower load and then decreases with a decrease in cooling tower load. This fact is valid regardless of the observed ambient temperature.

In the observed ambient temperature range (between 5 °C and 20 °C) a decrease in the ambient temperature results with an increase in cooling tower exergy power input. This fact is valid regardless of the observed cooling tower load. Therefore, the highest cooling tower exergy power inputs were obtained at the ambient temperature of 5 °C and are 8197.89 kW at low cooling tower load, 10612.60 kW at middle and 10883.66 kW at high cooling tower load, Fig. 2.

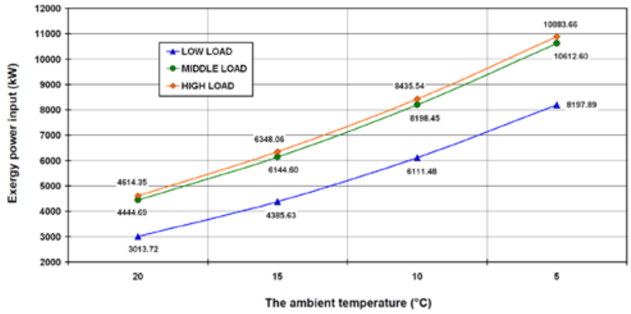

Fig. 2. *Change in the analyzed cooling tower exergy power input for the different ambient temperatures at three condenser loads*

Change in analyzed cooling tower exergy power output has identical trends as the change in cooling tower exergy power input, Fig. 2 and Fig 3. Cooling tower exergy power output at each observed load and at each ambient temperature is calculated by using Eq. 10.

The highest cooling tower exergy power output can be seen at the high cooling tower load and then decreases with a decrease in cooling tower load, what is a valid conclusion regardless of the observed ambient temperature, Fig. 3.

An increase in the ambient temperature resulted with a decrease in cooling tower exergy power output, what is a valid conclusion regardless of the observed cooling tower load. The highest cooling tower exergy power outputs were obtained at the ambient temperature of 5 °C and amounts 5272.24 kW at low cooling tower load, 5815.67 kW at middle cooling tower load and 5870.55 kW at high cooling tower load, Fig. 3.

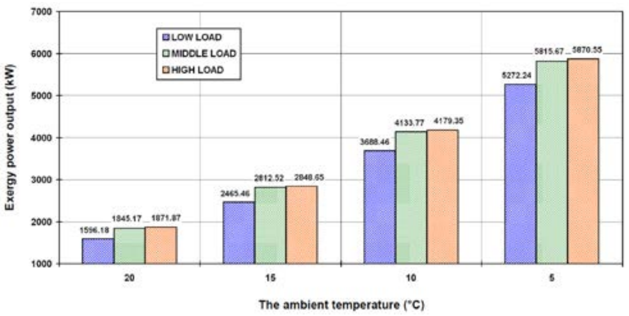

Fig. 3. *Change in the analyzed cooling tower exergy power output for the different ambient temperatures at three condenser loads*

Exergy destruction (exergy power losses) of the analyzed cooling tower is calculated by Eq. 11, regardless of cooling tower load and the ambient temperature.

The lowest cooling tower exergy destruction is obtained at low cooling tower load and in the observed ambient temperature range it amounts between 1417.54 kW and 2925.65 kW, Fig. 4. Increase in cooling tower load resulted with an increase in exergy destruction, which is therefore the highest at high cooling tower load.

An increase in the ambient temperature decreases cooling tower exergy destruction, regardless of the observed cooling tower load, Fig. 4. At the highest observed ambient temperature of 20 °C the lowest cooling tower exergy destructions are calculated which are 1417.54 kW at cooling tower low load, 2599.52 kW at the middle and 2742.48 kW at high cooling tower load.

From the exergy destruction aspect, for the analyzed cooling tower it would be advisable to operate at low load and at the highest possible ambient temperature - for such operating conditions cooling tower exergy destruction will be the lowest.

