Energy and Exergy Analysis of Steam Power Plant 3rd Unit PT PLN (PERSERO) Centre Unit Generation Tanjung Jati B Use BFP-T Modification Cycle

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Abstract. Steam power plant Generation of Tanjung Jati B 3rd unit has a capacity of 660 MW. The power plant operational in 2011, because of the long operation process, there will be a decrease in performance. The plant needs to be researched to analyze the performance and losses that occurs in the power plant. Because this also affects the environment if the efficiency of the power plant is high, it can reduce the use of coal. Because coal becomes air pollution and environmental pollution, which can cause acid rain, water pollution, and global warming. This research is used to analyze energy and exergy on the components of a steam power plant. From the results of this research, the largest of destruction exergy boiler is 881.08 MW and the exergetic efficiency is 48.66%. While the rate of the smallest destruction exergy in LPH 3 is 0.6 MW and the exergetic efficiency is 94.45%. The contribution of the largest Losses energy in the boiler is 231 MW and energetic efficiency is 87.05%. While the contribution of the smallest energy Losses in HPH 6 is 0.74 MW and energetic efficiency is 99.23%.

Keywords: Power plant; energy; exergy; exergy destruction; coal; pollution.

1 Introduction

Energy is used to support human life, one of them is electrical energy. Given how the vital benefits of electric power, so power plant infrastructure is vital in Indonesia. Therefore, technological advancements also support higher efficiency improvements. One of the electricity producers is the Steam Power Plant (PLTU) which is a thermal power center that is widely used because of its good efficiency to produce electricity that is safe for the environment. The basics that are required for the analysis of thermodynamic system in power plant is including the principles of the law of conservation of mass and of conservation energy, the second law of thermodynamics, and thermodynamic data [1]. We use the second law of thermodynamics to improve the performance of components of a steam power plant [2].

The method of energy analysis and exergy, which gives the conclusion that boilers are the main component of exergy destruction [3]. The entire power plant cycle is divided into three-cycle zones for exergy analysis of coalbased power plants [4]. Hasti et al. Have carried out exergy analysis on ultra-supercritical power plants to find exergy damage in each component of the power plant [5].

Therefore, it can be concluded that the exergy and energy analysis can provide a complete description of the characteristics of the power plant system [6-8]. Ganapathy et al. Have determined the energy losses and exergy losses of each component of the power plant [7]. Aljundi [9] showed the performance of a power plant by modeling a steam power plant in Jordan. Naterer et al. [10] Analyzed the coal-fired thermal power plant with measured boiler and turbine losses. Rosen [11] presented energy and exergy-based comparison of coal-fired and nuclear steam power plants. Oktay [12] presented exergy loss and proposed improving methods for a fluidized bed power plant in Turkey.

Based on the description and study of the literature that has been described that the energy and exergy analysis based on the first law and the second law of thermodynamics is used to identify the source of the inefficiency, determine the location and magnitude of the destruction exergy happen so that the power plant being optimal. On this research, analysis energy and exergy at the Steam power plant 3rd Unit PT PLN (Persero) Centre Unit Generation Tanjung Jati B to enhance the optimization of the power plant. This Results of research can be recommended to repair of a component. If the efficiency of a power plant is high, it can reduce the coals. Air pollution, water pollution and global warming much of that demand by coal. If we can reduce coal, the pollution on earth can be reduced.

2 Research Method

This study used calculations and analysis to obtain the results which are presented in graph plots and table. The

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overview scheme of Tanjung Jati B PLTU 3rd Unit is as follows in Fig. 1.



Fig. 1. Overview scheme of Tanjung Jati B PLTU 3rd Unit

2.1 Method of collecting data

This research was conducted by thermodynamic analysis on each component of a steam power plant. This system is simplified by using a volume control system by distinguishing between the inflow and outflow of components. The analysis was carried out to identify the level, type, and location of losses (exergy destruction) caused by incomplete combustion and friction, etc. Constant entropy applies to isentropic processes, so enthalpy when an isentropic state can be calculated by the following equation:

$$h_i = h_1 + \frac{s_i - s_1}{s_2 - s_1} (h_2 - h_1) \tag{1}$$

The enthalpy data, entropy, and mass flow rate at each point are used to calculate energy and exergy. To facilitate the conduct of research, a flowchart is arranged as shown in Fig. 2.

