Exergy Analysis of Steam Pressure Reduction Valve in Marine Propulsion Plant on Conventional LNG Carrier

Eksergijska analiza ventila tlaka pare kod pomorskoga porivnog postrojenja na konvencionalnom LNG tankeru

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Summary

Paper has presented an exergy analysis of steam pressure reduction valve, unavoidable element in the steam propulsion plant on LNG carrier. The steam pressure reduction valve was analyzed in a wide range of steam system loads. Along with pressure decrease, through the valve also occur decrease in steam temperature and increase in steam specific entropy. The pressure decrease of the analyzed valve ranges from 4.846 MPa up to 5.027 MPa while the average steam temperature decrease for the whole observed operating range amounts 74.8 °C. At the ambient temperature of 25 °C, valve exergy destruction ranges from 121.72 kW up to 180.64 kW, while exergy efficiency amounts from 80.28 % up to 80.54 %. Variation in the ambient temperature, for the expected engine room temperature range, showed that the exergy destruction of pressure reduction valve increases and exergy efficiency decreases during the increase in the ambient temperature. The lowest average value of pressure reduction valve exergy destruction was obtained at the ambient temperature of 10 °C and amounts 152.03 kW, while at the same ambient temperature was obtained the highest average exergy efficiency of 82.77 %. The highest valve exergy destruction and the lowest exergy efficiency were obtained at the highest observed ambient temperature of 40 °C.

KEY WORDS

pressure reduction valve
exergy destruction
exergy efficiency
ambient temperature

Sažetak

Članak predstavlja eksergijsku analizu redukcijskog ventila tlaka pare, nezaobilazni element u parnom porivnom postrojenju na LNG brodu. Redukcijski ventil tlaka pare analiziran je u širokom spektru opterećenja porivnog postrojenja. Uz pad tlaka kroz ventil se također događa pad temperature pare i rast u specifičnoj parnoj entropiji. Pad tlaka analiziranog ventila kreće se od 4.846 MP do 5.027 MP dok prosječan pad temperature pare za cijeli promatrani proces iznosi 74.8°C. Kod ambijentalne temperature od 25°C destrukcija eksergije ventila kreće se od 121.72 kW do 180.64 kW dok eksergijska djelotvornost iznosi od 80.28 % do 80.54 %. Varijacija u ambijentalnoj temperaturi za očekivani raspon temperature u strojarnici je pokazala da destrukcija eksergije redukcijskog ventila raste, a eksergijska djelotvornost opada za vrijeme rasta ambijentalne temperature. Najniža prosječna vrijednost destrukcije eksergije redukcijskog ventila dobivena je pri ambijentalnoj temperaturi od 10°C i iznosi 152.03 kW dok je istovremeno na istoj ambijentalnoj temperaturi dobivena najveća prosječna eksergijska djelotvornost od 82.77 %. Najviša destrukcija eksergije ventila i najniža eksergijska djelotvornost dobivene su na najvišoj promatranoj ambijentalnoj temperaturi od 40°C.

KLJUČNE RIJEČI

redukcijski ventil tlaka
eksergijska destrukcija
eksergijska djelotvornost
ambijentalna temperatura

1. INTRODUCTION / *Uvod*

Several authors investigated complete land-based steam power plants and among other things presented results of their exergy analysis [1,2]. In such exergy analysis, pressure reduction valves usually were not investigated in detail [3] or at all. As their name says, the main function of pressure reduction valves is reducing pressure of operating medium which flows through the valve (in the most of cases that operating medium is superheated steam). On that way in the system was maintained desired operating medium parameters [4].

The most important rule for pressure reduction valve operation is that before and after valve specific enthalpy of operating medium remains constant [5,6] while pressure decreases to desired values. If the operating medium is superheated steam, along with pressure decrease, there occurs also decrease in the steam temperature and increase in steam specific entropy through the pressure reduction valve [7].

Pressure reduction valves rarely appear in land-based steam power plants in comparison with marine steam power plants. On any ship, during its construction, one of the main goals is to reduce masses of all the constituent components. In order to remain the walls of every component from the steam propulsion plant as thick as possible (and thus reduce their mass), pressure reduction valves are necessary to reduce operating media pressure, but with specific enthalpy preservation. In comparison with land-based steam power plants which usually have one or two pressure reduction valves [5], marine steam propulsion plants have at least ten of them or more [8].

In scientific and professional literature can rarely be found detail analysis of any valves. If some of them were found, mostly it is investigations of control valves for steam turbines [9,10], in some cases along with its actuation systems [11]. Detailed analysis of steam pressure reduction valves is rare, especially for various steam system loads [12].

