Efficiencies and losses comparison of three steam turbines – from conventional, nuclear and marine power plant

Mrzljak Vedran[1], Prpić-Oršić Jasna[1], Poljak Igor[2], Baressi Šegota Sandi[1]
[1]Faculty of Engineering, University of Rijeka, Vukovarska 58, 51000 Rijeka, Croatia
[2]Department of maritime sciences, University of Zadar, Mihovila Pavlinovića 1, 23000 Zadar, Croatia
E-mail: vedran.mrzljak@riteh.hr, jasna.prpic-orsic@riteh.hr, ipoljak1@unizd.hr, sbaressisegota@riteh.hr

Abstract: *This paper presents an analysis and comparison of three steam turbines and its cylinders: from the conventional steam power plant, from nuclear power plant and from the marine propulsion plant. The best parameters for the comparison of whole turbines and its cylinders are: energy loss per unit of produced mechanical power, exergy destruction per unit of produced mechanical power, energy efficiency and exergy efficiency. Steam turbine from marine propulsion plant shows the worst performance, regardless if observing each cylinder or the whole turbine – it has the highest losses per unit of produced mechanical power and the lowest efficiencies (both energy and exergy). Such results can be explained by a fact that marine steam turbine must be much more dynamic in operation in comparison to other two turbines. Also, marine steam turbine analyzed in this paper did not possess steam reheating between the cylinders as the other two observed steam turbines, what has a dominant impact on the obtained results.*

KEYWORDS*: VARIOUS STEAM TURBINES, EFFICIENCIES, LOSSES, PERFORMANCE COMPARISON*

1. Introduction

Steam turbines are nowadays inevitable components of various power plants: conventional [1], nuclear [2], combined [3], cogeneration [4], marine [5] and many others. In the most of the cases, steam turbines are used for electrical generator drive and producing of electrical power [6], but also it can be used for various other purposes in various plants, processes and industries [7, 8].

In the literature can often be found analysis of various power plants inside which are mounted steam turbines as its constituent components [9]. However, a direct comparison of various steam turbines and its cylinders, from various steam power plants is rare.

In order to fulfill a literature gap, in this paper is presented analysis and comparison of three steam turbines and its cylinders: from the conventional steam power plant, from nuclear power plant and from the marine propulsion plant. Parameters selected for direct comparison of observed steam turbines and its cylinders are: energy loss per unit of produced mechanical power, exergy destruction per unit of produced mechanical power, energy efficiency and exergy efficiency.

2. Description of the analyzed steam turbines

In this paper were analyzed three steam turbines along with its cylinders, presented in Fig. 1.

In Fig. 1 (a) is presented scheme of a steam turbine from the conventional steam power plant. HPC has one steam extraction, while the steam mass flow rate which remains after expansion in HPC (operating point 3) is delivered to steam reheater which increases steam temperature. After reheater (operating point 4), steam is delivered to LPC. LPC of this turbine has four steam extractions. After expansion in LPC, remaining steam mass flow rate is delivered to steam condenser [10] for condensation.

Second analyzed steam turbine, from nuclear power plant, is presented in Fig. 1 (b). In comparison to other analyzed steam turbines, this steam turbine dominantly operates with wet steam. HPC of this turbine has two steam extractions. After HPC, it is performed process of steam reheating, which in the case of nuclear power plant consists of moisture separation and reheating [11]. LPC of steam turbine from nuclear power plant has three steam extractions. After LPC, remaining steam mass flow rate is delivered to steam condenser.

Third steam turbine analyzed in this paper is a steam turbine from the marine propulsion plant, presented in Fig. 1 (c). Each cylinder of this turbine (HPC and LPC) has one steam extraction, while the third steam extraction can be noted between two cylinders. In comparison to other analyzed steam turbines, this turbine did not possess steam reheating between cylinders what can be a significant disadvantage. After expansion, steam is delivered to marine steam condenser [12].

First two steam turbines – Fig. 1 (a) and Fig. 1 (b) are used for the Electrical Generator (EG) drive, while marine steam turbine, Fig. 1 (c), drives ship propulsion propeller through the gearbox.