2.2 Equations of Mass Equilibrium

Calculation of the energy in the flow system is open, there are three types of energy transfer the entire control surface: transferring work, heat transfer and energy associated with the transfer of the masses. The first law is applied to the process flow in a steady flow system. In the circumstances of the steady-state, then fluid properties do

not depend on time so
$$\frac{dm_{CV}}{dt} = 0$$
 and $\frac{dE_{CV}}{dt} = 0$.

$$\sum \dot{m}_i = \sum \dot{m}_e \tag{2}$$

2.2.1 Energy Calculation Equations in Each Point

In this study carried out by calculating the amount of energy contained in each cycle in Fig. 2 to analyze energy. Multiples of the mass flow rate at a certain point and with the amount of enthalpy at a certain point is the amount of the energy value or formulated in the equation (3) as follows:

$$\mathbf{E}\mathbf{i} = \dot{\mathbf{m}}_i \mathbf{X} \mathbf{h}_i \tag{3}$$

Energy calculations for coal fuel can be formulated using equation (4) as follows:





Fig. 2. Research flow chart

2.2.2 Exergy Calculation Equations in Each Point

The exergy calculation equation at each point can be analyzed based on the type of liquid at a certain point. Open system or control volume is a system in which mass can flow through the limits of the system. An equation of balance exergy control volume equation is as follows:

$$E_{i} = \dot{m}_{i} \left[h_{i} - h_{0} - T_{0} (S_{i} - S_{0}) \right]$$
(5)

Open system or control volume is a system in which mass can flow through the limits of the system. An equation of balance exergy control volume equation is as follows:

$$\frac{dE_{CV}}{dt} = \sum_{j} \left(1 - \frac{T_o}{T_j} \right) d\dot{Q}_{j} - \left(\vec{W}_{CV} - p_0 \frac{dV_{CV}}{dt} \right) + \sum_{i} \vec{m}_{i} e_{i} - \sum_{e} \vec{m}_{e} e_{e} - \dot{E} D$$
(6)

Assumptions are used for the analysis of destruction exergy on the system control volume follow as equation (6):

- a) $\frac{dE_{CV}}{dt} = \frac{dV_{CV}}{dt}$, volume system in steady-state
- b) $\dot{Q} = W = 0$, heat losses and works is noting
- c) EP = EK = 0, potential energy and kinetic energy

are neglected.

So, the equation is as follows [2].

$$\dot{E}D = \sum \dot{m_i} e_i - \sum \dot{m_e} e_e \tag{7}$$

The equation of energetic efficiency is as follows [2].

$$\eta = \frac{\dot{E}_P}{\dot{E}_F} = 1 - \frac{\dot{E}_D}{\dot{E}_F} \tag{8}$$

2.3 Parameters Work Data

Parameters work data is used to exergetic and energetic analysis of the Steam power plant 3rd Unit PT PLN (Persero) Centre Unit Generation Tanjung Jati B is as follows in Table 1.

Stream Id	Mass Flow (kg/s)	Temperature (°C)	Pressure (bar)	Fluid Phase
1	607.26	529.80	166.92	Superheated Vapor
2	57.20	413.55	72.35	Superheated Vapor
3	550.06	328.27	40.31	Superheated Vapor
4	41.48	326.22	39.84	Superheated Vapor
5	508.58	328.27	40.31	Superheated Vapor
6	508.58	547.42	36.63	Superheated Vapor
7	33.16	467.41	19.98	Superheated Vapor
8	22.23	333.24	7.78	Superheated Vapor
9	58.53	333.24	7.78	Superheated Vapor
10	22.23	42.70	0.08	Saturated vapor
11	394.66	333.24	7.78	Superheated Vapor
12	16.67	199.00	1.11	Saturated Vapor
13	23.89	102.00	1.09	Saturated Vapor
14	10.15	63.10	0.23	Saturated Vapor
15	343.95	56.80		Saturated Vapor
16	416.89	41.62	0.07	Saturated Liquid
17	416.89	42.60	20.46	Compressed Liquid
18	416.89	59.70	0.20	Saturated Liquid
19	416.89	96.00	0.88	Saturated Liquid
20	416.89	119.60	7.41	Saturated Liquid
21	607.26	169.09	7.63	Compressed Liquid
22	5.70	173.24	204.87	Compressed Liquid
23	601.56	173.24	204.87	Compressed Liquid
24	601.56	214.52	20.86	Saturated Liquid
25	601.56	248.40	38.70	Saturated Liquid
26	601.56	286.99	188.06	Saturated Liquid
27	57.20	255.68	43.72	Saturated Liquid
28	98.67	219.27	22.87	Saturated Liquid
29	131.84	178.33	9,65	Saturated Liquid
30	16.67	102.10	1 09	Saturated Liquid
31	40.56	64.80	0.25	Saturated Liquid
32	50 71	47.20	0.11	Saturated Liquid
52	30.71	47.20	0.11	Saturated Liquid

Table 1. Data flow thermodynamic of the Steam power plant 3rd Unit PT PLN (Persero) Centre Unit Generation Tanjung Jati B

The results of analysis coal are as follow in Table 2, value *High Heating Value (HHV)* is a 24306.98 kJ/kg.

