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Exergy Analysis of Thermal Power Plant for Three Different Loads

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Abstract: This paper presents the energy and exergy analysis of thermal power plant Tuzla in Tuzla, Bosnia and Herzegovina. The main aim of this paper is to analyze the components of a 200 MW steam power plant unit in order to identify and quantify the sites with the highest exergy losses and to calculate exergy efficiency values of all components when operating at nominal load. The influence of the change in ambient temperature and block load on the value of exergy losses and exergy efficiency was taken into analysis. The analysis further includes the impact of steam block operation without high-pressure and low-pressure heaters on the exergy efficiency of the steam block. The goal of the analysis is to determine the functional state of individual steam block components after a long period of exploitation and maintenance in order to take appropriate measures to improve their technical performance. Exergy losses during nominal operation of the steam power plant unit are the largest in boiler and amount to 313.42 MW, followed by a turbine with 205.60 MW, condenser 1 with 6.03 MW, condenser 2 with 5.75 MW, while other components of the steam power plant have exergy losses in the range of 0.03 to 2.15 MW. Operation of the unit at nominal load without HPH results in an exergy efficiency decrease from 5.60 to 9.80 %, while in case of operation without HPH and LPH it results in a decrease in exergy efficiency from 9.86 to 16.40 % depending on the pattern used to calculate. The conclusion after the analysis indicates that the biggest exergy losses are in the boiler and turbine and consequently these components have the lowest exergy efficiency values. The increase in ambient temperature has different effects on individual components of the thermal power plant, increasing exergy losses of the boiler while reducing the turbine exergy losses and condensers.

Keywords: dead state; exergy analysis; exergy efficiency; exergy losses; steam power plant

1 INTRODUCTION

Energy and exergy analysis of power generation systems are essential for the efficient utilization of energy resources. Therefore these analyses became interesting for researches and scientists in recent years. The most commonly - used method for analyzing energy conversion process is the first law of thermodynamics. However, a method combining the first and second law of thermodynamics has been increasingly used recently. This method is used to calculate exergy and exergy losses in order to determine the efficiency of use of available energy. Exergy analysis enables defining the difference between energy losses to the environment and the internal irreversibility of the process [1].

Exergy analysis evaluates the performance of system and process components, as well as the evaluation of exergy at individual points of the energy transformation process. Based on the obtained data, it is possible to assess efficiency and determine the places in the process with the greatest losses. [2]. It is for these reasons that today's approach to process analysis includes exergy analysis, which provides a more realistic view of the process and is a useful tool for engineering evaluation [3]. It enables a better assessment of the efficiency of the complete system, better optimization, designing and improving the performance of energy systems.

A large number of researchers have sought to understand and improve the operation of thermal power plants, steam turbines and advanced cycles, using the method of energy and exergy analysis. Exergy analysis of energy systems in general and thermal power plants was dealt with by Aljundi et al. [4]. Yang, et al. [5] investigated 660 MW ultra-supercritical steam power plant in China who have shown that, heavier exergy destruction is caused by exhaust flue gases with 73.51% of the total boiler subsystem. The exergy analysis of various thermal power plants led to the conclusion that the boiler is the main source of exergy losses [6-12]. Many researchers have linked exergy to the cost analysis of the thermal power plants [13]. Gogoi and Talukdar [14] analyzed how the pressure in the boiler and the fuel flow rate affect the parameters of the boiler, and found a significant influence of these two parameters on the performance of the energy cycle. Kanoglu, et al. [15] have analyzed and evaluated different efficiencies of energy conversion and heat transfer taking into account energy systems with constant flow (turbines, compressors, pumps, heat exchangers, etc.), various power plants, cogeneration plants and refrigeration systems. Rashad and Maihy [16] analyzed the exergy and energy of the Shobra El - Khima power plant in Cairo and found that the highest exergy destruction occurred in the turbine (about 28% at different loads), while the highest energy loss was recorded in the condenser (55% at different loads). Sengupata, et al. [17] analyzed the exergy of a supercritical coal-fired steam power plant with a capacity of 210 MW at the design values of the parameters and at different loads. Živić, Galović, Avsec and Holik [18] they analyzed four variables at the inlet to the turbine, namely: the ratio of gas inlet temperature to the turbine, the ratio of compressor outlet and inlet pressure and inlet air temperature to the compressor, and the isentropic efficiency of the compressor and turbine. The air temperature at the entrance to the turbine was kept constant, while the temperature of the flue gases at the entrance to the turbine varied from 900 to 1200 °C.

The aim of this paper is to analyze the 200 MW unit of thermal power plant in Tuzla from the perspective of energy and exergy. The primary task is the exergy analysis of thermal power plant components at nominal operating mode, as well as the impact of exergy losses and thermal power plant operation without high - pressure and low - pressure heaters on exergy efficiency.

For the operating modes at 90 % and 80 % the load, the exergy efficiencies will be calculated and a comparative analysis will be performed. Also, the influence of the outside temperature on exergy losses of boiler, turbine and both steam condensers will be analyzed.

2 PLANT DESCRIPTION

After the completion of construction, Tuzla thermal power plant 200 MW unit was for the first time synchronized with the grid in 1974 and a test facility has started that day. Prior to modernization, the unit had 153668 operating hours and 24267303 MWh of electricity submitted to the electricity grid. In the period from 2006 to 2008, the unit was revitalized by installing a new DCS control system, replacing electrostatic precipitators, coal mills, slag and ash transport systems, reconstructing boiler, installing electro - hydraulic turbine control and a new generator sealing system.