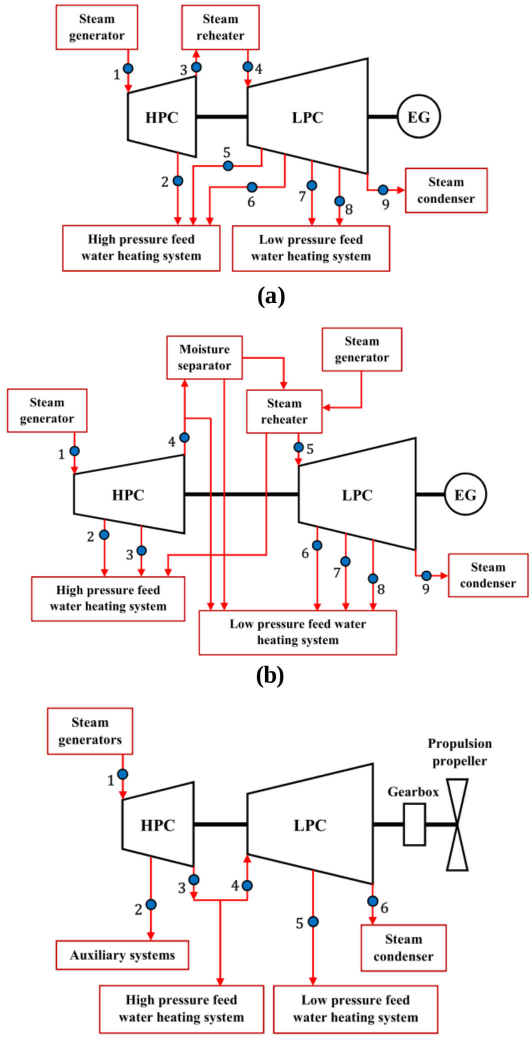

Fig. 1. *Observed steam turbines and operating points required for the analysis: (a) From the conventional power plant; (b) From nuclear power plant; (c) From the marine propulsion plant*

3. Equations for efficiencies and loss calculation

In this paper will be performed calculation of energy and exergy efficiencies and losses for each cylinder and the whole turbine for all three steam turbines presented in Fig. 1. It should be highlighted that an energy analysis of any system or a control volume did not take into consideration any parameter of the ambient in which system or a control volume operates [13], while exergy analysis takes into consideration parameters of the ambient [14].

3.1. Base energy and exergy balances and principles

The first law of thermodynamics is a baseline for energy analysis, while the second law of thermodynamics is a baseline for exergy analysis [15, 16]. The general energy and exergy balance equations valid for any system or a control volume are [17, 18]:

$$\dot{Q}_{\text{input}} + P_{\text{input}} + \sum \dot{E}n_{\text{input}} = \dot{Q}_{\text{output}} + P_{\text{output}} + \sum \dot{E}n_{\text{output}}, \quad (1)$$

$$\dot{X}_{\text{ex}} + P_{\text{input}} + \sum \dot{E}x_{\text{input}} = P_{\text{output}} + \sum \dot{E}x_{\text{output}} + \dot{E}x_{\text{des}}. \quad (2)$$

In the above equations, P in (kW) is used or produced mechanical power, $\dot{Q}$ in (kW) is the energy transfer by heat, $\dot{X}_{\text{ex}}$ in (kW) is the exergy transfer by heat at the temperature T in (K) and $\dot{E}x_{\text{des}}$ in (kW) is exergy destruction (exergy loss). $\dot{E}n$ in (kW) is a total energy of fluid flow, while $\dot{E}x$ in (kW) is a total exergy of fluid flow. A total energy and exergy of fluid flow are defined as [19, 20]:

$$\dot{E}n = \dot{m} \cdot h, \quad (3)$$

$$\dot{E}x = \dot{m} \cdot \varepsilon. \quad (4)$$

In Eq. (3) and Eq. (4), h in (kJ/kg) is fluid specific enthalpy, ε in (kJ/kg) is fluid specific exergy, while $\dot{m}$ in (kg/s) is the fluid mass flow rate. The overall definition of energy or exergy efficiency is:

$$\eta_{\text{en (ex)}} = \frac{\text{cumulative energy (exergy) output}}{\text{cumulative energy (exergy) input}}. \quad (5)$$

In any system or a control volume during standard operation, fluid mass flow rate leakage did not occur, so the valid mass flow rate balance is [21]:

$$\sum \dot{m}_{\text{input}} = \sum \dot{m}_{\text{output}}. \quad (6)$$

Above presented base equations and principles will be used in the calculation of energy and exergy losses and efficiencies of all turbines from Fig. 1 as well as of each cylinder.