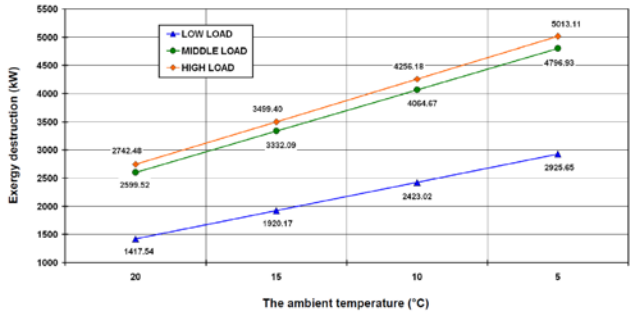

Fig. 4. *Change in the analyzed cooling tower exergy destruction for the different ambient temperatures at three condenser loads*

The exergy efficiency of the cooling tower analyzed in this paper is calculated by using Eq. 12 at any ambient temperature and cooling tower load.

Cooling tower at low load has the highest exergy efficiencies (between 52.96 % and 64.31 % in the observed ambient temperature range). Increase in cooling tower load results with a decrease in exergy efficiency at any ambient temperature, Fig. 5.

Decrease in the ambient temperature increases cooling tower exergy efficiency at any load. Therefore, the highest cooling tower exergy efficiencies are calculated at the ambient temperature of 5 °C and are 64.31 % at cooling tower low load, 54.80 % at middle load and 53.94 % at cooling tower high load, Fig. 5.

Considering the cooling tower exergy efficiency only, the best option for cooling tower operation will be low load and the lowest possible ambient temperature. During such operating condition cooling tower exergy efficiency will be the highest.

The analyzed cooling tower is one of the components of the entire cogeneration power plant which exergy efficiency is significantly influenced by the ambient temperature change. The change in ambient temperature for 5 °C resulted with a change in cooling tower exergy efficiency of 4 % or more on average, while taking into account all of the observed cooling tower loads.

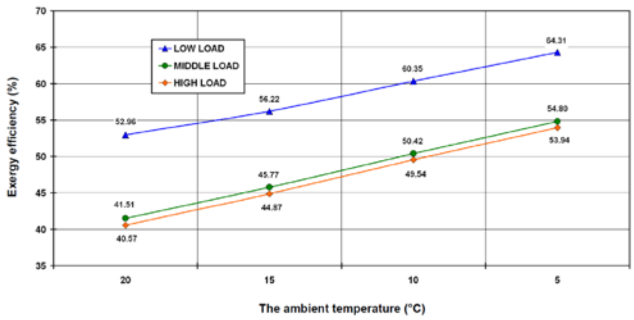

Fig. 5. *Change in the analyzed cooling tower exergy efficiency for the different ambient temperatures at three loads*

Presented wet cooling tower exergy analysis enables two important conclusions for its operation. From the aspect of cooling tower load its operation should be performed at low load - at low load cooling tower exergy destruction is the lowest while exergy efficiency is the highest when compared to other loads. This conclusion is valid for any ambient temperature.

From the ambient temperature aspect, optimal cooling tower operation cannot be obtained because at low ambient temperatures cooling tower will have the highest exergy efficiencies but also the highest exergy destructions. At high ambient temperatures, cooling tower exergy destructions will be the lowest but simultaneously, exergy efficiencies will be the lowest, Fig. 4 and Fig. 5. Finally, from the aspect of the ambient temperature, the priority in the analyzed cooling tower operation should be determined - minimum exergy destructions or maximum exergy efficiencies.