Tuzla thermal power plant 200 MW unit has a single-axle, three - cylinder, condensing turbine installed with two steam outputs and one intermediate heating. Each steam outlet from the turbine is connected to a special condenser. Inter - heating is performed between high - pressure and medium - pressure parts of the turbine.

The high - pressure section consists of 12 stages, the medium-pressure section of 11 stages, while the low - pressure part which is divided into two parts has 4 stages of rotor blades. The turbine is equipped with 7 uncontrolled extraction points used to preheat feedwater before it enters the boiler. The above mentioned 200 MW unit has 4 low pressure and 3 high pressure regenerative system heaters [19].

Extraction points are located at different turbine stages is as follows:

- I extraction point for HPH 7 - beyond 9th stage
- II extraction point for HPH 6 - beyond 12th stage (which is also the output from the high pressure section to the intermediate heating)
- III extraction point for HPH 5 - beyond 15th grade
- IV extraction point for LPH 4 - beyond 8th grade
- V extraction point for LPH 3 - beyond 21st degree
- VI extraction point for LPH 2 - beyond 23rd grade
- VII extraction point for LPH 1 - beyond 25th grade.

The data used for the thermodynamic analysis of the 200 MW unit are based on normative tests from 2014 at the state of the unit of 202 000 operating hours, with the data that the unit operated 6000 hours after the overhaul. The tests were performed for the operation at 100 % unit load (200 MW power) and steam production 600 t/h, 90 % unit load (180 MW power) and steam production 540 t/h, and 80 % unit load (160 MW power) with steam production 480 t/h. Boiler heating surfaces were cleaned.

Numerical analyses (energy and exergy analyses) performed in this paper do not require knowledge of the steam turbine or any other steam system component's internal structure [20-22]. The diagram of the 200 MW steam unit is shown in Fig. 1.

The operating conditions of the power plant are summarized in Tab. 1.

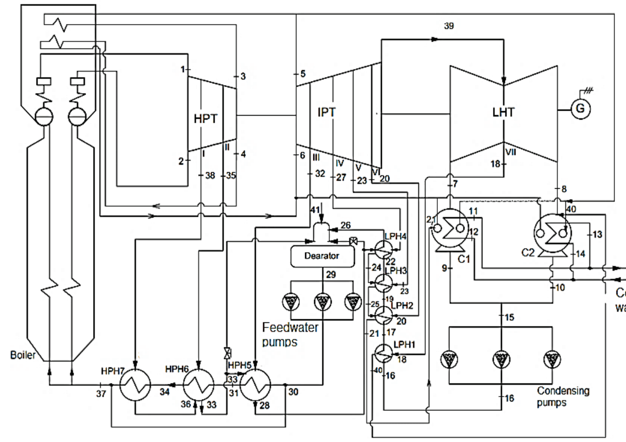

Figure 1 Schematic diagram of the thermal power plant

Table 1 Operating conditions of the thermal power plant

Operating condition	Value
Fuel mass flow rate	219.40 t/h
Lower heating value of fuel	8347.10 kJ/kg
Inlet gas volumetric flow rate to burners	577141 Nm^3/h
Feedwater inlet temperature	241.92 °C
Steam flow rate	608.50 t/h
Steam temperature	534.60 °C
Steam pressure	125.25 bar
Power output	195.99 MW
Number of turbine steam extraction points	7
Cooling water mass flow rate	28000 t/h
Isentropic efficiency of pumps	65 %
Boiler energy efficiency	88.24 %

3 THERMODYNAMIC ANSLYSIS

Exergy is the ability of a system to perform useful work when moving to a final state in equilibrium with the environment. In general, exergy is not conserved as energy, but destroyed in the system. Exergy destruction is a measure of irreversibility and is a source of performance loss. Through exergy analysis, it is possible to estimate the value of exergy losses, as well as the size and source of thermodynamic inefficiency of the heating system.

Mass, energy and exergy balances for any control volume at steady state, with negligible potential and kinetic energy changes, can be expressed, respectively, by

$$\sum m_i = \sum m_e \tag{1}$$

$$Q - W = \sum m_e h_e - \sum m_i h_i \tag{2}$$

$$E_{\text{heat}} - W = \sum m_e e_{xe} - \sum m_i e_{xi} \tag{3}$$

where the net exergy transfer by heat (E_{heat}) at temperature T is given by

$$E_{\text{heat}} = \sum \left(1 - \frac{T_o}{T}\right) \cdot Q \tag{4}$$

and the specific exergy is given by

$$e_x = h - h_0 - T_o (s - s_o) \tag{5}$$

Total exergy was calculated according to the formula

$$E_x = m\left[h - h_0 - T_o(s - s_o)\right] \tag{6}$$

where E_x, T, m, h and s indicate the total exergy rate, temperature, mass flow rate, enthalpy and entropy, respectively. The subscript 0 shows the dead state condition. Plant exergy efficiency can be defined as [23]:

$$\eta_{xe\ \text{plant1}} = \frac{E_{x\ \text{net},\ e}}{E_{xi}} \tag{7}$$

where $E_{x\ \text{net},\ e}$ and E_{xi} are net exergy at the output and exergy at the input, in order and are calculated:

$$E_{x\ \text{net},\ e} = W_T - W_{\text{own consum}} \tag{8}$$

$$E_{xi} = E_{x1} + E_{x2} + E_{x5} + E_{x6} - E_{x3} - E_{x37} - E_{x4} \tag{9}$$

where W_T denotes turbine power and $W_{\text{own consum}}$ refers to the auxiliary devices consuming 10 % of net power generation. E_x represents the exergy rate and subscripts indicate state points in Fig. 1. Exergy losses during coal combustion in the boiler and exergy losses related to exhaust gases were neglected in this analysis. On the other hand, plant exergy efficiency can be defined as:

$$\eta_{xe\ \text{plant2}} = \frac{E_{x\ \text{net},\ e}}{m_{\text{fuel}} \cdot e_{\text{fuel}}} \tag{10}$$