3.2. Energy and exergy efficiencies and losses of the observed steam turbines and cylinders

Equations for the calculation of energy and exergy efficiencies and losses of the whole turbines and each cylinder from Fig. 1 will be presented for steam turbine from the conventional steam power plant (Fig. 1 (a)). For the other observed steam turbines, equations will be defined in accordance to the presented ones. All of the equations are defined according to recommendations from the literature [22-24].

The baseline for the calculation of cylinder or the whole turbine energy losses and energy efficiencies is the comparison of steam expansion process throughout the cylinder or whole turbine. In Fig. 2 is presented comparison of real (polytropic) steam expansion process and ideal (isentropic) steam expansion process between two same pressures. Data of any cylinder or whole turbine real (polytropic) steam expansion process are obtained by measurements inside the power plant. Ideal (isentropic) steam expansion process is obtained mathematically by assuming always the same steam specific entropy during the expansion process, Fig. 2.

In the following equations, operating points for ideal (isentropic) steam expansion will have index IS.

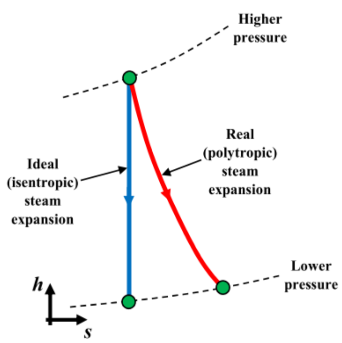

Fig. 2. *A comparison of real (polytropic) and ideal (isentropic) steam expansion processes in h-s diagram*

All required equations are as follows (operating points numeration is defined in accordance to Fig. 1 (a)):

<u>High Pressure Cylinder (HPC) - conventional steam power plant</u>

- Real (polytropic) mechanical power:

$$P_{\text{RE,HPC}} = \dot{m}_1 \cdot (h_1 - h_2) + (\dot{m}_1 - \dot{m}_2) \cdot (h_2 - h_3). \quad (7)$$

- Ideal (isentropic) mechanical power:

$$P_{\text{ID,HPC}} = \dot{m}_1 \cdot (h_1 - h_{2\text{IS}}) + (\dot{m}_1 - \dot{m}_2) \cdot (h_{2\text{IS}} - h_{3\text{IS}}). \quad (8)$$

- Energy loss:

$$\dot{E}n_{\text{loss,HPC}} = P_{\text{ID,HPC}} - P_{\text{RE,HPC}}. \quad (9)$$

- Energy loss per unit of produced mechanical power:

$$\dot{E}n_{\text{loss,HPC,kW}} = \frac{\dot{E}n_{\text{loss,HPC}}}{P_{\text{RE,HPC}}} \cdot 100. \quad (10)$$

- Energy efficiency:

$$\eta_{\text{en,HPC}} = \frac{P_{\text{RE,HPC}}}{P_{\text{ID,HPC}}} \cdot 100. \quad (11)$$

- Exergy destruction (exergy loss):

$$\dot{E}x_{\text{des,HPC}} = \dot{E}x_1 - \dot{E}x_2 - \dot{E}x_3 - P_{\text{RE,HPC}}. \quad (12)$$

- Exergy destruction per unit of produced mechanical power:

$$\dot{E}x_{\text{des,HPC,kW}} = \frac{\dot{E}x_{\text{des,HPC}}}{P_{\text{RE,HPC}}} \cdot 100. \quad (13)$$

- Exergy efficiency:

$$\eta_{\text{ex,HPC}} = \frac{P_{\text{RE,HPC}}}{\dot{E}x_1 - \dot{E}x_2 - \dot{E}x_3} \cdot 100. \quad (14)$$