In this paper it has been analyzed steam pressure reduction valve, through a wide range of steam system loads. For any load there has been presented a decrease in steam temperature and pressure on the analyzed valve. Performed exergy analysis showed exergy power inputs and outputs, as well as exergy destruction (exergy power losses) and exergy efficiency of pressure reduction valve in each observed system load. The exergy destruction and exergy efficiency of any steam system component are influenced by the ambient temperature. For the analyzed valve, it is presented change in exergy destruction and exergy efficiency in the complete range of expected ambient temperatures for every observed load.

2. PRESSURE REDUCTION VALVE POSITION AND ELEMENTS / *Pozicija redukcijskog ventila pare i elementi redukcijskog ventila*

Analyzed pressure reduction valve is one of many pressure reduction valves in LNG carrier steam propulsion plant. Main characteristics of the LNG carrier, on which the analyzed pressure reduction valve is mounted, are presented in Table 1:

Table 1 Main characteristics of the LNG carrier
Tablica 1. Glavne karakteristike LNG tankera

Dead weight tonnage	84.812 DWT
Overall length	288 m
Max breadth	44 m
Design draft	9.3 m
Propulsion turbine	Mitsubishi MS40-2 (29420 kW)

The position of the analyzed pressure reduction valve in steam system is near the steam generator second outlet, Fig. 1. The first steam generator outlet is used for delivering superheated steam to the turbo-generators and main propulsion turbine, while the second outlet is used for other steam plant components. The basic task of the analyzed pressure reduction valve is to reduce superheated steam pressure of approximately 6.13 MPa to 1.08 MPa and deliver steam with lower pressure to fuel heaters and for ship service needs.

Steam pressure reduction valve intersection, along with all main components can be seen in Fig. 2. Newer type of pressure reduction valve has two valves (main and auxiliary) for pressure pulsation compensation and for ensuring accurate outlet pressure. Turning the pressure adjusting stud on the one side (usually clockwise) increases the outlet pressure while turning the pressure adjusting stud on the other side (usually counter-clockwise) decreases the outlet pressure.

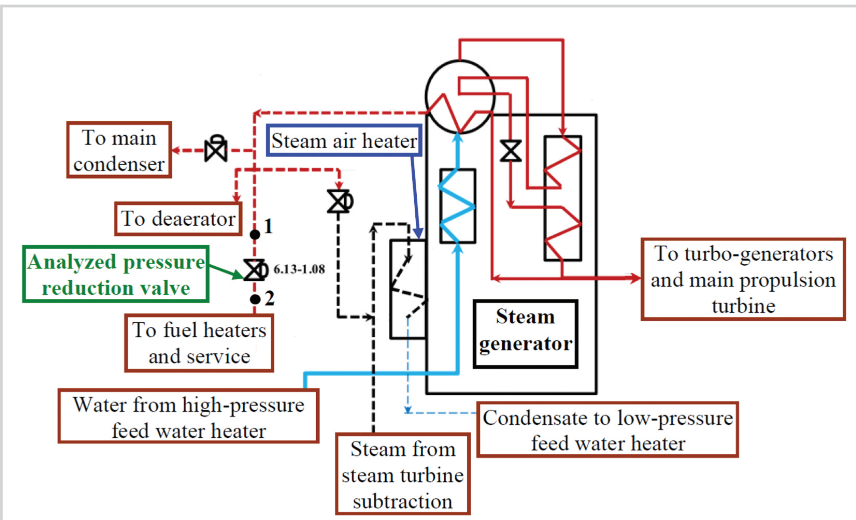

Figure 1 Analyzed steam pressure reduction valve position at the second steam generator outlet
Slika 1. Pozicija analiziranog redukcijskog ventila pare na drugom izlazu generatora pare

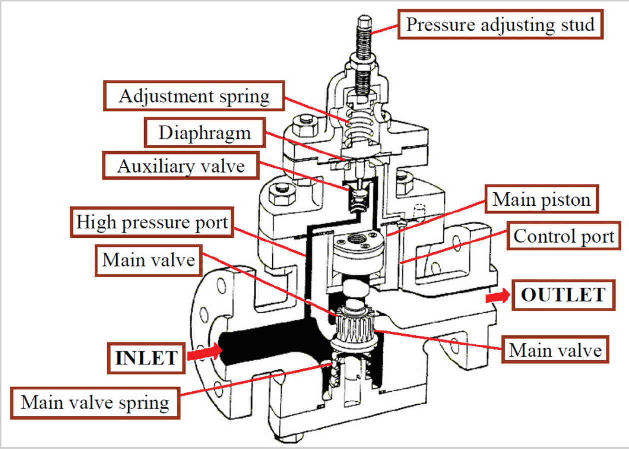

Figure 2 Analyzed steam pressure reduction valve intersection with the main elements [13]

