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ENERGY AND EXERGY ANALYSIS OF COAL FIRED POWER PLANT

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Abstract. *The global trend of growing energy demand, accompanied by the dependency on fossil fuels and their environmental impacts, provokes continuous interests for analyzing equipment efficiency and revision of existing energy production sites. This paper focuses on thermodynamic analysis of a coal-fired power plant "Kolubara – block A5", with respect to the concept of energy losses, production of entropy and exergy destruction. Most significant energy losses occur in the condenser where they are lost to the environment, whereas greatest exergy destruction is found in the boiler. The results of energy and exergy performance of the plant are calculated for maximum load and 75% of the maximum load. Each of the system components is modeled as a "black box", and the energy and exergy balances are determined according to operation data. Thermal efficiency, based on the specific heat input to the steam, was calculated and found to be 32.1% and 33.1%, while the exergy efficiency of the power plant cycle was 30% and 33% depending on the load.*

Key words: *thermal power plant, energy, exergy, efficiency*

1. INTRODUCTION

Constant growth in energy demand has already made its mark in the last century, and it will probably become even more distinct in the 21st century. There are new tendencies in the energy sector for sustainable energy production. Lior [1] analyzed possibilities for future power production, and identified space power systems for terrestrial use, solar, fuel cell and nuclear power as most promising technologies for the future. However, some of these technologies are still young and require much research and development to fulfill their potential. In the near future humanity will still greatly depend on less efficient and not so environmentally friendly combustion based technologies. Exergy analysis was

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identified as methodology for assessments of current power production sites and effective development of innovative future power generation.

Erstvag [2] compared and discussed data obtained by exergy analyses applied to societies (*i.e*. countries) and their energy sectors for a number of different countries, identifying efficiency of various societies, energy carriers and their use, reference of exergy efficiency, and concluded that a realistic level of exergy usage has to be found above the theoretical minimum given by the exergy efficiency, but still less than the 100% that is actually spent. Major part of the losses is at the end use, certain sectors conserve a large part of the exergy, whereas other sectors merely consume their exergy.

Energy efficiency is regularly used as a property of an energy conversion process, it may be considered somewhat misleading since it does not reveal the quality of the acquired energy. Energy efficiency is defined as the ratio of the useful output and the input of the device, with respect to the First Law of Thermodynamics. Exergy represents available work during a process which brings the system to equilibrium. It reveals the quality of the energy available for use in an energy conversion process, accounting for irreversibility of a process as a result of the generation of entropy. Hence, exergy analysis is useful for design, assessment, evaluation, optimization and improvement of energy systems and energy conversion processes in general.

According to Bejan [3] exergy represents quantitatively the useful energy, or ability to do or receive work of a variety of streams (mass, heat, work) which flow through the system, making possible to compare different interactions (inputs, outputs, work, heat). By analyzing exergy streams, it is possible to determine the locations of exergy destruction which is proportional to generated entropy, which is always present in a real process according to the Second Law of Thermodynamics.

Koreneos *et al*. [4] presented an exergy analysis of a solar thermal power system, exergy analysis of wind power systems and exergy analysis of geothermal power systems. They used this for comparison of renewable and non-renewable energy sources. Sharma and Praveen [5] quantified pollution sources and suggest that lowering thermal efficiency indirectly increases the consumption of raw material and pollution discharges in the same proportion.

Energy and exergy analysis studies of power plants are essential when it comes to effective utilization of energy sources. While energy balances do not provide information about internal loss, i.e. irreversibility due to entropy generation, the exergy analysis, introduced with respect to the Second Law of Thermodynamics, detects irreversibility in a process. If a system is not in equilibrium with its environment, by definition, it is capable of providing work, and vice versa. Exergy may be considered a measure of difference between the state of the given system and state of the environment, hence a property of both composition and the environment. Thus, exergy is a measure for assessment of energy quality, availability of a system for producing work with respect to the "dead state" of the environment. It determines the locations, sources, and values of the losses (or irreversibility) occurring in a system, as well as residues originating from thermal processes. Consequently, exergy analysis has drawn much attention of both scientists and system designers.