This definition takes into account the irreversibility of the heat transfer from gases to water in boiler pipe systems.

In Eq. (10) m_{fuel} stands for fuel mass flow rate and e_{fuel} is specific fuel exergy that can be expressed as:

$$e_{\text{fuel}} = \varphi \cdot LHV \tag{11}$$

where $\varphi = 1.05$ is exergy factor and *LHV* is fuel lower heating value [23]. The above forms are used for the analysis of the steam block and the ambient temperature is 293.15 K and the pressure is 101.3 kPa. The thermodynamic properties of the working fluid at the state points from Fig. 1 were calculated REFROP 8 software [24] and summarized in Tab. 2.

Thermodynamic properties of the working fluid and exergy values in the state points from Fig. 1 for operation of thermal power plant with 100%, 90 % and 80 % load were calculated and summarized in Tab. 2. The values of the parameters in the state points next to which the load is not specified are valid for the nominal load.

Values of *LHV* and mass flows of coal used for thermodynamic analysis are presented in Tab. 3.

For work in stationary mode and by choosing each component from Fig. 1 as control volume, exergy losses and exergy efficiencies can be calculated in the manner shown in Tab. 4.

Table 2 Thermodynamic properties, energy and exergy flow rates of state points in Fig. 1

State point /load	ϑ (°C)	p (bar)	m (t/h)	h (kJ/kg)	s (kJ/kgK)	E_x (MW)
1 100%	534.77	125.36	304.82	3434.64	6.57661	127.46
1 90%	534.96	125.35	285.32	3435.20	6.58347	119.18
1 80%	535.02	125.23	248.90	3435.73	6.5832	104.02
2 100%	534.58	125.14	303.65	3433.77	6.56920	127.08
2 90%	534.20	125,52	279,61	3434.67	6.57324	117.00
2 80%	534.83	125.14	253.18	3435.15	6.5714	106.01
3 100%	316.50	22.21	268.29	3056.48	6.77803	79.69
3 90%	313.54	21.17	254.96	3052.35	6.79205	75.15
3 80%	302.99	18.10	218.49	3036.46	6.8322	62.73
4 100%	314.12	22.19	268.29	3051.00	6.76913	79.48
4 90%	310.15	21.26	245.94	3044.28	6.77639	72.26
4 80%	300.57	18.20	215.89	3030.67	6.8243	61.77
5 100%	538.61	20.70	268.29	3552.88	7.52483	100.32
5 90%	536.32	19.51	254.96	3548.94	7.54695	94.60
5 80%	533.09	16.69	218.49	3544.53	7.6127	79.63
6 100%	535.20	20.70	268.29	3545.30	7.51548	99.96
6 90%	532.56	19.51	245.94	3540.60	7.53663	90.89
6 80%	532.10	16.69	215.89	3542.35	7.61000	78.60
7	35.38	0.0559	226.10	2565.33	8.35741	7.41
8	32.26	0.0537	226.10	2563.00	8.36853	7.10
9	35.41	0.0559	310.15	146.88	0.52143	0.91
10	32.31	0.0537	243.31	135.89	0.46881	0.092
11	27.79	1.30	14000	116.62	0.40618	2.13
12	22.10	1.70	14000	92.86	0.32633	0.76
13	27.35	1.30	14000	114.78	0.40005	2.02
14	22.10	1.70	14000	92.86	0.32633	0.76
15 100%	33.85	0.054	553.46	141.83	0.48954	0.18
15 90%	38.05	0.0681	511.26	159.39	0.54632	0.30
15 80%	36.80	0.060	454.05	151.24	0.52005	0.21
16 100%	33.91	0.27	553.46	142.06	0.49021	0.19
16 90%	38.30	0.22	511.26	160.45	0.54967	0.31
16 80%	36.95	16.40	454.05	156.26	0.5309	0.44
17	60.71	6.37	553.46	254.64	0.83979	1.76
18	65.90	0.255	17.21	2619.19	7.82621	1.56
19	95.43	6.27	553.46	400.27	1.25469	5.16
20	173.23	1.22	22.10	2821.29	7.62652	3.60
21	99.87	1.01	84.05	418.54	1.30554	0.90
22	120.99	6.17	553.46	508.28	1.53811	9.24
23	250.40	2.39	21.67	2970.77	7.62746	4.48
24	127.84	3.08	37.11	537.20	1.61167	0.69
25	106.89	2.34	58.78	448.28	1.38413	0.74
26	146.20	5.97	536.70	615.96	1.80298	13.43
27	337.12	3.08	10.75	3145.33	7.81965	5.03
28	163.72	9.44	15.91	691.91	1.97952	0.51
29 100%	162.30	8.17	618.21	685.67	1.96553	19.25
29 90%	162.20	8.10	574.86	685.23	1.96454	17.87
29 80%	162.15	7.90	510.55	685.00	1.96406	15.86
30 100%	162.20	170.00	610.99	694.75	1.94554	21.45
30 90%	162.20	170.00	567.16	694.75	1.94554	20.00
30 80%	162.40	172.00	504.65	695.73	1.9472	17.86
31	177.70	169.20	610.99	761.51	2.09642	29.10
32	450.04	9.71	15.89	3371.56	7.63378	5.01
33	199.42	22.86	71.88	850.08	2.32413	3.42
34	218.72	167.41	610.99	942.31	2.48056	36.90
35	370.77	22.86	37.40	3178.34	6.96304	11.80
36	221.22	34.68	26.37	949.57	2.52706	1.55
37 100%	241.92	166.15	610.99	1048.35	2.69148	44.39
37 90%	241.10	167.30	567.16	1035.98	2.66714	40.38
37 80%	232.14	169.30	504.65	1003.29	2.60242	34.01
38	480.15	34.70	26.37	3406.78	7.10433	9.69
39	173.23	1.117	469.40	2821.66	7.67201	74.83
40	32.80	0.25	17.21	137.468	0.47522	0.005
41	450.00	7.00	5.70	3375.21	7.7884	6.24
0	20.00	1.01	-	84.01	0.29648	0