6. Conclusions

In this paper an exergy analysis of wet cooling tower from cogeneration power plant is presented. The cooling tower is analyzed at three different loads and in a range of the ambient temperatures. The most important conclusions of the analysis are:

- Cooling tower exergy power input and output has identical trends during the change in load and ambient temperature. Increase in cooling tower load resulted with an increase in the exergy power input and output (at any ambient temperature), while an increase in the ambient temperature resulted with a decrease in cooling tower exergy power input and output (at any cooling tower load).
- Increase in cooling tower load increases cooling tower exergy destruction, regardless of the ambient temperature. An increase in the ambient temperature causes a decrease in cooling tower exergy destruction, regardless of the current load. In a range of observed ambient temperatures (from 5 °C to 20 °C) cooling tower exergy destruction at low load is between 1417.54 kW and 2925.65 kW, while at high load exergy destruction range is between 2742.48 kW and 5013.11 kW.
- Increase in cooling tower load decreases cooling tower exergy efficiency, regardless of the ambient temperature. An increase in the ambient temperature causes a decrease in cooling tower exergy efficiency, regardless of the current load. The highest cooling tower exergy efficiencies are calculated at the lowest observed ambient temperature of 5 °C - they amounts 64.31 % at low load, 54.80 % at middle load and 53.94 % at high load.
- The analyzed cooling tower is one of the steam power plant components which exergy efficiency is significantly influenced by the ambient temperature change. The change in ambient temperature for 5 °C resulted with a change in cooling tower exergy efficiency of 4 % or more on average (by taking into account any cooling tower load).
- From the viewpoint of cooling tower load - cooling tower should operate at low load - at low load cooling tower exergy destruction is the lowest and exergy efficiency is the highest when compared to other loads, at any ambient temperature.
- Optimal cooling tower operation from the viewpoint of the ambient temperature cannot be obtained because an increase in the ambient temperature resulted with a simultaneous decrease in exergy destruction and in exergy efficiency, and vice versa. Therefore, from the aspect of the ambient temperature the priority in the analyzed cooling tower operation should be determined - minimum exergy destructions or maximum exergy efficiencies.

7. Acknowledgment

This work has been fully supported by the Croatian Science Foundation under the project IP-2018-01-3739.

8. Nomenclature

Latin Symbols:		***Greek symbols:***	
$\dot{E}$	the total exergy of flow, kW	ε	specific exergy, kJ/kg
h	specific enthalpy, kJ/kg	η	efficiency, -
$\dot{m}$	mass flow rate, kg/s		
p	pressure, bar	***Subscripts:***	
P	power, kW	0	ambient state
$\dot{Q}$	heat transfer, kW	D	destruction (ex. loss)
s	specific entropy, kJ/kg·K	ex	exergy
T	temperature, °C or K	IN	inlet (input)
$\dot{X}_{\text{heat}}$	heat exergy transfer, kW	OUT	outlet (output)

9. References

[1] Erdem, H.H., Akkaya, A.V., Cetin, B., Dagdas, A., Sevilgen, S.H., Sahin, B., Teke, I., Gungor, C., Atas, S.: *Comparative energetic and exergetic performance analyses for coal-fired thermal power plants in Turkey*, International Journal of Thermal Sciences 48, p. 2179–2186, 2009. (doi:10.1016/j.ijthermalsci.2009.03.007)

[2] Koroglu, T., Sogut, O. S.: *Conventional and Advanced Exergy Analyses of a Marine Steam Power Plant*, Energy 163, p. 392-403, 2018. (doi:10.1016/j.energy.2018.08.119)

[3] Aljundi, I. H.: *Energy and exergy analysis of a steam power plant in Jordan*, Applied Thermal Engineering 29, p. 324–328, 2009. (doi:10.1016/j.applthermaleng.2008.02.029)

[4] Blecich, P., Senčić, T., Wolf, I., Bonefačić, I.: *Numerical investigation of heat and mass transfer inside a wet cooling tower*, Technical Journal 12 (3), p. 131-138, 2018. (doi:10.31803/tg-20171017145907)

[5] Mrzljak, V., Poljak, I., Medica-Viola, V.: *Energy and Exergy Efficiency Analysis of Sealing Steam Condenser in Propulsion System of LNG Carrier*, International Journal of Maritime Science & Technology "Our Sea" 64 (1), p. 20-25, 2017. (doi:10.17818/NM/2017/1.4)

