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Analysis of the Performance of Extraction-Condensing Turbine Unit 1 at Bablean Power Plant

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Abstract

Purpose: This study aims to evaluate the performance of the steam turbine unit at Bablean Coal-Fired Power Plant or *Pembangkit Listrik Tenaga Uap (PLTU) Bablean*, analyzing its output power, heat rate, and turbine efficiency compared to the design specifications.
Research Methodology: The performance test was conducted following the ASME PTC 6 standard, with parameters including capability tests, heat rate calculations, and turbine efficiency assessments. Data was collected weekly from May to August 2020, during the base-load operation of the steam turbine.
Results: The results show that the output power, heat rate, and turbine efficiency during the actual data collection were within the tolerance limits set by ASME PTC 6. The actual turbine efficiency was higher than the design specification, largely due to a lower turbine exhaust pressure.
Conclusions: The performance test revealed that the steam turbine at Bablean coal-fired power plant is operating within acceptable limits, and maintaining low turbine exhaust pressure is crucial to optimizing turbine efficiency.
Limitations: The study focused on the performance testing of the turbine unit during base-load conditions and may not reflect performance under varying operational loads.
Contributions: This research provides valuable insights into the optimization of turbine performance and offers recommendations for improving efficiency through maintenance practices, particularly concerning turbine exhaust pressure.

Keywords: *ASME PTC 6, Coal-Fired Power Plant, Exhaust Pressure, Extraction-Condensing Turbine, Heat Rate*

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1. Introduction

The efficiency and reliability of power plants are essential factors in ensuring sustainable and continuous electricity generation. These aspects are closely related to fuel consumption and the decreasing availability of primary energy resources, particularly fossil fuels such as coal. Improving efficiency not only reduces operational costs but also minimizes environmental impacts caused by excessive fuel usage (Junior et al., 2017; Lisin et al., 2018). In addition, maintaining high reliability ensures that all equipment operates optimally, thereby reducing the risk of unexpected failures and unplanned shutdowns (Lin et al., 2020).

A reliable power plant system must be supported by proper operation and maintenance strategies. This includes precise and timely maintenance activities to ensure that each component performs according to its design specifications. With effective maintenance, power generation units can continue operating efficiently while maintaining the stability of the electrical system (Nikolaidis & Poullikkas, 2017). Therefore, performance evaluation becomes a critical activity to monitor the condition of the equipment and detect early signs of degradation.

PLTU XX is a coal-fired power plant with a capacity of 1 × 25 MW, which plays an important role in maintaining the stability of electricity supply, particularly on Lombok Island. As electricity demand continues to grow, the performance of power plants must be maintained at optimal levels (Ali et al., 2020; Hayat et al., 2019). However, in *PLTU* Jeranjang Unit 3, several operating parameters have shown a decline over time. This degradation has contributed to a decrease in generator efficiency, which can significantly affect the overall performance of the plant.

One of the key indicators used to evaluate the efficiency of a power plant is the plant heat rate. The plant heat rate represents the amount of energy required to produce one kilowatt-hour (kWh) of electricity, typically expressed in kJ/kWh or kcal/kWh. This parameter is influenced by several factors, including turbine heat rate and boiler efficiency. A lower plant heat rate indicates a more efficient generating unit, as less fuel is required to produce the same amount of electrical energy (Ahmadi et al., 2018, 2019; Gambini & Vellini, 2019).

The calculation and analysis of plant heat rate are essential for identifying performance degradation in power generation systems. Through this analysis, it is possible to determine the extent of efficiency losses and identify the root causes of such degradation (Kumar, Gupta, et al., 2019; Lavrik et al., 2018). Furthermore, the results can be used to develop appropriate recommendations and mitigation strategies, particularly during periodic maintenance activities (Triki-Lahiani et al., 2018). These efforts are expected to restore the plant's performance to conditions close to those achieved during the commissioning phase (Burnett & Kiesling, 2019; Fathi et al., 2018; Haseli, 2018).

Based on these conditions, the main problems identified in this study include the actual value of the *PLTU* plant heat rate before periodic maintenance, the factors contributing to the increase in heat rate, and the necessary steps to reduce the heat rate so that it approaches the values obtained during commissioning tests.

This study aims to analyze the actual heat rate of a coal-fired power plant (*PLTU*) and compare it with the heat rate during the commissioning phase using the heat loss method. The findings of this study are expected to provide practical recommendations for improving plant performance. Ultimately, it is hoped that the implementation of these recommendations will reduce the plant heat rate and restore the generating unit's efficiency to near its optimal condition at the time of commissioning.