Table 3 Values used for thermodynamic analysis

Load	Coal *LHV* (kJ/kg)	Coal mass flow (t/h)
100%	8347.10	237.10
90%	8207.20	219.14
80%	8006.70	210.60

Table 4 Expressions of exergy efficiency and exergy destruction rate for each component

Boiler	$I_{B} = m_{fuel}e_{fuel} + (E_{x37} + E_{x3} + E_{x3}) - (E_{x1} + E_{x2} + E_{x5} + E_{x6})$ $\eta_{exB} = \dfrac{E_{xi}}{m_{fuel}e_{fuel}}$
Turbine	$I_{TUR} = (E_{x1} + E_{x2} + E_{x5} + E_{x6}) - (E_{x\,extr} + E_{x7} + E_{x8} + W_{el})$ $E_{x\,extr} = E_{x38} + E_{x35} + E_{x32} + E_{x27} + E_{x23} + E_{x20} + E_{x18}$ $\eta_{exTUR} = \dfrac{W_{el}}{(E_{x1} + E_{x2} + E_{x5} + E_{x6}) - (E_{x\,extr} + E_{x7} + E_{x8})}$
Condenser 1	$I_{C1} = (E_{x7} + E_{x21} + E_{x12}) - (E_{x11} + E_{x9})$ $\eta_{exC1} = \dfrac{E_{x11} - E_{x12}}{E_{x7} + E_{x21} - E_{x9}}$
Condenser 2	$I_{C2} = (E_{x8} + E_{x14} + E_{x40}) - (E_{x13} + E_{x10})$ $\eta_{exC2} = \dfrac{E_{x13} - E_{x14}}{E_{x8} + E_{x40} - E_{x10}}$
Condensing pumps	$I_{CP} = W_{CP} + E_{x15} - E_{x16}$ $W_{CP} = m_{15}(h_{16} - h_{15})$ $\eta_{exCP} = \dfrac{E_{x16} - E_{x15}}{W_{CP}}$
LPH 1	$I_{LHP1} = (E_{x16} + E_{x18}) - (E_{x17} + E_{x40})$ $\eta_{exLHP1} = \dfrac{E_{x17} - E_{x16}}{E_{x18} - E_{x40}}$
LPH 2	$I_{LHP2} = (E_{x17} + E_{x20} + E_{x25}) - (E_{x19} + E_{x21})$ $\eta_{exLHP2} = \dfrac{E_{x19} - E_{x17}}{(E_{x20} + E_{x25}) - E_{x21}}$
LPH 3	$I_{LHP3} = (E_{x19} + E_{x23} + E_{x24}) - (E_{x25} + E_{x22})$ $\eta_{exLHP3} = \dfrac{E_{x22} - E_{x19}}{(E_{x23} + E_{x24}) - E_{x25}}$
LPH 4	$I_{LHP4} = (E_{x22} + E_{x27} + E_{x28}) - (E_{x24} + E_{x26})$ $\eta_{exLHP4} = \dfrac{E_{x26} - E_{x22}}{(E_{x28} + E_{x27}) - E_{x24}}$
Deaerator	$I_{DEA} = E_{x26} + E_{x41} + E_{x29}$ $\eta_{exDEA} = \dfrac{m_{26}(e_{x29} - e_{x26})}{m_{41}(e_{x41} - e_{x29})}$
Feedwater pumps	$I_{FWP} = W_{FWP} + E_{x29} - E_{x30}$ $W_{FWP} = m_{29}(h_{30} - h_{29})/\eta_{p}$ $\eta_{exFWP} = \dfrac{E_{x30} - E_{x29}}{W_{FWP}}$
HPH 5	$I_{HPH5} = (E_{x30} + E_{x32} + E_{x33}) - (E_{x31} + E_{x28})$ $\eta_{exHPH5} = \dfrac{E_{x31} - E_{x30}}{(E_{x32} + E_{x33}) - E_{x28}}$
HPH 6	$I_{HPH6} = (E_{x31} + E_{x35} + E_{x36}) - (E_{x34} + E_{x33})$ $\eta_{exHPH6} = \dfrac{E_{x34} - E_{x31}}{(E_{x35} + E_{x36}) - E_{x33}}$
HPH 7	$I_{HPH7} = (E_{x34} + E_{x38}) - (E_{x37} + E_{x36})$ $\eta_{exHPH7} = \dfrac{E_{x37} - E_{x34}}{E_{x38} - E_{x36}}$