[6] Mrzljak, V., Poljak, I., Medica-Viola, V.: *Thermodynamical analysis of high-pressure feed water heater in steam propulsion system during exploitation*, Shipbuilding 68 (2), p. 45-61, 2017. (doi:10.21278/brod68204)

[7] Mrzljak, V., Senčić, T., Žarković, B.: *Turbogenerator Steam Turbine Variation in Developed Power: Analysis of Exergy Efficiency and Exergy Destruction Change*, Modelling and Simulation in Engineering 2018. (doi:10.1155/2018/2945325)

[8] Poljak, I., Orović, J., Mrzljak, V.: *Energy and Exergy Analysis of the Condensate Pump During Internal Leakage from the Marine Steam Propulsion System*, Scientific Journal of Maritime Research 32 (2), p. 268-280, 2018. (doi:10.31217/p.32.2.12)

[9] Mrzljak, V., Poljak, I., Medica-Viola, V.: *Dual fuel consumption and efficiency of marine steam generators for the propulsion of LNG carrier*, Applied Thermal Engineering 119, p. 331–346, 2017. (doi:10.1016/j.applthermaleng.2017.03.078)

[10] Mrzljak, V., Poljak, I., Mrakovčić, T.: *Energy and exergy analysis of the turbo-generators and steam turbine for the main feed water pump drive on LNG carrier*, Energy Conversion and Management 140, p. 307–323, 2017. (doi:10.1016/j.enconman.2017.03.007)

[11] Orović, J., Mrzljak, V., Poljak, I.: *Efficiency and Losses Analysis of Steam Air Heater from Marine Steam Propulsion Plant*, Energies 2018, 11 (11), 3019 (doi:10.3390/en11113019)

[12] Mrzljak, V., Prpić-Oršić, J., Senčić, T.: *Change in Steam Generators Main and Auxiliary Energy Flow Streams During the Load Increase of LNG Carrier Steam Propulsion System*, Scientific Journal of Maritime Research 32, p. 121-131, 2018. (doi:10.31217/p.32.1.15)

[13] Mrzljak, V.: *Low power steam turbine energy efficiency and losses during the developed power variation*, Technical Journal 12 (3), p. 174-180, 2018. (doi:10.31803/tg-20180201002943)

[14] Mrzljak, V., Poljak, I., Medica-Viola, V.: *Efficiency and losses analysis of low-pressure feed water heater in steam propulsion system during ship maneuvering period*, Scientific Journal of Maritime Research 30, p. 133-140, 2016. (doi:10.31217/p.30.2.6)

[15] Mrzljak, V., Poljak, I., Žarković, B.: *Exergy Analysis of Steam Pressure Reduction Valve in Marine Propulsion Plant on Conventional LNG Carrier*, International Journal of Maritime Science & Technology "Our Sea" 65(1), p. 24-31, 2018. (doi:10.17818/NM/2018/1.4)

[16] Burin, E. K., Vogel, T., Multhaupt, S., Thelen, A., Oeljeklaus, G., Gorner, K., Bazzo, E.: *Thermodynamic and economic evaluation of a solar aided sugarcane bagasse cogeneration power plant*, Energy 117, Part 2, p. 416-428, 2016. (doi:10.1016/j.energy.2016.06.071)

[17] Medica-Viola, V., Pavković, B., Mrzljak, V.: *Numerical model for on-condition monitoring of condenser in coal-fired power plants*, International Journal of Heat and Mass Transfer 117, p. 912–923, 2018. (doi:10.1016/j.ijheatmasstransfer.2017.10.047)

[18] Lemmon, E.W., Huber, M.L., McLinden, M.O.: *NIST reference fluid thermodynamic and transport properties REFPROP*, version 9.0, User's guide, Colorado, 2010.

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YEAR III,
ISSN 2535-0315(Print),
ISSN 2535-0323 (Online)
ISSUE 1 (7),
SOFIA, BULGARIA 2019

VOLUME 1

ENGINEERING. TECHNOLOGIES.
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