<u>Low Pressure Cylinder (LPC) - conventional steam power plant</u>

- Real (polytropic) mechanical power:

$$P_{\text{RE,LPC}} = \dot{m}_4 \cdot (h_4 - h_5) + (\dot{m}_4 - \dot{m}_5) \cdot (h_5 - h_6) + (\dot{m}_4 - \dot{m}_5 - \dot{m}_6) \cdot (h_6 - h_7) + (\dot{m}_4 - \dot{m}_5 - \dot{m}_6 - \dot{m}_7) \cdot (h_7 - h_8) + \dot{m}_9 \cdot (h_8 - h_9). \quad (15)$$

- Ideal (isentropic) mechanical power:

$$P_{\text{ID,LPC}} = \dot{m}_4 \cdot (h_4 - h_{5\text{IS}}) + (\dot{m}_4 - \dot{m}_5) \cdot (h_{5\text{IS}} - h_{6\text{IS}}) + (\dot{m}_4 - \dot{m}_5 - \dot{m}_6) \cdot (h_{6\text{IS}} - h_{7\text{IS}}) + (\dot{m}_4 - \dot{m}_5 - \dot{m}_6 - \dot{m}_7) \cdot (h_{7\text{IS}} - h_{8\text{IS}}) + \dot{m}_9 \cdot (h_{8\text{IS}} - h_{9\text{IS}}). \quad (16)$$

- Energy loss:

$$\dot{E}n_{\text{loss,LPC}} = P_{\text{ID,LPC}} - P_{\text{RE,LPC}}. \quad (17)$$

- Energy loss per unit of produced mechanical power:

$$\dot{E}n_{\text{loss,LPC,kW}} = \frac{\dot{E}n_{\text{loss,LPC}}}{P_{\text{RE,LPC}}} \cdot 100. \quad (18)$$

- Energy efficiency:

$$\eta_{\text{en,LPC}} = \frac{P_{\text{RE,LPC}}}{P_{\text{ID,LPC}}} \cdot 100. \quad (19)$$

- Exergy destruction (exergy loss):

$$\dot{E}x_{\text{des,LPC}} = \dot{E}x_4 - \dot{E}x_5 - \dot{E}x_6 - \dot{E}x_7 - \dot{E}x_8 - \dot{E}x_9 - P_{\text{RE,LPC}}. \quad (20)$$

- Exergy destruction per unit of produced mechanical power:

$$\dot{E}x_{\text{des,LPC,kW}} = \frac{\dot{E}x_{\text{des,LPC}}}{P_{\text{RE,LPC}}} \cdot 100. \quad (21)$$

- Exergy efficiency:

$$\eta_{\text{ex,LPC}} = \frac{P_{\text{RE,LPC}}}{\dot{E}x_4 - \dot{E}x_5 - \dot{E}x_6 - \dot{E}x_7 - \dot{E}x_8 - \dot{E}x_9} \cdot 100. \quad (22)$$

<u>Whole Turbine (WT) - conventional steam power plant</u>

- Real (polytropic) mechanical power:

$$P_{\text{RE,WT}} = P_{\text{RE,HPC}} + P_{\text{RE,LPC}}. \quad (23)$$

- Ideal (isentropic) mechanical power:

$$P_{\mathrm{ID,WT}} = P_{\mathrm{ID,HPC}} + P_{\mathrm{ID,LPC}}. \quad (24)$$

- Energy loss:

$$\dot{E}n_{\mathrm{loss,WT}} = P_{\mathrm{ID,WT}} - P_{\mathrm{RE,WT}}. \quad (25)$$

- Energy loss per unit of produced mechanical power:

$$\dot{E}n_{\mathrm{loss,WT,kW}} = \frac{En_{\mathrm{loss,WT}}}{P_{\mathrm{RE,WT}}} \cdot 100. \quad (26)$$

- Energy efficiency:

$$\eta_{\mathrm{en,WT}} = \frac{P_{\mathrm{RE,WT}}}{P_{\mathrm{ID,WT}}} \cdot 100. \quad (27)$$