Slika 2. Presjek analiziranoga redukcijskog ventila pare s glavnim elementima [13]

3. EQUATIONS FOR PRESSURE REDUCTION VALVE EXERGY ANALYSIS / *Jednadžbe za eksergijsku analizu redukcijskoga ventila pare*

3.1. Governing equations for component exergy analysis / *Osnovne jednadžbe za eksergijsku analizu komponente*

Mass balance equation for a standard volume in steady state disregarding potential and kinetic energy can be expressed as [6,14]:

$$\sum \dot{m}_{\mathrm{IN}} = \sum \dot{m}_{\mathrm{OUT}} \tag{1}$$

Exergy analysis is based on the second law of thermodynamics [15]. The main exergy balance equation for a standard volume in steady state is [16,17]:

$$\dot{X}_{\mathrm{heat}} - P = \sum \dot{m}_{\mathrm{OUT}} \cdot \varepsilon_{\mathrm{OUT}} - \sum \dot{m}_{\mathrm{IN}} \cdot \varepsilon_{\mathrm{IN}} + \dot{E}_{\mathrm{ex,D}} \tag{2}$$

where the net exergy transfer by heat ($\dot{X}_{\mathrm{heat}}$) at the temperature *T* is equal to [18]:

$$\dot{X}_{\mathrm{heat}} = \sum (1 - \frac{T_0}{T}) \cdot \dot{Q} \tag{3}$$

Specific exergy was defined according to [19] by an equation:

$$\varepsilon = (h - h_0) - T_0 \cdot (s - s_0) \tag{4}$$

The total exergy of a flow (exergy power) can be calculated according to [20,21]:

$$\dot{E}_{\mathrm{ex}} = \dot{m} \cdot \varepsilon = \dot{m} \cdot \left[(h - h_0) - T_0 \cdot (s - s_0) \right] \tag{5}$$

Exergy efficiency is also called second law efficiency or effectiveness [22]. It is usually defined as:

$$\eta_{\mathrm{ex}} = \frac{\text{Exergy output}}{\text{Exergy input}} \tag{6}$$

3.2. Exergy analysis of steam pressure reduction valve / *Eksergijska analiza redukcijskog ventila tlaka pare*

For the analyzed pressure reduction valve, all necessary operating points were presented in Fig. 3. The required specific enthalpies and specific entropies were calculated from measured steam pressures and temperatures by using NIST REFPROP software [23].

Steam pressure reduction valves are not interesting from the viewpoint of energy, because without any mass flow leakage and with constant specific enthalpy at valve inlet and outlet, steam pressure reduction valves have energy efficiency of 100 %. Change in steam temperature and pressure through the valve resulted with change in steam specific entropy, which has significant impact on specific exergy and exergy power, as presented in the above equations (4) and (5). Change in steam specific entropy finally has an impact on pressure reduction valve exergy efficiency, equation (6), which is surely not equal to 100 % as energy efficiency.

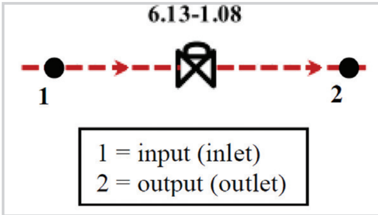

Figure 3 Steam pressure reduction valve scheme with marked input and output for exergy analysis (above the valve is general pressure reduction operating range)

Slika 3. Shema redukcijskoga ventila tlaka pare s označenim ulazima i izlazima za eksergijsku analizu (iznad ventila je generalni radni raspon redukcije tlaka)

Mass and exergy balances for the analyzed steam pressure reduction valve are:

Mass balance:

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

Exergy balance:

- Exergy power input:

$$\dot{E}_{\mathrm{ex,IN}} = \dot{m}_1 \cdot \varepsilon_1 \tag{8}$$

- Exergy power output:

$$\dot{E}_{\mathrm{ex,OUT}} = \dot{m}_2 \cdot \varepsilon_2 \tag{9}$$

- Exergy power loss (exergy destruction):

$$\dot{E}_{\mathrm{ex,D}} = \dot{E}_{\mathrm{ex,IN}} - \dot{E}_{\mathrm{ex,OUT}} = \dot{m}_1 \cdot \varepsilon_1 - \dot{m}_2 \cdot \varepsilon_2 \tag{10}$$