4 RESULTS AND DISCUSSION

Exergy losses of all components of the thermal power plant are shown in Fig. 2. It was found that the exergy destruction rate of the boiler is dominant over all other irreversibility in the cycle. Boiler exergy losses alone amount to 59 % of losses in the plant, while the exergy destruction rate of the condenser is only 0.84 to 1.07 %. Other components (HPH, LPH, feedwater pumps, condensing pumps and deaerator) have an exergy loss percentage of 0.001 to 0.4 %. Moreover, research shows that 38.50 % of exergy losses occur in turbine.

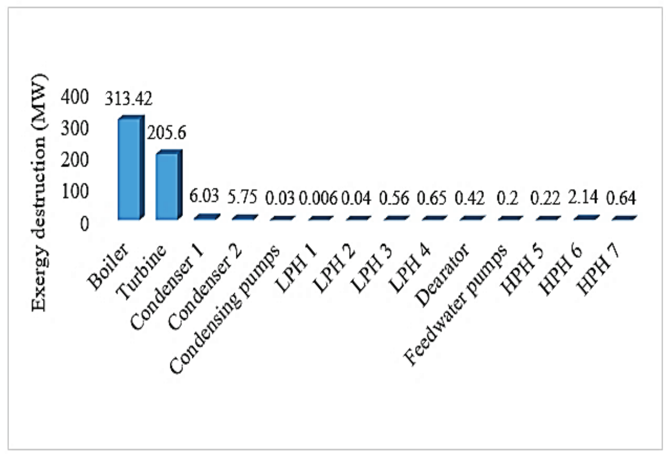

Figure 2 Exergy destruction of the thermal power plant components for nominal operation mode

The values of exergy destruction, the percentage values of exergy destruction and the exergy efficiency of all components for the nominal operation of the block are calculated and given in the Tab. 5.

Table 5 Exergy destruction and exergy efficiency of the thermal power plant components for nominal operation mode

	Exergy destruction (MW)	Percent exergy destruction (%)	Percent exergy efficiency (%)
Boiler	313.42	58.67	44.49
Turbine	205.60	38.49	49.42
Condenser 1	6.03	1.07	18.50
Condenser 2	5.75	0.84	17.95
Condensing pumps	0.03	0.006	28.57
LPH 1	0.006	0.001	99.56
LPH 2	0.04	0.007	98.80
LPH 3	0.56	0.10	87.08
LPH 4	0.65	0.12	86.61
Deaerator	0.42	0.078	54.22
Feedwater pumps	0.20	0.037	91.66
HPH 5	0.22	0.041	96.51
HPH 6	2.15	0.40	78.47
HPH 7	0.64	0.12	91.84

The exergy efficiencies of the thermal power plant components were calculated and shown in the Fig. 3. It is found that condensing pumps with the exergy efficiencies of 28.60 % are the least efficient devices in the plant and LPH1 with exergy efficiency 99.60 % is the most efficient one. Components with lower exergy efficiency values are condenser 1 (18.50 %), condenser 2 (17.95 %), boiler (44.50 %), turbine (49.42 %) and deaerator (54.22 %).

The influence of the change in ambient temperature on the values of exergy losses of boiler, turbine and both steam condensers during operation of the unit at nominal load are shown in Fig. 4.

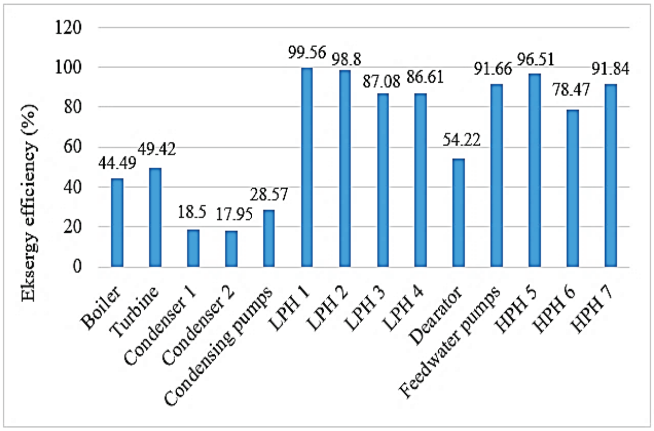

Figure 3 Exergy efficiency of the thermal power plant components for nominal operation mode

Fig. 4 shows that with increasing ambient temperature the boiler exergy losses increase and turbines and both steam condensers decrease. More detailed analysis of the influence of ambient temperature on the exergy efficiency of steam condensers for three different loads of the 200 MW unit was processed in the research of the authors of this paper [25].