- Exergy destruction (exergy loss):

$$\dot{E}x_{\mathrm{des,WT}} = \dot{E}x_1 - \dot{E}x_2 - \dot{E}x_3 + \dot{E}x_4 - \dot{E}x_5 - \dot{E}x_6 - \dot{E}x_7 - \dot{E}x_8 - \dot{E}x_9 - P_{\mathrm{RE,WT}}. \quad (28)$$

- Exergy destruction per unit of produced mechanical power:

$$\dot{E}x_{\mathrm{des,WT,kW}} = \frac{Ex_{\mathrm{des,WT}}}{P_{\mathrm{RE,WT}}} \cdot 100. \quad (29)$$

- Exergy efficiency:

$$\eta_{\mathrm{ex,WT}} = \frac{P_{\mathrm{RE,WT}}}{Ex_1 - Ex_2 - Ex_3 + Ex_4 - Ex_5 - Ex_6 - Ex_7 - Ex_8 - Ex_9} \cdot 100. \quad (30)$$

4. Steam operating parameters for each turbine

Table 1. *Steam operating parameters of the turbine from the conventional power plant [25]*

O.P.*	Steam mass flow rate (kg/s)	Steam temperature (°C)	Steam pressure (bar)	Steam quality
1	119.25	556.45	148.96	Superheated
2	15.51	370.00	38.90	Superheated
3	103.74	362.78	36.67	Superheated
4	103.74	512.17	35.80	Superheated
5	6.97	480.53	23.53	Superheated
6	6.86	360.00	10.50	Superheated
7	7.12	248.20	2.50	Superheated
8	4.87	160.00	1.10	Superheated
9	77.92	42.94	0.08625	0.94

* O.P. = Operating point; in accordance with Fig. 1. (a)

Table 2. *Steam operating parameters of turbine from nuclear power plant [26]*

O.P.*	Steam mass flow rate (kg/s)	Steam temperature (°C)	Steam pressure (bar)	Steam quality
1	1543.58	274.63	59.130	0.994
2	129.95	225.11	25.550	0.925
3	64.63	185.280	11.306	0.885
4	1349.00	163.33	6.724	0.865
5	1057.27	240.60	6.650	Superheated
6	46.72	128.19	1.961	Superheated
7	43.55	93.72	0.807	0.964
8	45.73	73.32	0.360	0.931
9	921.27	40.63	0.076	0.898

* O.P. = Operating point; in accordance with Fig. 1. (b)

Table 3. *Steam operating parameters of turbine from marine propulsion plant [27]*

O.P.*	Steam mass flow rate (kg/s)	Steam temperature (°C)	Steam pressure (bar)	Steam quality
1	26.798	500.00	58.99	Superheated
2	0.908	350.00	15.65	Superheated
3	25.891	256.00	5.93	Superheated
4	22.110	256.00	5.93	Superheated
5	0.932	153.00	1.21	Superheated
6	21.178	34.94	0.0561	92.100

* O.P. = Operating point; in accordance with Fig. 1. (c)

Steam operating parameters (temperature, pressure, steam quality and mass flow rate) in each operating point of each observed turbine from Fig. 1 are presented in Table 1 for turbine from the conventional power plant, in Table 2 for turbine from nuclear power plant and in Table 3 for turbine from the marine propulsion plant. Other steam operating parameters are calculated by using NIST REFPROP 9.0 software [28]. In this analysis, the base ambient state is defined by the ambient pressure of 1 bar and the ambient temperature of 25 °C.

5. Results and discussion

In comparison to turbines from conventional and nuclear power plant, the highest energy loss per unit of produced mechanical power has steam turbine from the marine propulsion plant (conventional = 20.74%, nuclear = 23.24% and marine = 31.02%), Fig. 3. When observing the whole turbines, turbine from the conventional steam power plant has the highest energy efficiency (82.82%), followed by turbine from nuclear power plant (81.14%), while the lowest energy efficiency has a turbine from marine propulsion plant (76.33%).

Obtained results can be explained by a fact that marine steam turbine must be much more dynamic in operation in comparison to other two turbines. Also, marine steam turbine did not possess steam reheating between the cylinders – a newer version of marine steam turbines have three cylinders with steam reheating between HPC and IPC (Intermediate Pressure Cylinder) [29].