- Exergy efficiency:

$$\eta_{\mathrm{ex}} = \frac{\dot{E}_{\mathrm{ex,OUT}}}{\dot{E}_{\mathrm{ex,N}}} = \frac{\dot{m}_2 \cdot \varepsilon_2}{\dot{m}_1 \cdot \varepsilon_1} \tag{11}$$

The ambient state in the LNG carrier engine room during the measurements was:

- pressure: p_0 = 0.1 MPa = 1 bar,
- temperature: T_0 = 25 °C = 298.15 K.

4. PRESSURE REDUCTION VALVE STREAM FLOWS - MEASURING EQUIPMENT AND MEASUREMENT RESULTS / *Struje radnog medija redukcijskog ventila-mjerna oprema i rezultati mjerenja*

Measurement results of required operating parameters (pressures, temperatures and mass flows) for each pressure reduction valve steam stream are presented in Table 2 in relation to the main propulsion propeller speed. Main propulsion propeller speed is directly proportional to steam system load. Measurement results were obtained by using the existing measuring equipment mounted before and after analyzed pressure reduction valve, Fig 3. list of used measuring equipment is presented in Table 3.

Table 2 Measurement results for steam at the pressure reduction valve inlet and outlet

Tablica 2. Izmjereni rezultati za paru na ulazu i izlazu redukcijskog ventila

Propulsion propeller speed (rpm)	Pressure reduction valve - steam inlet (1*)			Pressure reduction valve - steam outlet (2*)		
	Temperature (°C)	Pressure (MPa)	Mass flow (kg/h)	Temperature (°C)	Pressure (MPa)	Mass flow (kg/h)
0.00	284.5	5.985	2125	201	1.079	2125
25.58	312.5	6.010	3022	244	1.077	3022
34.33	309.0	6.080	2794	238	1.085	2794
41.78	304.0	6.110	2687	230	1.083	2687
53.50	297.0	6.070	2794	220	1.079	2794
56.65	297.0	5.940	2794	223	1.079	2794
61.45	296.5	5.940	2687	222	1.084	2687
62.52	299.0	5.950	2906	225	1.081	2906
63.55	298.0	5.950	2687	223	1.081	2687
65.10	299.0	6.096	2584	222	1.088	2584
66.08	300.0	6.040	2687	225	1.074	2687
67.68	301.0	6.040	2794	226	1.076	2794
68.66	301.5	6.050	2687	227	1.084	2687
69.49	302.0	6.050	2794	228	1.080	2794
70.37	302.0	6.045	2687	228	1.084	2687
71.03	302.0	6.060	2687	228	1.074	2687
73.09	301.0	6.070	2584	226	1.082	2584
74.59	298.5	6.040	2687	223	1.082	2687
76.56	298.5	6.040	2794	222	1.079	2794
78.41	299.0	6.060	2687	224	1.085	2687
79.46	298.0	5.920	2794	224	1.074	2794
80.44	297.0	5.940	2906	222	1.075	2906

* Streams numeration refers to Fig. 3.

Table 3 Used measurement equipment (pressure reduction valve inlet and outlet, propulsion propeller shaft)

Tablica 3. Korištena mjerna oprema (redukcijski ventil pare ulaz i izlaz, porivna osovina propelera)

Steam temperature (valve inlet and outlet)	Greisinger GTF 401-Pt100 - Immersion probe [24]
Steam pressure (valve inlet)	Yamatake JTG960A - Pressure Transmitter [25]
Steam pressure (valve outlet)	Yamatake JTG940A - Pressure Transmitter [25]
Steam mass flow (valve inlet and outlet)	Yamatake JTD960A - Differential Pressure Transmitter [26]
Main propulsion propeller speed	Kyma Shaft Power Meter (KPM-PFS) [27]

5. THE RESULTS OF PRESSURE REDUCTION VALVE EXERGY ANALYSIS AND DISCUSSION / *Rezultati eksergijske analize redukcijskoga ventila tlaka i diskusija*

Steam pressure decrease at the analyzed pressure reduction valve, for each of the observed propulsion propeller speeds is presented in Fig. 4. As the steam pressure at the pressure reduction valve outlet is approximately equal to 1.08 MPa (Table 2), steam pressure decrease at the pressure reduction valve is the most influenced by pressure at the reduction valve inlet. So, for higher inlet pressures, pressure decrease will be higher and vice versa.