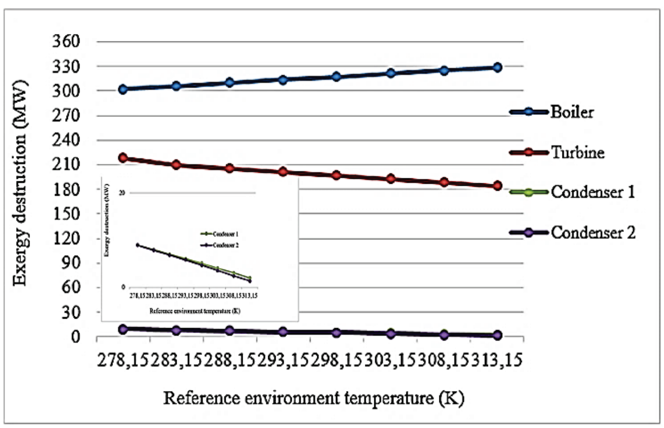

Figure 4 Exergy destruction in function of environment temperature

As previously presented, exergy efficiency power plant can be calculated based on two different methods using two different equations, Eq. (7) and Eq. (10).

Eq. (7) takes into account the energy carried by working fluid, neglecting the irreversibility of combustion process in furnace. Eq. (10) is based on exergy carried by the fuel combusted in furnace where irreversibility of the combustion process and exergy losses in exhaust gases are not neglected.

Thus obtained exergy efficiency values of the thermal power plant unit for operation at 100 %, 90 % and 80 % load are shown in the Fig. 5. For power plant unit operating at 100 % load, the values of exergy efficiencies are 77.26 % (Eq. (7)) and 34.37 % (Eq. (10)). The obtained values of exergy efficiency according to Eq. (10) refer to the coal consumption of 237.10 t/h, coal lower heating value of 8347.10 kJ/kg, the boiler efficiency of 87.88 % and the power at the generator terminals of 195.99 MW. Exergy efficiencies at 90 % load are 76.89 % and 35 %. These values were obtained for coal consumption of 219.20 t/h, coal lower heating value of 8207.20 kJ/kg, boiler efficiency of 88.24 % and electric generator power output of 182.30 MW. Operating at 80 % load, unit exergy efficiency values 75.58 % and 32.96 %. At the same time coal consumption is 210.60 t/h, coal lower heating value 8006.70 kJ/kg, boiler efficiency of 86.50 % and power at generator terminals of 161.50 MW.

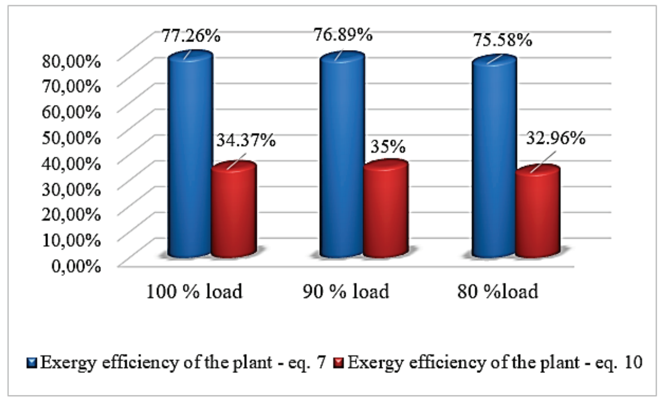

Figure 5 Exergy efficiency of the thermal power plant unit for operation at 100 %, 90 % and 80 % load

The influence of the 200 MW unit operation at the nominal regime without HPH in one and without HPH and LPH in the other case, on its exergy efficiency was calculated and shown in the Fig. 6. In the first case, when operating without HPH, efficiencies according to Eqs. (7) and (10) are 67.74 % and 28.80 %, respectively. These exergy efficiencies values are lower by 5.6 % and 9.8 % compared to operating a thermal power plant with HPH.

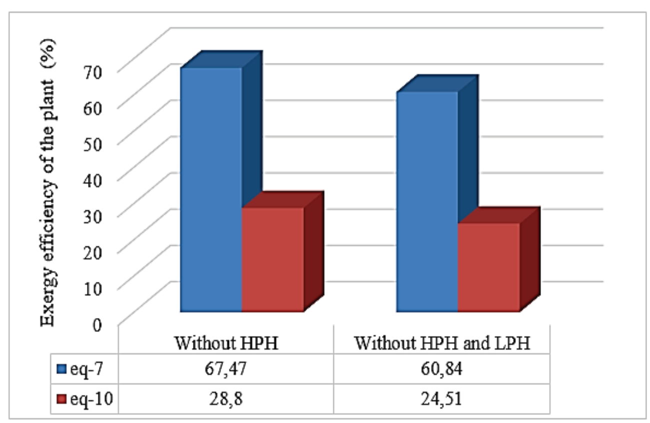

Figure 6 Exergy efficiency of the thermal power plant for operation at 100 % load without HPH and without HPH and LPH

In the other case, when operating thermal power plant unit without HPH and LPH, the exergy efficiencies amount to 60.84 % and 24.51 %, respectively, which are 9.90 % and 16.40 % lower than the values when operating with HPH and LPH.

Fig. 7 shows the exergy efficiencies of the boiler and turbine when the unit is operating at nominal mode without HPH and without HPH and LPH. Operation of the unit at nominal load without HPH and without HPH and LPH results with boiler efficiencies of 42.40 % and 40.30 %, respectively. Compared to the same values when unit is operating with HPH and LPH, these values are lower by 2 % and 4.2 %. Furthermore the exergy efficiencies of the turbine are 44.20 % and 40 % in the case when unit is operating without HPH and operating without HPH and LPH. When both HPH and LPH are operative, the turbine has by 5.2 % and 10 % higher exergy efficiency than in the previously mentioned case.