Table 2. Coal analysis of the Steam power plant 3rd Unit PT

 PLN (Persero) Centre Unit Generation Tanjung Jati B.

Parameters	Percentage of Parameters (%)
Carbon (ar)	60.08
Hydrogen (ar)	4.92
Nitrogen (ar)	1.11
Sulfur (ar)	0.55
Oxygen (ar)	11.82

A specific heat, mass flow, temperature at flue gas and air supply to the boiler is as follow in Table 3.

 Table 3. Specific heat and temperature of a flue gas and air supply to boiler.

Parameters Specific heat (kJ/kg)		Temperature (°C)	Mass flow (kg/s)	
Flue gas	1.32	148.15	563.06	
Air supply to boiler	1.01	351	563.06	

In condenser have cooling water flow to calculate a heat rejected. Specific of cooling water is as follow Table 4.

Table 4. Specific of cooling water.

Density (kg/m3)	Specific heat (kJ/kg)	Tempera ture inlet (°C)	Tempera ture outlet (°C)	Mass flow (m3/min)
994	4.178	29.93	41.62	920

3 Results and Discussion

The data used to analyze energy and exergy is from the performance 2017 of Steam power plant 3rd Unit. The analysis of energy and exergy is as follows:

3.1 Energetic and Exergetic Analysis

The energetic analysis is including energetic efficiency and energy losses. The results of exergy efficiency calculations, exergy efficiency, and exergy destruction. The energetic analysis uses data from the performance test in 2017. The results of energetic and exergetic analysis are as follow in Table 5. The exergy efficiency value of HPT, IPT, and LPT has a greater value than the value of energy efficiency, this is because the isentropic value of HPT, IPT, and LPT is greater than the exergy value of the fuel. The exergy efficiency value of BFPT has a greater value than the energy efficiency value, this is because the isentropic value of BFPT is greater than the exergy value of the fuel. The energy efficiency value of HPH 7, HPH 6, HPH 5, LPH 3, LPH 2, and LPH 1 has a greater value than the exergy efficiency value, this is due to the percentage comparison of product exergy and exergy fuel HPH 7, HPH 6, HPH 5, LPH 3, LPH 2, and LPH 1 are greater than the percentage of product energy value and inlet energy.

Table 5. Result of energetic and exergetic analysis in Steam powt 3rd Unit PT PLN (Persero) Centre Unit Generation Tanjung Jati B.

Component	Energetic power input (MW)	Energetic power input (MW)	Energetic power loss (MW)	Energetic efficiency (%)	Exergetic power input (MW)	Exergetic power input (MW)	Destruction exergy (MW)	Exergetic efficiency (%)
Boiler	1783.46	1552.46	166.92	87.05%	1716.25	835.17	881.08	48.66%
Condenser	890.07	744.40	72.35	83.63%	143.99	55.88	88.11	38.81%
HPH 7	118.82	117.70	1.11	99.06%	56.78	54.23	2.56	95.50%
HPH 6	96.70	95.96	0.74	99.23%	41.84	40.03	1.81	95.68%
HPH 5	105.76	104.77	0.99	99.06%	42.79	34.25	8.54	80.04%
LPH 3	39.41	37.19	2.22	94.37%	10.80	10.21	0.60	94.45%
LPH 2	60.12	56.73	3.39	94.37%	12.08	9.54	2.53	79.02%
LPH 1	27.51	25.96	1.55	94.37%	3.05	1.55	1.49	50.93%
Deaeretor	492.01	432.70	59.31	87.95%	93.45	68.54	24.91	73.34%

In each components use energetic analysis based of isentropic calculation. Results of energetic analysis with isentropic calculation is as follow in Table 6.

Table 6. Result of isentropic analysis in Steam power plant 3rd Unit PT PLN (Persero) Centre Unit Generation Tanjung Jati B.