For the whole range of observed propulsion propeller speeds, pressure decrease on the analyzed pressure reduction valve is the lowest at propulsion propeller speed of 79.46 rpm and amounts 4.846 MPa. The highest pressure decrease is obtained at propulsion propeller speed of 41.78 rpm and amounts 5.027 MPa. The average pressure decrease on the analyzed pressure reduction valve, for all the observed propulsion propeller speeds, amounts 4.942 MPa.

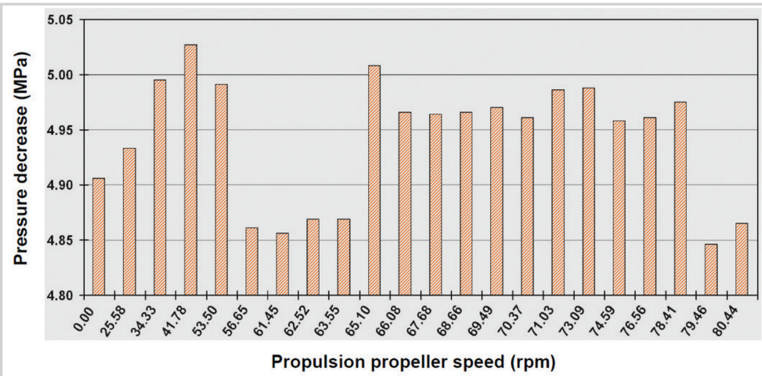

Figure 4 Steam pressure decrease at the pressure reduction valve (difference between inlet and outlet steam pressure)

Slika 4. Pad tlaka kod redukcijskoga ventila pare (razlika između ulaznog i izlaznog tlaka pare)

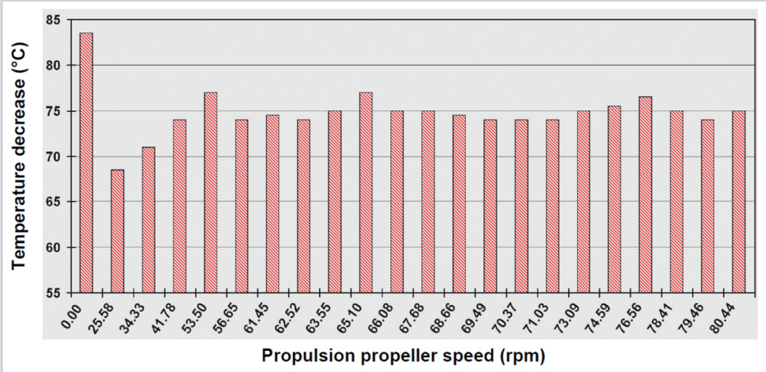

Figure 5 Steam temperature decrease at the pressure reduction valve (difference between inlet and outlet steam temperature)
Slika 5. Pad temperature pare na redukcijskom ventilu (razlika između ulazne i izlazne temperature pare)

Values for steam temperature decrease on the analyzed pressure reduction valve for the all observed propulsion propeller speeds do not exceed 85 °C, Fig. 5. The highest steam temperature decrease occurs during the steam system startup (0.00 rpm) and amounts 83.5 °C. The lowest steam temperature decrease at the analyzed pressure reduction valve is obtained right after the steam system startup, at the propulsion propeller speed of 25.58 rpm and amounts 68.5 °C. The average steam temperature decrease for the whole observed valve operating range amounts 74.8 °C.

Temperature decrease on the analyzed pressure reduction valve is reverse proportional to steam temperature at the valve outlet. Higher valve steam outlet temperature resulted with lower temperature decrease and lower valve steam outlet temperature resulted with higher temperature decrease. In the whole observed valve operating range the lowest steam outlet temperature occurs during the steam system startup (201 °C - 0.00 rpm) and the highest steam outlet temperature occurs at 25.58 rpm and amounts 244 °C, what can be seen from Table 2.

Steam pressure reduction valve has identical trends for exergy power input and output, Fig. 6. From one observed operating point to the other, exergy power input and output faithfully follow one another in increase or decrease from the lowest to the highest observed propulsion propeller speeds.

Pressure reduction valve exergy power input has the lowest value of 620.80 kW at the 0.00 rpm while the highest value of exergy power input amounts 924.56 kW at the 25.58 rpm. During the whole observed steam system loads, the average value of analyzed pressure reduction valve exergy power input amounts 816.55 kW.