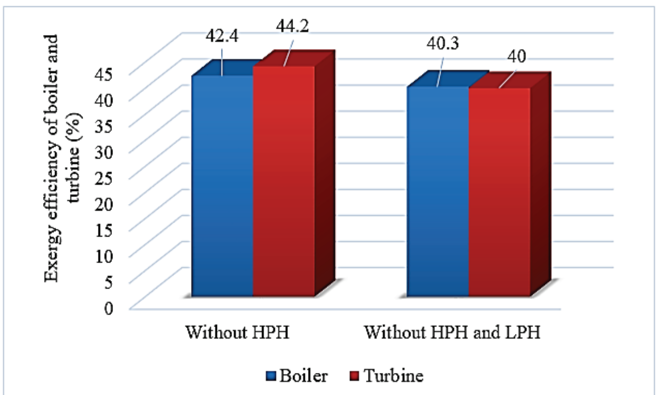

Figure 7 Exergy efficiency of boiler and turbine when unit is operating without HPH and without HPH and LPH

5 CONCLUSIONS

In this article, an analysis of the energy and exergy of a 200 MW steam block was performed, as well as the influence of the change in ambient temperature on the values of exergy losses and exergy efficiency. The analysis of this energy system revealed that the largest exergy loss is in the boiler and is 58.7%, followed by the turbine with an exergy loss of 38.5%. The percent exergy destruction in the condenser 1 and condenser 2 was 1.07 % and 0.84 % respectively, while all heaters, dearator and pumps destroyed less than 1 %.

With the change in ambient temperature, the percentage of exergy losses and exergy efficiency of all components also changed, but the conclusion remained the same, that the boiler and the turbine primarily affect the irreversibility of the analyzed cycle. The exergy efficiency of the block when working at nominal load is the highest, regardless of the method of calculating it. Different ways of calculating exergy efficiency lead to different values of exergy efficiencies and they are significantly less when the irreversibility of heat transfer in the boiler from flue gases to steam is taken into account in the calculation.

The exergy efficiency of the unit when operating at nominal load and without high - pressure heaters is 6 to 10 % lower, depending on the calculation method, while when operating the unit without high - pressure and low pressure heaters, it is lower by 10 to 16.5 %.

The exergy efficiencies of the boiler and turbine during the operation of the unit at nominal load and without high pressure heaters are 2 to 4.2 % less compared to the operation of the unit with high pressure heaters. The exergy efficiencies of the turbine at this load and operation without high pressure and low pressure heaters are further reduced and are 5 to 10 % lower. The operation of the unit at nominal load and without high pressure and low pressure heaters leads to a greater reduction in the exergy efficiency of the turbine than the boiler.

The analysis confirmed previous researches that indicate that the boiler within the steam block has the highest exergy losses. The analysis of exergy losses and exergy efficiency indicates that certain components such as LPH3, LPH4 and HPH6 have significantly lower values of exergy efficiency and that their performance can be improved with certain measures through revitalization or maintenance. Also, there is room for increasing exergy efficiency in both steam condensers. The fact that about 3 MW of cooling water exergy is released into the atmosphere at the cooling tower indicates the possibility of installing commercially available technologies for its use and generation of additional electrical and thermal energy.

NOMENCLATURE

Abbreviations:

HPH High pressure regenerative system heaters
LPH Low pressure regenerative system heaters
LHV Fuel lower heating value (kJ/kg)

Latin Symbols:

m mass flow rate (kg/s)
Q heat transfer rate to the system (W)
W work rate or power done by the system (W)
h specific enthalpy (J/kg)
e_x specific exergy (J/kg)
E_x total exergy rate (W)
T temperature (K)
s specific entropy (J/kg K)
ϑ temperature (°C)
p pressure (bar)

Greek symbols:

φ exergy factor
η exergy efficiency

Subscripts:

net netto
own consump own consumption
TUR turbine
o dead state conditions
B boiler
ex exergy
extr extraction
el electrical
C1 condenser 1
C2 condenser 2
CP condensing pump
FWP feed water pumps
DEA deaerator

P pump
i inlet
e exit

6 REFERENCES

[1] Kopac, M. & Hilalci, A. (2007). Effect of ambient temperature on the efficiency of the regenerative and reheat Çatalağzı power plant in Turkey. *Applied Thermal Engineering, 27*(8-9), 1377-1385. https://doi.org/10.1016/j.applthermaleng.2006.10.029

[2] Rosen, M. & Dincer, I. (2004). Effect of varying dead - state properties on energy and exergy analyses thermal systems. *International Journal of Thermal Sciences, 43(2),* 121-133 https://doi.org/10.1016/j.ijthermalsci.2003.05.004

[3] Utlu, Z. & Hepbasli, A. (2007). A review on analyzing and evaluating the energy utilization efficiency of countries. *Renewable and Sustainable Energy Reviews, 11*, 1-29. https://doi.org/10.1016/j.rser.2004.12.005

[4] Kanoglu, M., Dincer, I., & Rosen, A. M. (2007). Understanding Energy and Exergy Efficiencies for Improved Energy Management in Power Plants, *Energy Policy, 35*, 3967-3978. https://doi.org/10.1016%2Fj.enpol.2007.01.015