Verkhivker and Kosoy [6] explained the concept of exergy analysis of steam power plants and nuclear power plants, and explained effects of adding reheaters between the turbine stages, reheating in the steam generator and cooling of steam entering the heaters to exergy destruction in the plant's cycle. Rosen [7] made an evaluation of a coal fired and nuclear power plant through exergy analysis. Habib and Zubair [8] conducted an analysis based on the second law of thermodynamics of a regenerative Rankine-cycle power plant with reheating. Dincer and Muslim [9] report about a thermodynamic analysis of a power plant cycle with reheating. Cihan *et al.* [10] and Ameri and Ahmadi [11] have shown that, apart from energy analysis, a complete exergy analysis can be used for identifying components and places of highest inefficiency. By improving these components, the overall improvement of the power plant efficiency can be achieved. Sengupta *et al.* [12] conducted an exergy analysis of a coal fired power plant, uses design operation data to investigate irreversibility in the plant, and decomposes the plant into zones. They indicated that increased exergy efficiency of the turbine may be achieved by reducing the condenser pressure and by less throttling of the control valves with sliding pressure can help reduce exergy destruction in the plant. Part load operation increases the irreversibility in the cycle and the effect is more pronounced with the reduction of the load and that an increase in the condenser back pressure decreases the exergy efficiency. Habib *et al.* [13] used exergy and energy analysis to distinguish a difference in the design and actual plants performance, concluding that improvements in the efficiency are possible by adding feed water heaters to the plant. Kangoly [14] quantified exergy destruction throughout the plant using an exergy flow diagram and compared it to the energy flow diagram.

2. ENERGY PERFORMANCE ANALYSIS OF THE POWER PLANT

Energy performance analysis is based on the First Law of Thermodynamics, according to which the common main performance criteria are power output and thermal efficiency. In this analysis, the input and output values of the plant components are determined using the measured or calculated thermodynamic variables such as enthalpy, pressure, temperature, entropy, mass flow rate and quality.

Each device in the power plant forms a control volume, with associated equations for energy analysis as described further in the text.

Continuity equation:

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \tag{1}$$

where *m* is the mass flow rate whereas the subscripts *in* and *out* represent the inlet and outlet conditions, respectively. The energy balance equation:

$$-\dot{W} + \dot{Q} = \sum \dot{m}_i \cdot (h_{out,\,i} - h_{in,\,i}) \tag{2}$$

where $\dot{Q}$ is the heat transfer rate to the control volume, $\dot{W}$ is the given work per unit of time and *h* is the enthalpy. Kinetic and potential energy changes, considered negligibly small compared to the changes of enthalpy, are neglected. The power output of a steam turbine is calculated by:

$$\dot{W}_T = \dot{m}_{in} \cdot (h_{in} - h_1) + (\dot{m}_{in} - \sum_{j=1}^{n} \dot{m}_j) \cdot (h_j - h_{j+1}) \tag{3}$$

where the subscript n represent the number of steam extraction in the steam turbine. The power consumed by pumps is the only internally consumed power considered in the plants model. This power is calculated by:

$$\dot{W}_P = \dot{m}_{in} \cdot (h_{out} - h_{in}) / \eta_P \tag{4}$$

where, η_P is pump efficiency. Net electrical power output is given by:

$$\dot{W}_{Net} = \sum \dot{W}_T - \sum \dot{W}_P \tag{5}$$

The thermal efficiency of the power plant can be calculated as follows:

$$\eta_{th} = \frac{\dot{W}_{Net}}{\dot{m}_f \cdot LHV} \tag{6}$$

where *LHV* is lower heating value of the coal, and $\dot{m}_f$ is fuel consumption rate.

3. Exergy Performance Analysis of the Power Plant

Exergy performance analysis is based on Second Law of Thermodynamics. The results obtained from such analysis can be used for determining and diminishing the irreversibility sites in the power plant, and thus for performance enhancement. Exergy is a thermodynamic indicator which shows the transformation potential and conversion limit of an energy carrier to maximum theoretical work under the conditions imposed by an environment at given pressure and temperature.

For a control volume of any plant's component at steady-state conditions, a general equation of exergy destruction rate derived from the exergy balance can be given as:

$$\dot{E}_{in} + \dot{E}_Q = \dot{E}_{out} + \dot{E}_W + \dot{E}_D + \dot{E}_L \tag{7}$$

where subscripts *in* and *out* refer to inlet and outlet flows with respect to the control volume, and

$$\dot{E}_Q = (1 - \frac{T_o}{T_i}) \cdot \dot{Q}_i \tag{8}$$

$$\dot{E}_W = \dot{W} \tag{9}$$

where T is the absolute temperature, whilst subscripts i and o refer to the surface and environment conditions, respectively. Exergy destruction $\dot{E}_D$ and exergy loss $\dot{E}_L$ represent a measure of the inefficiency of the irreversible processes occurring in the k^{th} component of the plant. When considering a single component of a thermal system, the exergy losses are usually equal to zero as shown by Ameri *et al.* [11]:

$$\dot{E}_L = 0 \tag{10}$$

Exergy flow rate of a system consists of a kinetic, potential, physical and a chemical one:

$$\dot{E} = \dot{E}_{PH} + \dot{E}_{KN} + \dot{E}_{PT} + \dot{E}_{CH} \quad (11)$$

where $\dot{E}_{PH}$, $\dot{E}_{KN}$, $\dot{E}_{PT}$ and $\dot{E}_{CH}$ are the physical exergy, kinetic exergy, potential exergy and chemical exergy, respectively, formulations of which are presented by Bejan *et al.* [15].