The exergy power output has the lowest value of 499.07 kW at the 0.00 rpm while the highest value of exergy power output is equal to 743.92 kW at the 25.58 rpm. For the whole observed propulsion propeller speeds, the average value of analyzed pressure reduction valve exergy power output amounts 656.46 kW.

The change in both exergy power input and output for the analyzed steam pressure reduction valve is the most influenced by steam mass flow (which is equal at the valve inlet and outlet because there was no observed leakage through the valve). Increase in steam mass flow through the valve resulted in an increase in the exergy power input and output, while a decrease in steam mass flow through the valve resulted with a decrease in the exergy power input and output.

Exergy destruction for the analyzed steam pressure reduction valve has the same trend as exergy power input and output, for all observed propulsion propeller speeds. Therefore, valve exergy destruction is also the most influenced by steam mass flow. The lowest and the highest valve exergy destruction were observed at the propulsion propeller speeds of 0.00 rpm and 25.58 rpm, similar to the exergy power input and output. At 0.00 rpm pressure reduction valve exergy destruction is the lowest and amounts 121.72 kW, while at 25.58 rpm exergy destruction is the highest and amounts 180.64 kW. The average value of valve exergy destruction, across the whole observed steam system loads amounts 160.09 kW, Fig. 7. Exergy destruction of the analyzed steam pressure reduction valve is caused by an increase in steam specific entropy at the valve outlet during the pressure reduction. Increase in outlet steam specific entropy causes decrease in outlet specific exergy, equation (4), what causes that exergy destruction is sensibly higher than zero, equation (10).

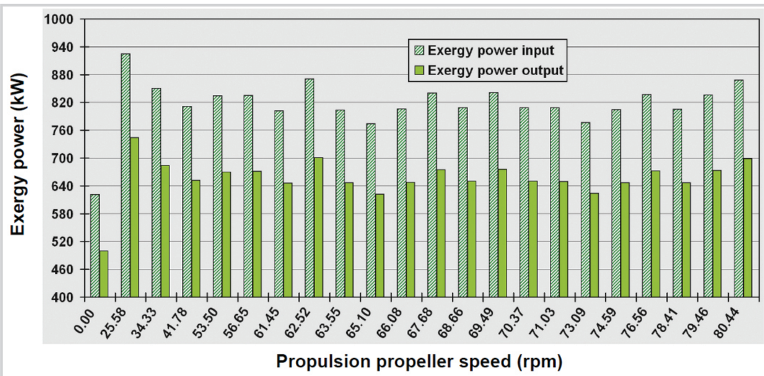

Figure 6 Steam pressure reduction valve exergy power input and output change for all observed loads
Slika 6. Promjena eksergijske snage na ulazu i izlazu redukcijskog ventila za sva promatrana opterećenja

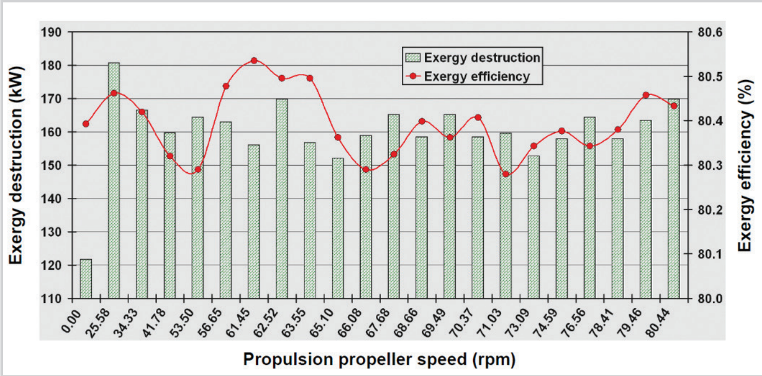

Figure 7 Pressure reduction valve exergy destruction and exergy efficiency change for all observed propulsion propeller speeds
Slika 7. Promjena destrukcije eksergije i eksergijske učinkovitosti redukcijskog ventila za sve promatrane brzine vrtnje propelera

Pressure reduction valve exergy efficiency was calculated according to equation (11). In the whole range of observed propulsion propeller speeds, analyzed pressure reduction valve exergy efficiency amounts around 80 %, Fig. 7. From the viewpoint of exergy this fact means that approximately 20 % of available exergy was lost on the pressure reduction valve in the observed operating range. The highest pressure reduction valve exergy efficiency amounts 80.54 % and was obtained at propulsion propeller speed of 61.45 rpm, while the lowest valve exergy efficiency amounts 80.28 % and was obtained at 71.03 rpm.