2. Literature Review

2.1 Steam Power Generation System

A coal-fired power plant (*PLTU*) is a power plant that converts the kinetic energy of steam into electrical energy. This process occurs through three main stages:

1. The chemical energy in the fuel is converted into heat energy in the form of steam at high pressure and temperature (Carrillo et al., 2019).
2. The heat energy (steam) is converted into mechanical energy through turbine rotation (Kareem et al., 2018).
3. The mechanical energy is converted into electrical energy by a generator (Kumar, Singh, & Khare, 2019).

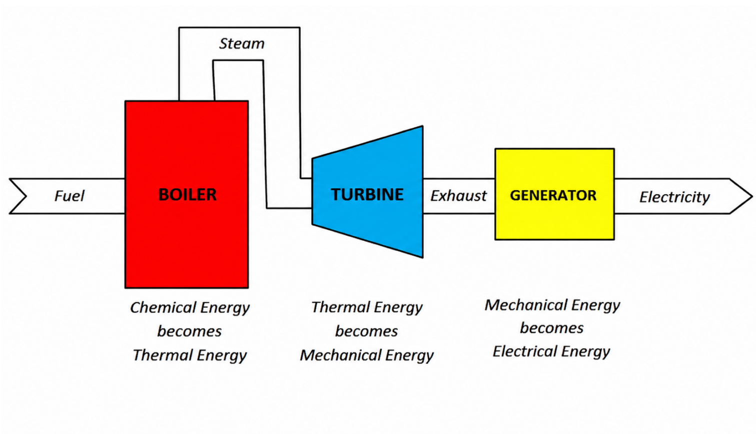

Figure 1. *PLTU* Energy Conversion
Source: Suralaya PLTU

Based on Figure 1, the diagram illustrates the energy conversion process in a coal-fired power plant. It starts with fuel, which is converted into thermal energy in the boiler. The thermal energy then drives the turbine, where it is transformed into mechanical energy. Finally, the mechanical energy is converted into electrical energy by the generator, producing electricity.

2.2 Working Principle of Coal-Fired Power Plant

The Rankine cycle is widely used in thermal power plants that use steam to drive the turbines. A Rankine cycle power plant has four main components: a boiler, turbine, condenser, and pump (Huang et al., 2018; Njoku et al., 2018; Rajesh & Kishore, 2018; Salgado et al., 2017).

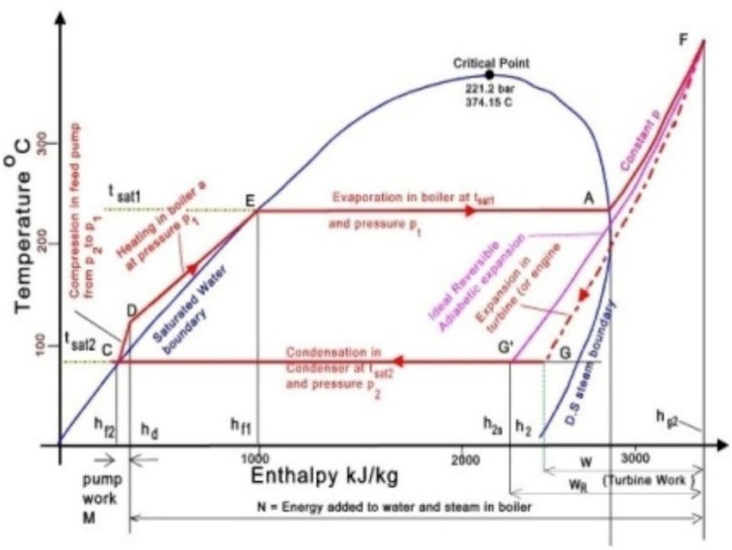

Figure 2. TS Diagram of the Rangkine Cycle
Source: http://artikel-teknologi.com/siklus-rankine/

In the Rankine cycle, water undergoes four processes as shown in Figure 2

1. CD process: This process is called the isentropic compression process because when it is pumped ideally, no entropy change occurs.

2. DF process: High-pressure water enters the boiler to undergo a heating process. isobaric (constant pressure).
3. FG Process: This process occurs in a steam turbine. Dry steam from the boiler enters the turbine and undergoes isentropic expansion.
4. GC Process: Water vapor that comes out of the steam turbine enters the condenser and undergoes condensation. isobaric.