Thermal exergy is defined as the maximum amount of work which can be obtained from a flow of matter brought from its initial state to the (restricted) state of the environment while exchanging heat only with the environment. Chemical exergy is defined as the maximum amount of work which can be obtained when the flow of matter is brought from the (restricted dead) state of the environment to the total dead (unrestricted) state as a result of heat transfer and exchange of substances only with the environment. Eqs. (12)-(14) shows some of the typical expressions for exergy, as reported by Zaleta *et al.* [16]. In the eqs. (13) and (14) e_k^{CH} denotes the standard exergy of component gas *k*, and $x_k^{'}$ the volume percent of the component gas *k*, and $\bar{R}$ the universal gas constant. Exergy functions are defined for different energy stream conditions as:

- for a pure substance

$$\dot{E} = \dot{m} \cdot [(h - h_o) - T_o \cdot (s - s_o)] \quad (12)$$

- for a solid fuel (semi-empirical correlation)

$$\dot{E} = \dot{m} \cdot \left[\begin{array}{l} (LHV) \cdot (1.0438 + 0.0013 \cdot \frac{x_H}{x_C} + 0.1083 \cdot \frac{x_O}{x_C} + \\ + 0.0549 \cdot \frac{x_N}{x_C}) + 6740 \cdot x_S \end{array} \right] \quad (13)$$

- for a gas phase (flue gas)

$$\dot{E} = \dot{m} \cdot [(h - h_o) - T_o \cdot (s - s_o) + \sum x_k^{'} \cdot e_k^{CH} + \bar{R} \cdot T_o \cdot \sum x_k^{'} \cdot \ln x_k^{'}] \quad (14)$$

3.1 Exergy efficiency

The exergy of steam is calculated at all states and the changes of the exergy are determined for each major component. The source of exergy destruction (or irreversibility) in the boiler and steam turbine is mainly combustion (chemical reaction) and thermal losses in the flow path, respectively. On the other side, the exergy destruction in the heat exchangers of the system, i.e. condenser, feed water heater, is due to the large temperature difference between the hot and cold fluid. The exergy destruction rate and the exergy efficiency for each component and for the whole system in the power plant are represented by eqs. (15) - (26).

Table 1 The exergy destruction rate and exergy efficiency equations for plant components

Component	Exergy destruction	Eq.	Exergy efficiency	Eq.
Boiler	$\dot{E}_{D,B} = \dot{E}_F + \sum \dot{E}_{in,B} - \sum \dot{E}_{out,B}$	(15)	$\eta_{ex,B} = (\dot{E}_{out,B} - \dot{E}_{in,B}) / \dot{E}_F$	(21)
Steam turbine	$\dot{E}_{D,T} = \sum \dot{E}_{in,T} - \sum \dot{E}_{out,T} - \dot{W}$	(16)	$\eta_{ex,T} = \dot{W}_T / (\dot{E}_{in,T} - \dot{E}_{out,T})$	(22)
Pump	$\dot{E}_{D,P} = \sum \dot{E}_{in,P} - \sum \dot{E}_{out,P} + \dot{W}_P$	(17)	$\eta_{ex,P} = (\dot{E}_{out,P} - \dot{E}_{in,P}) / \dot{W}_P$	(23)
Heater	$\dot{E}_{D,H} = \sum \dot{E}_{in,H} - \sum \dot{E}_{out,H}$	(18)	$\eta_{ex,H} = \dot{E}_{out,H} / \dot{E}_{in,H}$	(24)
Condenser	$\dot{E}_{D,C} = \sum \dot{E}_{in,C} - \sum \dot{E}_{out,C}$	(19)	$\eta_{ex,C} = \dot{E}_{out,C} / \dot{E}_{in,C}$	(25)
Cycle	$\dot{E}_{cycle} = \sum \dot{E}_{all components,D}$	(20)	$\eta_{ex,T} = \dot{W}_{net out} / \dot{E}_F$	(26)

4. Exergy and Energy Analysis of the Power Plant Kolubara – Block A5

This paper presents a thermodynamic energy and exergy analysis of a steam power plant Kolubara – A5, 110MW block and discuses results of the analysis. The plant is lignite coal fired. Used lignite coal originates from a nearby open pit. Fig. 1 shows the scheme of the plant.