[5] Yang, Y., Wang, L., Dong, C., Xu, G., Morosuk, T., & Tasatsaronis, G. (2013). Comprehensive Exergy – Based Evaluation and Parametric Study of a Coal – fired Ultra Supercritical Power Plant. *Aplied Energy, 112,* 1087-1099. https://doi.org/10.1016/j.apenergy.2012.12.063

[6] Aljundi, H. (2009). Energy and Exergy Analysis of a Steam Power Plant in Jordan, *Applied Thermal Engineering*, *29*, 324-328. https://doi.org/10.1016/j.applthermaleng.2008.02.029

[7] Ehsan, A. & Yilmazoglu, M. Z. (2011). Design and Exergy Analysis of a Thermal Power Plant Using Different Types of Turkish Lignite, *International Journal of Thermodynamics, 14(3),* 125-133. https://doi.org/10.5541/ijot.288

[8] Erdem, H. H., Akkaya, A. V., Cetin, B., Dagdas, A., Sevilgen, H. K., Sahin, B., Teke, I., Gungor, C., & Atas, C. (2009). Comparative Energetic and Exergetic Performance Analyses for Coal - Fired Thermal Power Plants in Turkey. *International Journal of Thermal Sciences, 48,* 2179-2186 https://doi.org/10.1016%2Fj.ijthermalsci.2009.03.007

[9] Hastia, S., Aroonwilasa, A., & Veawab, A. (2013). Exergy Analysis of Ultra Supercritical Power Plant. *Energy Procedia, 37,* 2544-2551. https://doi.org/10.1016/j.egypro.2013.06.137

[10] Hongbin, Z. & Yuman, C. (2009). Exergy Analysis of a Steam Power Plant with Direct Air - Cooling System in China. *IEEE School of Mechatronics Engineering*, 1-4. https://doi.org/10.1109%2FAPPEEC.2009.4918346

[11] Ghasemzadeh, B. & Sahebi, Y. (2010). Optimization and Exergy Analysis for Advanced Steam Turbine Cycle. The *2nd International Conference on Mechanical and Electronics Engineering,* 2, 190.

[12] Dincer, I. & Muslim, H. A. (2001). Thermodynamic Analysis of Reheat Cycle Steam Power Plants, *International Journal of Energy Research, 25,* 727-739. https://doi.org/10.1002/er.717

[13] Ray, T. K., Datta, A., Gupta, A., & Ganguly, R. (2010). Exergy Based Performance Analysis for Proper O&M Decisions in a Steam Power Plant. Energy *Conversion and Management, 51*, 1333-1344. https://doi.org/10.1016/j.enconman.2010.01.012

[14] Gogoi, T. K. & Talukdar, K. (2014). Thermodynamic Analysis of A Combined Reheat Regenerative Thermal Power Plant and Water – LiBr Vapor Absorption Refrigeration System. *Energy Conversion and Management, 78*, 595-610. https://doi.org/10.1016/j.enconman.2013.11.035

[15] Kanoglu, M., Cengel, Y. A., & Dincer, I. (2012). *Efficiency Evaluation of Energy Systems*, Springer, New York. https://doi.org/10.1007/978-1-4614-2242-6

[16] Rashad, A. & Maihy, A. E. (2009). Energy and Exergy Analysis of a Steam Power Plant in Egypt. *The 13th International Conference on Aerospace Sciences & Aviation Technology*, 1-12.

[17] Sengupta, S., Datta, A., & Duttagupta, S. (2007). Exergy Analysis of a Coal - Based 210 MW Thermal Power Plant. *International Journal of Energy Research*, *31*(1), 14-28 https://doi.org/10.1002/er.1224

[18] Živić, M., Galović, A., Avsec, J., & Holik, M. (2016). Exergy analysis of a Brayton cycle with variable physical properties and variable composition of working substance. *Technical Gazette, 23*(3), 801-808. https://doi.org/10.17559/TV-20160208112755

[19] Ćehajić, N. & Hafizović, S. (2021). Comparative analysis of power distribution, exergy losses and exergy efficiencies of the 200 MW steam turbine for three operating modes with and without turbine steam extraction. *Tehnika, 76*(6), 765-773. https://doi.org/10.5937/tehnika2106765c

[20] 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. https://doi.org/10.1016/j.enconman.2017.04.067

[21] Kumar, S., Kumar, D., Memon, R. A., Wassan, M. A., & Ali, M. S. (2018). Energy and exergy analysis of a coal fired power plant. *Mehran University Research Journal of Engineering & Technology*, *37* (4), 611-624. https://doi.org/10.22581/muet1982.1804.13

[22] Adibhatla, S. & Kaushik, S. C. (2017). Energy, exergy, economic and environmental (4E) analyses of a conceptual solar aided coal fired 500 MWe thermal power plant with thermal energy storage option. *Sustainable Energy Technologies and Assessments*, *21*, 89-99. https://doi.org/10.1016/j.seta.2017.05.002

[23] Kotas, T. J. (1995). *The Exergy Method in Thermal Plant Analysis,* second ed. Krieger, Malabar

[24] Lemmon, E., Huber, M., & McLinden, M. (2007). *NIST Reference Fluid Thermodynamic and Transport Properties REFPROP 8, NIST Standard Reference Database 23*.

[25] Ćehajić, N. & Žigić, H. (2021). Parametric analysis of steam condenser block of 200 MW, *Scientific Review, 1*(8).

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