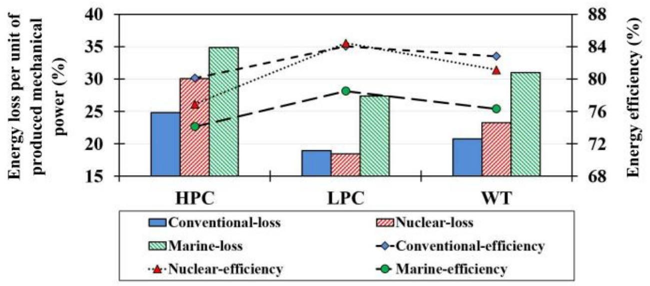

Fig. 3. *Energy analysis parameters of three observed steam turbines and its cylinders*

Exergy destruction per unit of produced mechanical power for the whole turbines is equal to 15.18% for turbine from the conventional steam power plant, 18.62% for turbine from nuclear power plant and 23.78% for the turbine from the marine propulsion plant, Fig. 4.

Turbine from the conventional steam power plant has the highest exergy efficiency (86.82%), followed by turbine from nuclear power plant (84.30%), while the lowest exergy efficiency has a turbine from marine propulsion plant (80.79%).

As in comparison of energy analysis parameters, Fig. 3, comparable exergy analysis parameters of all turbines and its cylinders, Fig. 4, show again that the steam turbine from the marine propulsion plant has the worst performance.

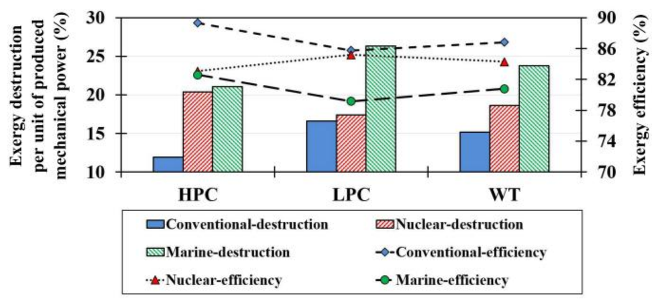

Fig. 4. *Exergy analysis parameters of three observed steam turbines and its cylinders*

Further analyses will be performed by using various artificial intelligence methods [30-33].

6. Conclusions

In this paper is performed analysis and comparison of three steam turbines and its cylinders: from the conventional steam power plant, from nuclear power plant and from the marine propulsion plant. The most important conclusions of the performed analysis are:

- Comparison of the whole turbines show that the lowest energy loss per unit of produced mechanical power has steam turbine from the conventional steam power plant (20.74%), followed by steam turbine from nuclear power plant (23.24%), while the highest energy loss per unit of produced mechanical power has steam turbine from the marine propulsion plant (31.02%). Exergy destruction per unit of produced mechanical power for the whole turbines is equal to 15.18% for turbine from the conventional steam power plant, 18.62% for turbine from nuclear power plant and 23.78% for the turbine from the marine propulsion plant.
- Turbine from the conventional steam power plant has the highest energy efficiency (82.82%), followed by turbine from nuclear power plant (81.14%), while the lowest energy efficiency has a turbine from marine propulsion plant (76.33%). Also, turbine from the conventional steam power plant has the highest exergy efficiency (86.82%), followed by turbine from nuclear power plant (84.30%), and turbine from marine propulsion plant (80.79%).
- The worst performance shows steam turbine from the marine propulsion plant because it did not possess steam reheating between the cylinders as the other two observed steam turbines.

7. Acknowledgment

This research has been supported by the Croatian Science Foundation under the project IP-2018-01-3739, CEEPUS network CIII-HR-0108, European Regional Development Fund under the grant KK.01.1.1.01.0009 (DATACROSS), project CEKOM under the grant KK.01.2.2.03.0004, CEI project “COVIDAi” (305.6019-20), University of Rijeka scientific grant uniri-tehnic-18-275-1447 and University of Rijeka scientific grant uniri-tehnic-18-18-1146.