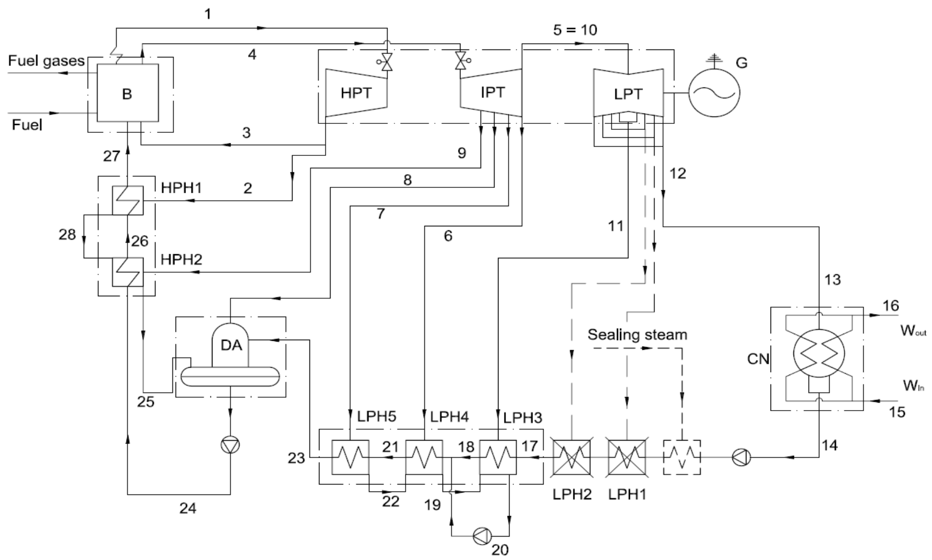


Fig. 1 Scheme of the coal fired power plant Kolubara A5 110MW

The steam produced in the Boiler (B), is regulated by two main valves. After flowing through the main valve to the High pressure turbine (HPT) for expanding, it is sent back to the steam boiler for reheating. After reheating, the steam is sent through the main valve to the Medium pressure turbine (IPT) and two Low pressure turbines, respectfully, for further expansion. The Steam boiler is fed by the condensate which is preheated by two high pressure regenerative heat exchangers (HPH1, HPH2) supplied with steam extracted from the High Pressure Extraction Turbine, two Medium Pressure Regenerative Heat Exchangers (LPH5, LPH4) supplied with steam from the Medium Pressure Turbine (IPT), and three Low Pressure Regenerative Heat Exchangers (LPH3, LPH2, LPH1) supplied with the steam from the Low Pressure Turbine. Steam and non-condensable cycle gas separation is conducted in the Deaerator unit (DA). The exhaust steam from the low pressure turbine (LPT) is completely condensed in the Round Cooled Condenser (CN), after which the condensate is pumped and preheated on the way towards the Deaerator and the Boiler. It should be noted that the final two Low Pressure Regenerative Heat Exchangers (LPH1, LPH2) are not in operation, as illustrated in fig. 1.

For the purpose of this study kinetic and potential energy are assumed negligibly small. The temperature and pressure values of the reference environment, *i.e*. dead state, considered in the exergy analysis are T_0 = 298.15 K and P_0 = 1.013 bars. Fuel considered in the calculation is lignite coal, which is the same as the coal used to fire the plant. Combustion is considered to be complete with 70% of excess air. Flue gas temperature at the output is 150 °C. The exergy of coal is taken from equation (13) (semi-empirical correlation in terms of carbon, hydrogen, oxygen, nitrogen, and sulfur composition). The value of exergy for the flue gas is taken from equation (14). The reference ambient model for air that is used in the current analysis is given in Bejan *at al.* [15]. Thermodynamic properties at points of interest in the plant's cycle used in the analysis are presented in tab. 2 represent actual operation data for full load regime.

The simulation model of the admission properties of each turbine section is based on the determination of the mass flow coefficient, except for the first section, which is defined according to Cooke's model and Stodola's ellipse model as shown by Bresolin *et al.* [17]. The efficiency model of each section is defined as a function of the mass flow coefficient. Performance test data presented are used to determine the coefficients in these functions.

The steam turbines effective efficiencies are evaluated using the model of Spenser *et al.* [18]. The basic efficiency of the turbine, which is a function of the load, is corrected by factors taking into account volume flow, pressure ratio, initial pressure and temperature, thus obtaining effective efficiency. The evaluation of different correction factors is performed for each turbine section, *i.e.* from one extraction point to the next, resulting in different effective efficiency calculated for each section.

Exhaust losses, mechanical losses and generator losses are also considered. The model of the feed water heaters is based on a correlation of the terminal temperature differences (TTD) for different loads as done by Uche [19]. Simulation of feed pumps was done with their efficiency, considered to be a function of the mass flow, evaluated from experimental data. The condensate pump was neglected in the simulator, due to its negligible consumption. Although the condenser, the boiler and the reheater are not simulated, properties of their unknown flows are evaluated by matter and energy balances. Energy efficiency of the boiler and reheater has been evaluated according to actual plant's data. The input data used represent the operating conditions of the plant. The steam for turbine seals was considered negligibly small and was not considered in the simulator. The relative error between the simulation results and the plant test data is considered to be less than 2% for the power output, the mass flow rates, the pressures and the specific enthalpy of the streams.