Component	Isentropic work (MW)	Actual work (MW)	Energetic power loss (MW)	Energetic efficiency (%)	Exergetic power input (MW)	Exergetic power input (MW)	Destructi on exergy (MW)	Exergetic efficiency (%)
НРТ	239.59	196.60	42.99	82.06%	215.08	196.60	18.49	91.41%
IPT	244.29	209.85	34.44	85.90%	223.98	209.85	14.13	93.69%
LPT	311.73	201.79	109.94	64.73%	202.82	201.79	1.02	99.49%
BFPT	12.32	12.20	0.12	99.04%	17.76	12.20	5.56	68.70%
СЕР	0.48	1.35	0.48	35.52%	2.70	0.94	1.76	34.91%
BFP	29.41	42.68	29.41	68.92%	19.25	10.82	8.43	56.22%

3.2 Grassman Diagram

The results of the analysis of energetic and exergetic can be seen in Table 7. The Comparison with a research of Sairam and Kaushik [13] is presented that the boiler has the greatest destruction exergy 1196 MW. The results from Table 7 can be plotted into the Grassman diagram in Figure 3.

Table 7. Destruction exergy to plot in Grassman Diagram

Component	Destruction exergy (MW)	Percentage of destruction exergy (%)	
СЕР	1.76	0.10%	
BFP	8.43	0.49%	
LPH	4.63	0.27%	
BFPT	5.56	0.32%	
HPH	12.90	0.75%	
Deaeretor	24.91	1.45%	
Turbine	33.64	1.96%	
Condenser	88.11	5.13%	
Boiler	881.08	51.34%	
Net Power Output	655.24	38.18%	



Fig. 3. Steam power plant 3rd Unit PT PLN (Persero) Centre Unit Generation Tanjung Jati B.

3.3 Comparison of Energetic Efficiency and Exergetic Efficiency with other Study.

Comparison of energetic efficiency and energetic efficiency with other study is as follows in Table 8 Results of analysis of energetic and exergetic use to plot in Grassman diagram. The Comparison with a research of Sairam and Kaushik [13] is presented that the boiler has the greatest destruction exergy 1196 MW.

 Table 8. Destruction exergy to be plotted in the Grassman Diagram

Parameters	Efficiency (%)	Error (%)		
Energetic efficiency (%)				
Present study	39.72 %			
Reference of Performance				
test power plant Tanjung	39.81	0.24 %		
Jati B 3rd Unit				
Reference Sairam [13]	38.98	1.9 %		
Exergetic efficiency (%)				
Present study	38.18 %			
Reference Seytomer power plant <u>[3]</u>	37.88 %	0.79 %		
Reference Soma power plant <u>[3]</u>	37.36 %	2.19 %		

4 Conclusion

The conclusions obtained from the results of energy and exergy analysis according to the research objectives are: Steam power plant 3rd Unit PT PLN (Persero) Centre Unit Generation Tanjung Jati B is a thermal power plant with coal fuel, to utilizing the working fluid to rotate a turbine. A steam power plant of Tanjung Jati B 3rd Unit has a capacity of 660 MW and operational in 2011. The first laws and the second laws of thermodynamics used to analyze of exergetic and energetic. The results of the research contributions of the greatest exergy destruction in a boiler with value 569.31 MW and the exergy efficiency of boiler 79.1%. while the rate of exergy destruction of the smallest in LPH 3 with value 0.6 MW and the exergy efficiencies of LPH 3 94.45%. While the largest contribution of the energy Losses in the boiler with value 231 MW and the energy efficiency of boiler 87.5%, while the smallest contribution of the energy Losses in the HPH with value 0.74 6 MW and energy efficiency 99.23%.

5 Nomenclature

m_n	Mass flow in point n (kg//s)
h_n	Enthalpy in point <i>n</i> (kJ/kg)
S_n	Entropy in point <i>n</i> (kj/kgK)
Ε	A rate of exergy (kJ/s)
$\eta_{{\scriptscriptstyle II}}$	Exergetic efficiency
EL	Energy losses (kJ/s)
IIIII/	TT (1) (1) (1) (1) (1) (1) (1) (1) (1) (1)

HHV Heat heating value (kJ/kg)

- h_{ns} Enthalpy of insentropic in point *n* (kJ/kg)
- T_n Temperature of n (K)
- $E_D^{(k)}$ Exergetic destruction (kJ/s)
- S_{gen} Entropy generation (kJ/kgK)
- η Energetic efficiency

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