Losses during the pressure and temperature reduction on pressure reduction valve can be observed only from the viewpoint of exergy, which gives a realistic image of valve losses and efficiency. The energy analysis of this valve would not give any data of its losses, nor would be achieved valve realistic efficiencies.

In the energy and exergy analysis of land-based steam power plants, some authors investigate the influence of the ambient temperature change on exergy destruction and exergy efficiency for a large number of plant components [28,29]. They concluded that the ambient temperature change has a low impact on exergy efficiency and exergy destruction change for the most of the analyzed components. In general, exergy destruction for the most of analyzed steam plant component increases and exergy efficiency decreases during the increase in the ambient temperature. It will be interesting to examine does the same conclusion is also valid for the analyzed pressure reduction valve.

Change in exergy destruction for the analyzed pressure reduction valve during the change in ambient temperature is presented in Fig. 8. As for the most other steam system components, exergy destruction of pressure reduction valve increases during the increase in the ambient temperature, for each observed propulsion propeller speed. Ambient temperature in this analysis was varied from 10 °C to 40 °C (in steps of 10 °C) what is an expected range of engine room temperatures.

At all of the observed propulsion propeller speeds, the lowest pressure reduction valve exergy destruction was obtained for the ambient temperature of 10 °C and it amounts from the lowest value of 115.61 kW (0.00 rpm) up to the highest value of 171.51 kW (25.58 rpm).

The highest pressure reduction valve exergy destruction was obtained for the ambient temperature of 40 °C and it amounts from the lowest value of 127.87 kW (0.00 rpm) up to the highest value of 189.79 kW (25.58 rpm).

The average value of pressure reduction valve exergy destruction, during the whole observed propulsion propeller speeds was 152.03 kW for the ambient temperature of 10 °C, 157.40 kW for the ambient temperature of 20 °C, 162.78 kW for the ambient temperature of 30 °C and 168.14 kW for the ambient temperature of 40 °C.

The change in exergy destruction for any steam plant component, during the change in the ambient temperature, must be reverse proportional to component exergy efficiency. So, the increase in exergy destruction, during the increase in the ambient temperature, leads to decrease in exergy efficiency of the analyzed steam pressure reduction valve. For the most of steam plant components [29], change in the ambient

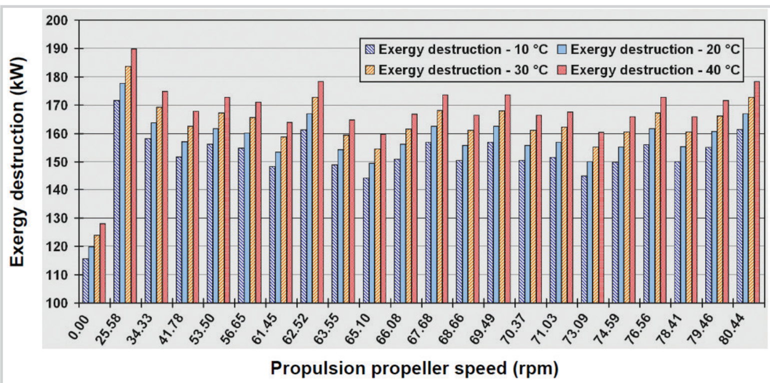

Figure 8 Pressure reduction valve exergy destruction change during variation in the ambient temperature
Slika 8. Promjena destrukcije eksergije redukcijskog ventila tijekom variranja ambijentalne temperature

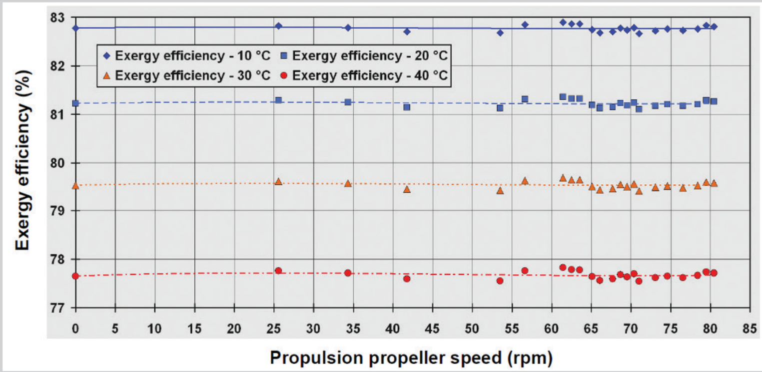

Figure 9 Pressure reduction valve exergy efficiency change during variation in the ambient temperature
Slika 9. Promjena eksergijske učinkovitosti redukcijskog ventila tijekom variranja ambijentalne temperature

temperature for 10 °C resulted with the change of component exergy efficiency for about 1 % or less.