Table 2 Values of thermodynamic properties at the points of interest in the plants cycle

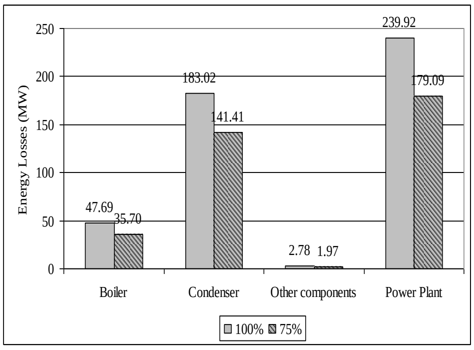
	t [C]	*p* [bar]	*h* [KJ/kg]	*s* [KJ/kgK]	$\dot{m}$ [kg/s]	$\dot{E}$ [KW]
1	531	126.7	3424.84	6.5502	106.50	157243.68
2	375.26	35.9	3163.43	6.7416	7.52	8705.77
3	375.26	35.9	3163.47	6.7416	98.98	114624.18
4	538.7	32.2	3541.96	7.3106	98.98	135296.77
5	222.13	2.5	2913.38	7.4997	82.93	56551.93
6	222.13	2.5	2913.38	7.4997	4.33	2949.96
7	307.92	5.5	3079.75	7.4440	4.70	4061.52
8	383.07	10.5	3227.55	7.3900	1.80	1854.92
9	455.31	18.2	3372.07	7.3489	5.23	6195.48
10	222.13	2.5	2913.38	7.4997	82.93	56551.93
11	162.77	1.2	2800.79	7.5976	4.53	2445.76
12	48.15	0.1	2533.39	7.9371	78.40	13447.11
13	48.15	0.1	2533.39	7.9371	78.40	13447.11
14	47.55	0.2	199.08	0.6720	78.40	258.34
15	27	1	113.30	0.3952	4375.00	160.59
16	37	1	155	0.5300	4375.00	6777.18
17	62.72	18	264.03	0.8643	78.40	855.34
18	95.28	15	400.28	1.2523	78.40	2466.95
19	126.02	2.4	529.40	1.5924	9.02	534.04
20	103.28	1.1	432.95	1.3439	13.55	498.95
21	123.02	12	517.30	1.5594	91.95	5235.52
22	154.30	5.3	650.83	1.8855	4.70	437.82
23	153.30	9	646.73	1.8749	91.95	8486.77
24	165.90	7.2	701.27	2.0014	106.50	11621.32
25	174.04	17.6	737.40	2.0803	12.74	1551.02
26	201.11	173	864.05	2.3172	106.50	18929.75
27	236.23	172	1022.15	2.6389	106.50	25552.18
28	211.11	34.8	903.31	2.4325	7.52	1372.97
fuel	/	/	/	/	57	361764.8
gas	150	1	/	/	220	13200

Exergy and energy analysis is used and demonstrated as a tool for improving system performance. The method provides the major sources of exergy losses and destruction in the power plant, thus indicating possibilities for further system improvement in the terms of both performance and environment impact. Finally, a parameter study, including system parameters for two operating load regimes with the highest efficiencies, is performed. A discussion is given about the possibilities for further system development by energy and exergy loss reduction, with respect to the maximum irreversibility sites identified by the analysis.

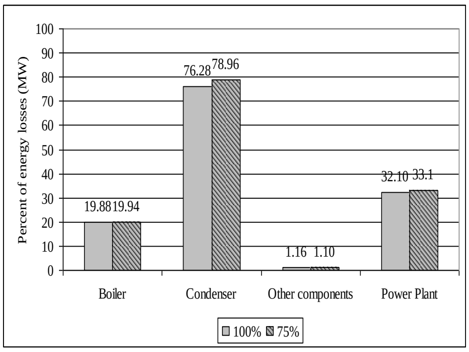
4.1. Results and discussion

Energy and exergy flow rates, energy and exergy rejection rates and exergy consumption/destruction rates for the complete turbine cycle are computed from the plant's operation data for operating regimes considered to have best efficiencies: 100% load or maximum load with 110MW output and 75% of the maximum load or 81 MW output. The operational thermodynamic properties for the various power plant points are given in Table 3 (for 100% of maximum load).