8. References

[1] Noroozian, A., Mohammadi, A., Bidi, M., & Ahmadi, M. H. (2017). *Energy, exergy and economic analyses of a novel system to recover waste heat and water in steam power plants*. Energy conversion and management, 144, 351-360. (doi:10.1016/j.enconman.2017.04.067)

[2] Kostyuk, A., & Frolov, V. (1988). *Steam and gas turbines*. Mir Publishers.

[3] Lorencin, I., Anđelić, N., Mrzljak, V., & Car, Z. (2019). *Genetic Algorithm Approach to Design of Multi-Layer Perceptron for Combined Cycle Power Plant Electrical Power Output Estimation*. Energies, 12(22), 4352. (doi:10.3390/en12224352)

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

[5] Mrzljak, V., & Poljak, I. (2019). *Energy Analysis of Main Propulsion Steam Turbine from Conventional LNG Carrier at Three Different Loads*. NAŠE MORE, 66(1), 10-18. (doi:10.17818/NM/2019/1.2)

[6] Ahmadi, G. R., & Toghraie, D. (2016). *Energy and exergy analysis of Montazeri steam power plant in Iran*. Renewable and Sustainable Energy Reviews, 56, 454-463. (doi:10.1016/j.rser.2015.11.074)

[7] Hafdhi, F., Khir, T., Yahyia, A. B., & Brahim, A. B. (2015). *Energetic and exergetic analysis of a steam turbine power plant in an existing phosphoric acid factory*. Energy Conversion and Management, 106, 1230-1241. (doi:10.1016/j.enconman.2015.10.044)

[8] Mrzljak, V., Prpić-Oršić, J., & Poljak, I. (2018). *Energy Power Losses and Efficiency of Low Power Steam Turbine for the Main Feed Water Pump Drive in the Marine Steam Propulsion System*. Pomorski zbornik, 54(1), 37-51. (doi:10.18048/2018.54.03)

[9] Kumar, V., Pandya, B., & Matawala, V. (2019). *Thermodynamic studies and parametric effects on exergetic performance of a steam power plant*. International Journal of Ambient Energy, 40(1), 1-11. (doi:10.1080/01430750.2017.1354326)

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

[11] Wang, C., Yan, C., Wang, J., Tian, C., & Yu, S. (2017). *Parametric optimization of steam cycle in PWR nuclear power plant using improved genetic-simplex algorithm*. Applied Thermal Engineering, 125, 830-845. (doi:10.1016/j.applthermaleng.2017.07.045)

[12] Škopac, L., Medica-Viola, V., & Mrzljak, V. (2020). *Selection Maps of Explicit Colebrook Approximations according to Calculation Time and Precision*. Heat Transfer Engineering, 1-15. (doi:10.1080/01457632.2020.1744248)

[13] Kocijel, L., Poljak, I., Mrzljak, V., & Car, Z. (2020). *Energy Loss Analysis at the Gland Seals of a Marine Turbo-Generator Steam Turbine*. Tehnički glasnik, 14(1), 19-26. (doi:10.31803/tg-20191031094436)

[14] Medica-Viola, V., Mrzljak, V., Anđelić, N., & Jelić, M. (2020). *Analysis of Low-Power Steam Turbine With One Extraction for Marine Applications*. NAŠE MORE, 67(2), 87-95. (doi:10.17818/NM/2020/2.1)

[15] Kanoğlu, M., Çengel, Y. A. & Dincer, I. (2012). *Efficiency Evaluation of Energy Systems*. Springer. (doi:10.1007/978-1-4614-2242-6)

[16] Baldi, F., Ahlgren, F., Nguyen, T. V., Thern, M., & Andersson, K. (2018). *Energy and exergy analysis of a cruise ship*. Energies, 11(10), 2508. (doi:10.3390/en11102508)

[17] Mrzljak, V., Blecich, P., Anđelić, N., & Lorencin, I. (2019). *Energy and Exergy Analyses of Forced Draft Fan for Marine Steam Propulsion System during Load Change*. Journal of Marine Science and Engineering, 7(11), 381. (doi:10.3390/jmse7110381)