For the analyzed pressure reduction valve, in observed steam system loads, the highest exergy efficiency was obtained at the lowest ambient temperature of 10 °C and amounts 82.77 % in average, Fig. 9. Increase in the ambient temperature from 10 °C to 20 °C resulted with pressure reduction valve exergy efficiency decrease and on the ambient temperature of 20 °C exergy efficiency amounts 81.22 % in average. A further increase in the ambient temperature resulted with further decrease in valve exergy efficiency, which amounts 79.53 % in average for the ambient temperature of 30 °C and 77.67 % in average for the ambient temperature of 40 °C.

The ambient temperature increase in steps of 10 °C causes decrease of steam pressure reduction valve exergy efficiency for about 1.7 % in average. It should be noted that the decrease in the valve exergy efficiency during the ambient temperature increase has a higher values for the higher ambient temperatures.

During the ambient temperature change, exergy destruction and exergy efficiency of the analyzed steam pressure reduction valve has trend similar to the most other components in steam plants. However, decrease in valve exergy efficiency during the increase in the ambient temperature for 10 °C, is higher in comparison to most other steam plant components, regardless of steam plant type.

6. CONCLUSION / *Zaključak*

This paper has presented exergy analysis of steam pressure reduction valve which is an unavoidable element in the steam propulsion plant on LNG carrier. Pressure reduction valves rarely appear in land-based steam power plants because in that plants, unlike marine steam plants, is not a goal to reduce masses of all the constituent components.

Analyzed pressure reduction valve was investigated in a wide range of steam system loads. From the viewpoint of energy, specific enthalpy of operating fluid remains the same before and after pressure reduction valve and if there is no leakage, the energy efficiency of pressure reduction valve will be 100 %. So, only the exergy analysis can present correct valve efficiencies and power losses (destruction).

Operating fluid of the analyzed pressure reduction valve is superheated steam, therefore along with pressure decrease, through the valve also occur decrease in the steam temperature and increase in steam specific entropy.

Pressure decrease on the analyzed valve ranges from the lowest value of 4.846 MPa up to the highest value of 5.027 MPa. For observed valve pressure decrease range, the temperature decrease amounts from 68.5 °C up to 83.5 °C. The average steam temperature decrease for the whole observed valve operating range was 74.8 °C.

Exergy analysis of pressure reduction valve was firstly obtained for the ambient temperature of 25 °C, which was recorded in ship engine room during measurements. For the observed steam system loads, valve exergy destruction at the ambient temperature of 25 °C ranges from 121.72 kW up to 180.64 kW, while valve exergy efficiency amounts from 80.28 % up to 80.54 %.

Variation in the ambient temperature, for the expected engine room temperature range, showed that the exergy destruction of the steam pressure reduction valve increases during the increase in ambient temperature. The lowest average value of valve exergy destruction is obtained at the ambient temperature of 10 °C and amounts 152.03 kW, while the highest average valve exergy destruction is obtained at the ambient temperature of 40 °C and amounts 168.14 kW.

As opposed to valve exergy destruction, exergy efficiency decreases during the increase in the ambient temperature. For the analyzed pressure reduction valve, the highest exergy efficiency was obtained at the lowest ambient temperature of 10 °C and amounts 82.77 % in average, while the lowest exergy efficiency was obtained at the highest ambient temperature of 40 °C and amounts 77.67 % in average. Analyzed steam pressure reduction valve exergy efficiency change, during the variation in the ambient temperature, is higher in comparison to the most other steam plant components.

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NOMENCLATURE

Abbreviations:

LNG	Liquefied Natural Gas

Latin Symbols:

$\dot{E}$	stream flow power, kJ/s
h	specific enthalpy, kJ/kg
$\dot{m}$	mass flow rate, kg/s or kg/h
p	pressure, MPa
P	work done, kJ/s
$\dot{Q}$	heat transfer, kJ/s
s	specific entropy, kJ/kg·K
T	temperature, °C or K
$\dot{X}_{heat}$	heat exergy transfer, kJ/s

Greek symbols:

ε	specific exergy, kJ/kg
η	efficiency, -

Subscripts:

0	ambient conditions
D	destruction
ex	exergy
IN	inlet
OUT	outlet

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