Thermal efficiency, defined as the ratio of net electrical energy output to coal energy input, is found to be 32.1% and 33.1% for operating regimes with 100% and 75% of the maximum load. Clearly, this efficiency was based on the specific heat input to the steam. The energy balance also reveals that 76.3% of the energy added in the boiler is lost in the condenser and lost to environment, while only 19.9% is lost in the boiler, for operating regime with 100% of the maximum load. At the operating regime with 75% of the maximum load, 78.9% of energy is lost in the condenser and 19.9% in the boiler. Losses in other components of the plant are negligible small compared to these major losses. Nevertheless, efficiencies based on energy analysis can often turn out non-intuitive or even because a measure of ideality of energy conversion is not provided. Greatest energy losses may have a large value, but their thermodynamic significance is low if they account for energy of low quality. On the other hand, exergy based efficiencies and exergy destruction or entropy generation indicate a measure of approach to process ideality or deviation from ideality, and thus a measure of energy quality. A comparison of energy losses for various components is given in figs. 2(a) and 2(b).



a) Energy losses for the plants components

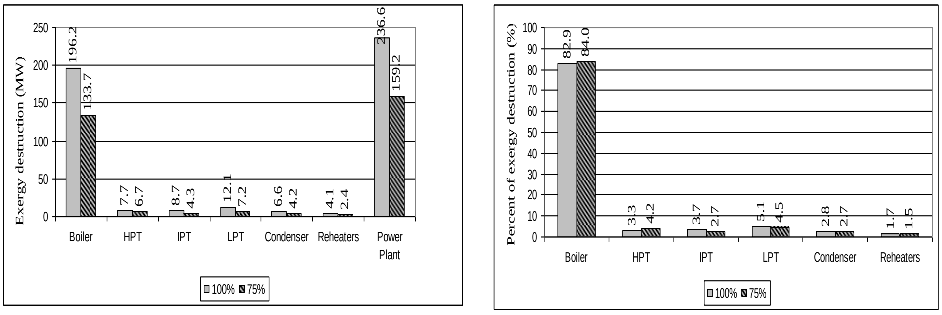


b) Percent of energy losses

Fig. 2 Energy losses for the plant components – for 100% and 75% of the full load

Exergy and percent of exergy destruction and Second law efficiency are summarized in fig. 3, for components of the power plant. It is found that the exergy destruction rate of the boiler is dominant compared to all other irreversibility sites in the cycle. Exergy destruction in the boiler accounts for 74.7% and 84% of total losses in the plant, for operating regimes with 100% and 75% of the maximum load, respectfully.

On the other side, exergy destructions found in the condenser are only 4.2% and 2.5% for the same loads, respectively. The cause of this can be irreversibility inherent in the combustion process, heat loss, and incomplete combustion and exhaust losses. Hence, we can pinpoint that the boiler requires some necessary modification for reduction of its exergy destructions and thereby the plant performance improvement. Also, the energy losses in the condenser cannot be practically utilized to achieve an improvement of the power output of the plant, due to its low quality. The calculated exergy efficiency of the power cycle of 30% and 33%, respectfully, is considered to be low. This may be the result of the plants age, or the fact that it is not operating completely in design conditions. We can conclude that significant opportunities are available for efficiency improvement. Naturally, some irreversibility cannot be avoided due to physical, technological, and economic constraints.



a) Exergy losses for the plants components b) Percent of exergy destruction

Fig. 3 Exergy and percent of exergy destruction

The Second law efficiency, *i.e.* the exergy efficiency of different components is also calculated and their comparison is depicted in Fig. 4.

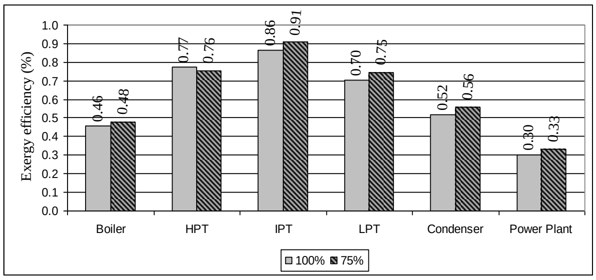


Fig. 4 Exergy efficiency

The exergy efficiencies of the turbine - HPT, IPT and LPT are 77.2%, 86.42% and 70.1%, respectively, for the maximum load regime, and 75.5%, 90.9% and 74.5% for the regime with 75% of the maximum load. The calculated exergy efficiency of the boiler and the condenser are 45.8% and 51.7%, respectively, for the maximum load, and 47.6% and 56% for 75% of the maximum load. An exergy-flow diagram for the plants cycle, based on the obtained results is shown in fig. 5, showing the sites of exergy efficiencies and dominant contributors to exergy destruction and losses, as well as conserved and non conserved parts of the exergy flow through the plants cycle.