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

[19] Tan, H., Shan, S., Nie, Y., & Zhao, Q. (2018). *A new boil-off gas re-liquefaction system for LNG carriers based on dual mixed refrigerant cycle*. Cryogenics, 92, 84-92. (doi:10.1016/j.cryogenics.2018.04.009)

[20] Medica-Viola, V., Baressi Šegota, S., Mrzljak, V., & Štifanić, D. (2020). *Comparison of conventional and heat balance based energy analyses of steam turbine*. Pomorstvo, 34(1), 74-85. (doi:10.31217/p.34.1.9)

[21] Lorencin, I., Anđelić, N., Mrzljak, V., & Car, Z. (2019). *Exergy analysis of marine steam turbine labyrinth (gland) seals*. Pomorstvo, 33(1), 76-83. (doi:10.31217/p.33.1.8)

[22] Erdem, H. H., Akkaya, A. V., Cetin, B., Dagdas, A., Sevilgen, S. H., Sahin, B., ... & Atas, S. (2009). *Comparative energetic and exergetic performance analyses for coal-fired thermal power plants in Turkey*. International Journal of Thermal Sciences, 48(11), 2179-2186. (doi:10.1016/j.ijthermalsci.2009.03.007)

[23] Baressi Šegota, S., Lorencin, I., Anđelić, N., Mrzljak, V., & Car, Z. (2020). *Improvement of Marine Steam Turbine Conventional Exergy Analysis by Neural Network Application*. Journal of Marine Sci. and Eng., 8(11), 884. (doi:10.3390/jmse8110884)

[24] Adibhatla, S., & Kaushik, S. C. (2014). *Energy and exergy analysis of a super critical thermal power plant at various load conditions under constant and pure sliding pressure operation*. Applied thermal engineering, 73(1), 51-65. (doi:10.1016/j.applthermaleng.2014.07.030)

[25] Uysal, C., Kurt, H., & Kwak, H. Y. (2017). *Exergetic and thermoeconomic analyses of a coal-fired power plant*. International Journal of Thermal Sciences, 117, 106-120. (doi:10.1016/j.ijthermalsci.2017.03.010)

[26] Naserbegi, A., Aghaie, M., Minuchehr, A., & Alahyarizadeh, Gh. (2018). *A novel exergy optimization of Bushehr nuclear power plant by gravitational search algorithm (GSA)*. Energy, 148, 373-385. (doi:10.1016/j.energy.2018.01.119)

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

[28] Lemmon, E. W., Huber, M. L., & McLinden, M. O. (2010). *NIST Standard Reference Database 23, Reference Fluid Thermodynamic and*

Transport Properties (REFPROP), version 9.0, National Institute of Standards and Technology. R1234yf. fld file dated December, 22, 2010.

[29] Koroglu, T., & Sogut, O. S. (2018). *Conventional and advanced exergy analyses of a marine steam power plant*. Energy, 163, 392-403. (doi:10.1016/j.energy.2018.08.119)

[30] Lorencin, I., Anđelić, N., Mrzljak, V., & Car, Z. (2019). *Multilayer Perceptron approach to Condition-Based Maintenance of Marine CODLAG Propulsion System Components*. Pomorstvo, 33(2), 181-190. (doi:10.31217/p.33.2.8)

[31] Baressi Šegota, S., Lorencin, I., Ohkura, K., & Car, Z. (2019). *On the Traveling Salesman Problem in Nautical Environments: an Evolutionary Computing Approach to Optimization of Tourist Route Paths in Medulin, Croatia*. Pomorski zbornik, 57(1), 71-87. (doi:10.18048/2019.57.05)

[32] Lorencin, I., Anđelić, N., Mrzljak, V., & Car, Z. (2019). *Marine Objects Recognition Using Convolutional Neural Networks*. NAŠE MORE, 66(3), 112-119. (doi:10.17818/NM/2019/3.3)

[33] Car, Z., Baressi Šegota, S., Anđelić, N., Lorencin, I., & Mrzljak, V. (2020). *Modeling the Spread of COVID-19 Infection Using a Multilayer Perceptron*. Computational and Mathematical Methods in Medicine, 2020. (doi:10.1155/2020/5714714)