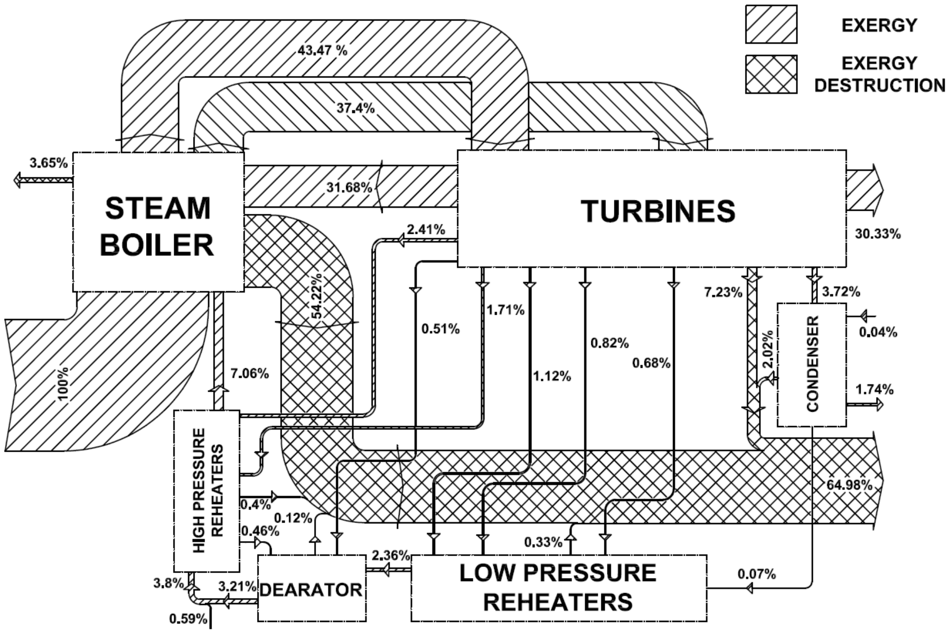


Fig. 5 Exergy and exergy destruction flow diagram for the maximum load operating regime of the plant

The exergy analysis of the plant pinpoints that the prospective improvement in the boiler can improve the overall plant efficiency. It is obvious that the major concerns in the terms of energy losses and exergy destruction are the condenser and the boilre, respectfully. Since reconstruction of the boiler for further overall efficiency improvement would be dificult, expensive, and possibly not even feasible, it has come to our attention that further improvements should be investigated in the direction of integration with another process.

The overall energy efficiency and exergy efficiency can range around 30÷40%, respectively, for the thermal power plant (Sengupta *et al.* [12], Rosen and Dincer [20] and Mitrović *et al.* [21]), which concurs with the results obtained for the power plant Kolubara – block A5.

5. CONCLUSION

This paper explains the methodology for energy and exergy evaluation in a power plant cycle. We conclude that energy and exergy analysis are useful for understanding the performance of a power plant. Energy analysis shows the locations in the plants cycle where most energy is lost to the environment. Exergy analysis reveals the locations in the plants cycle with greatest process irreversibility, providing the information about the quality of energy conversion. Hence, exergy analysis pinpoints the possibilities for improvement, with a restraint that some irreversibility is inevitable as implied by the Second law of thermodynamics.

Energy and exergy analysis of a coal fired power plant Kolubara - A5 in Serbia, presented in this study, analyzes system components separately in order to identify and quantify the sites having the largest energy losses and exergy destruction at different loads. Analysis of the plant based only on the First law of thermodynamics reports greatest energy losses in the condenser. However the conclusions deducted just by the First law analysis, *i.e*. energy analysis, cannot be used to pinpoint prospective areas for improving the efficiency of the power generation, since it does not reveal the information about the quality of the lost energy. Fortunately, the Second law analysis serves to identify the irreversibility in the power plant, revealing the information about energy quality for power production. The exergy analysis of the plant shows that the energy loss in the condenser is thermodynamically insignificant due to its low quality, and that the greatest process iriversibility and possibility for efficiency improvement is found in the boiler. Nevertheless, some irreversibilities are inevitable and can not be avoided due to physical, technological and economic constraints.

Exergy analysis based operation and maintenance decision-making in steam turbine cycle systems proved more effective. Power plant equipment involve a high density of exergy transfer, thus rising the importantance of bringing exergy destruction in such devices to a minimum possible level. Exergy-based approach of performance monitoring in operating power plants helps in better management of both energy resources and the environment.

REFERENCES

1. Lior, N., (2002): *Thoughts About Future Power Generation Systems and the Role of Exergy Analysis in Their Development*, Energy Conversion and Management, Vol. 43, pp. 1187–1198.
2. Ertesvag, I., (2001): *Society exergy analysis: a comparison of different societies*, Energy, Vol 26, pp. 253–270.
3. Bejan, A., (2002): *Fundamentals of exergy analysis, entropy generation minimization, and the generation of flow architecture*, International Journal of Energy Research, Vol. 26, pp. 545-565.
4. Koroneos, C., Spachos, T., Moussiopoulos N., (2003): *Exergy Analysis of Renewable Energy Sources*, Renewable Energy, Vol 28, pp. 295–310.
5. Sharma, M., Praveen, V., (2001): *Identification and Quantification Of Environmental Issues Of Aging Coal-Based Power Plant - Case Study*, Journal of Energy Engineering, Vol. 127, pp. 59-73.
6. Verkhivker, G., Kosoy, B., (2001): *On the Exergy Analysis of Power Plants, Energy conversion and management*, Vol. 42, pp. 2053-2059.
7. Rosen, M., (2001): *Energy and Exergy-based Comparison of Coal-fired and Nuclear Steam Power Plants*, Exergy, Vol. 3, pp. 180–192.
8. Habib, M., Zubair S., (1992): *2^{nd}-law-based Thermodynamic Analysis of Regenerative-reheat Rankine-cycle Power Plants*, Energy, Vol. 17, pp. 295-301.
9. Dincer, I., Muslim, H., (2001): *Thermodynamic analysis of reheat cycle steam power plants*, International Journal of Energy Research, Vol. 25, pp. 727–739.

10. Cihan, A., Hacihafizoglu O., Kahveci K., (2006): *Energy–exergy analysis and modernization suggestions for a combinedcycle power plant*, International Journal of Energy Research, Vol. 30, pp. 115–126.
11. Ameri, M., Ahmadi, P., Khanmohammadi, S., (2008): *Exergy analysis of a 420 MW combined cycle power plant*, Short communication, International Journal of Energy Research, Vol. 32, pp. 175-183.
12. Sengupta, S., Datta, A., Duttagupta, S., (2007): *Exergy Analysis of a Coal-based 210 MW Thermal Power Plant*, International Journal Of Energy Research, Vol. 31, pp. 14–28.
13. Habib M., Said S., Al-Bagawi J., (1995): *Thermodynamic Performance Analysis Of The Ghazlan Power Plant*, Energy, Vol. 20, pp. 1121-1130.
14. Kanoglu, M., (2002): Exergy *Analysis of a Dual-level Binary Geothermal Power Plant*, Geothermics, Vol. 31, pp. 709–724.
15. Bejan, A., Tsatsaronis, G., Moran, M., (1996): *Thermal Design and Optimization*, John Wiley and Sons, Inc., New York.
16. 16. Zaleta-Aguilar, A., Correas-Uson, L., Kubiak-Szyszka, J., Sierra-Espinosa, F., (2007): *Concept on Thermoeconomic Evaluation of Steam Turbines*, Applied Thermal Engineering, Vol. 27, pp. 457-466.
17. Bresolin, C., Schneider P., Vielmo H. and França F., (2006): *Application of steam turbines simulation models in power generation systems***,** Engenharia Térmica (Thermal Engineering), Vol. 5, pp. 73-77.
18. Spenser, R., Cotton, K., Cannon, C., (1963): *A Method for Predicting the Performance of Steam Turbine Generators 16500 kW and Larger*, Journal of Engineering for Power, Seria A, Vol. 85, pp. 249-301.
19. Uche, J., (2000): *Thermoeconomic Analysis and Simulation of a Combined Power and Desalination Plant*, Ph. D. Thesis, Departamento de Ingeniería Mecánica Universidad de Zaragoza.
20. Rosen, M., Dincer, I., (2003): *Thermoeconomic Analysis of Power Plants: an Application to a Coal Fired Electrical Generating Station*, Energy Conversion and Management, Vol. 44, pp. 2743-2761.
21. Mitrović, D., Živković, D., Laković M., (2010): *Energy and Exergy Analysis of a 348.5 MW Steam Power Plant*, Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, Vol. 32, pp. 1016 – 1027.

ENERGETSKA I EKSERGETSKA ANALIZA TERMOELEKTRANE NA FOSILNA GORIVA

Globalni rastući trend potražnje energije, praćen zavisnošću od fosilnih goriva i njihovim uticajem na životnu sredinu, izaziva stalan interes za anlizu efikasnosti opreme i reviziju postojećih energetskih postrojenja. Ovaj rad je fokusiran na termodinamičku analizu termoelektrane na ugalj "Kolubara – blok A5", uzimajući u obzir koncept energetskih gubitaka, produkcije entropije i destrukcije eksergije. Najznačajniji energetski gubici javljaju se u kondenzatoru, gde se energija predaje okolini, dok se destrukcija eksergije najvećim delom dešava u kotlu. Rezultati energetskog i eksergetskog učinka elektrane sračunati su za radne režime pri maksimalnom opterećenju i pri 75% od maksimalnog opterećenja. Svaka komponenta sistema je modelirana kao "crna kutija", dok su energetski i eksergetski bilansi određeni na osnovu radnih parametara postrojenja. Energetska efikasnost energetskog ciklusa, sračunata na osnovu specifične količine toplote dovedene pari, iznosi 32,1% i 33,1%, dok je eksergetska efikasnost 30% i 33%, u zavisnosti od radnog režima.

Ključne reči: *termoelektrana, energija, eksergija, efikasnost*