2.3 *Main Equipment at PLTU*

The main equipment at the *PLTU* includes (Nuraini et al., 2020; Reddy et al., 2017; Tumanovskii et al., 2017):

1. Boiler
   A boiler is a piece of equipment used to convert the energy contained in fuel to produce high-pressure and high-temperature superheated steam.
2. Air Heater
   Air heaters are used to heat combustion air by utilizing the exhaust gas flow from the combustion in the boiler.
3. Turbine
   A steam turbine is a component of a *PLTU* that converts the thermal energy obtained from the boiler into electrical energy.
4. Condenser
   The condenser is a heat exchanger that condenses the steam leaving the turbine until it changes back to water. The cooling water of the condenser uses seawater for circulation.

2.4 *Plant Heat Rate*

The plant heat rate is the amount of energy required by a power plant to produce 1 kWh of electricity. The plant heat rate is a measure of the efficiency of generating units. A lower plant heat rate indicates a more efficient unit than a higher one. Furthermore, the plant heat rate can reflect the condition of the generating unit (Marty et al., 2017).

2.5 *Plant Heat Rate Calculation Based on Ptc - 4 & 6*

Energy Balance Method

Calculations using this method require more data, resulting in a greater number of measurements being required. The energy balance method used is in accordance with the American Society of Mechanical Engineers Performance Test Code (ASME PTC) 4 concerns fired steam generators, and ASME PTC 6 concerns steam turbines (Freitas, 2020; Le Galudec, 2017). The plant heat rate was calculated using the energy balance method as follows:

$$\text{Gross Plant Heat Rate} = \frac{\text{THR}}{\text{Boiler Efficiency}} \times 100 \quad (\text{kJ/kWh}) \tag{1}$$

$$\text{Net Plant Heat Rate} = \frac{\text{Gross Plant Heat Rate} \times \text{Generator Power Output}}{\text{Delivered Power}} \quad (\text{kJ/kWh}) \tag{2}$$

Where:

- THR: Turbine heat rate (kJ/kWh)

- Boiler Efficiency: in percentage (%)
- Turbine Heat Rate (THR)

Turbine heat rate is the energy required by the turbine, which is obtained from the heat transfer process to produce 1 kWh electricity (Samarasinghe et al., 2019).

$$\text{Turbine Heat Rate} = \frac{\text{Heat in} - \text{Heat out}}{\text{Generator Power Output}} \quad (\text{kJ/kWh}) \tag{3}$$

Where:

- Heat in: The heat energy entering the turbine (kJ/hr)
- Heat out: The heat energy leaving the turbine (kJ/hr)

2.5.1 Heat In

Heat in is the energy that enters the turbine boundary system (Maravilla Herrera et al., 2017). The heat in the turbine is the energy in the main steam.

$$\text{Heat in} = Q_{ms} \quad (\text{kJ/hr})$$
$$Q_{ms} = M_s \times H_s \quad (\text{kJ/hr})$$

Where:

$Q_m s$ = Energy in primary steam (kJ/h)

M_s = Mass flow rate of main steam   kg/hr

H_s = Enthalpy of main steam   kJ/kg

$$M_s = M_{fw} + M_{is} \quad (\text{kg/hr})$$

Where: M_s = Mass flow rate of main steam   kg/hr

$M_f w$ = Mass flow rate of final feed water   kg/hr

$M_i s$ = Mass flow rate of superheater spray water   kg/hr

2.5.2 Heat Out

Heat out is the total energy leaving the turbine's boundary system. Heat out in the turbine includes energy in the final feed water and superheater spray water.

$$\text{Heat out} = Q_{fw} \quad (\text{kJ/hr})$$
$$\text{Heat out} = (M_{fw} \times H_f) \quad (\text{kJ/hr})$$

Where:

$M_f w$ = Feed water flowkg/hr

H_f = Enthalpy value   kJ/kg

Boiler Efficiency

Boiler efficiency is defined as the ratio of output to input in a process.

a. Heat Loss Due to Dry Gas Losses, with Eq:

$$\text{QpLDfg} = \frac{\text{HDFglvCr x MFrDFg}}{H_f} \times 100 \quad (\%)$$

Where:

$HDFgLvCr$ = Enthalpy of temperature outlet of flue gas kJ/kg

$MFrDFg$ = Dry gas mass flow kg/kg-fue

Hf = High heating value batubara (kJ/kg)

b. Heat Loss Due to H_2O Content in Fuel, calculated from:

$$\text{QpLWF} = \frac{MFrWFx(HstLvCr - Hw)}{H_f} \times 100\%$$

Where:

$MFrWF$ = Moisture content of coal (kg/kg-fuel

H_sLvC = Enthalpy steam at AH outlet temperature excluding leakage (kJ/kg)

H_w = Enthalpy of water vapor at reference temperature (kJ/kg)

H_f = High heating value of coal (kJ/kg)

c. Heat Loss due to the Evaporation of Hydrogen

$$\text{QpLH2F} = \frac{MFrWFx(HstLvCr - Hw)}{H_f} \times 100\%$$

Where:

$MFrWH2F$: Moisture content of hydrogen combustion (kg/kg fuel)

$HstLvCr$: Steam enthalpy at AH outlet temperature excluding leakage (kJ/kg)

Hw: Enthalpy of water vapor at reference temperature (kJ/kg)

Hf: High heating value of coal (kJ/kg)

d. Heat Losses due to Moisture in the Air

$$\text{QpLWA} = \frac{Q_{MFrWFx(HstLvCr-Hw)}}{100xH_f} \times 100\%$$

Where:

$MFrWA$: Moisture at AH inlet wet air (kJ/kg)

$HWvLvCr$: Enthalphy water vapor at AH outlet gas exclude leakage (kJ/kg)

Hf : High heating value of coal (kJ/kg)

e. Heat Loss due to Unburned Carbon

$$\text{QpLUbC} = \frac{MpUbCx33700}{100xH_f} \times 100\%$$

Where: 33700: Calorific value of carbon in the residue (kJ/kg)

$MpUbC$: Unburned carbon during combustion (kg/kg-refuse)

Hf: High heating value of coal (kJ/kg)

f. Heat Loss due to Surface Radiation and Convection

$$Q_{rLsrc} = \frac{C1x(Hcaz + Hraz)xAfzxTdi}{3600x100xH_f} \times 100\%$$

$Hcaz = 0.35\ V_a^{0.8}$ (Btu/ft^2·h·°F)

$Hraz = 0.847 + 2.376 \times 10^{-3} T_{di} + 2.94 \times 10^{-6} T_{di}^2 + 1.37 \times 10^{-9} T_{di}^3$ (Btu/ft^2·h·°F)

Where:

C_1 = 0.293 (J/s)

H_{caz} = Convection heat transfer coefficient for area z (Btu/ft^2·h·°F)

H_{raz} = Radiation heat transfer coefficient for area z (Btu/ft^2·h·°F)

A_{fz} = Casing surface area for location z (ft^2)

T_{di} = Temperature difference between casing surface and ambient air (°F)

H_f = High heating value of coal (kJ/kg)

g. Heat Loss from Waste Heat

$$Q_{pLUn} = \text{Referring to the design}$$

h. Heat Losses Akibat Sensible Heat Of Residue

$$Q_{pLRs} = \frac{(xUcbxMFrRxHcba) + (xUcfxMFrRxHcfa)}{H_f} \times 100\%$$

Where:
$MFrR$: Mass of residue (kg/kg-fuel)
$xUcb$: Bottom ash split at design (%)
$Hcba$: Enthalpy of bottom ash at bottom ash temperature (kJ/kg)
$xUcf$: Fly ash split at design (%)
$Hcfa$: Enthalpy of fly ash at fly ash temperature (kJ/kg)
Hf: High heating value of coal (kJ/kg)

i. Heat Loss Due to the Content of CO in Coal

$$Q_{pLCO} = \frac{DVpCO \times MoDFg \times MwCO \times HHVCO}{H_f} \times 100\%$$

Where:

$DVpCO$ = Density of CO in flue gas (%)

M_CO = Molecular weight of CO = 28.01 (kg/mol)

H_HVCO = High heating value of CO, 10111 (kJ/kg)

H_f = High heating value of coal (kJ/kg)

j. Heat Loss Due to the Content of NO in Coal

$$Q_{pLN0x} = \text{DVpNOx MoDFg}\frac{HrNOX}{H_f}100\%$$

$$MoDFg = \text{MoDPc MoThACr}(0.7905 + \frac{XpA}{100})100\%$$

Where:

$DvpNOx$ = NO mass from flue gas emission

$MoDFg$ = Moles of dry gas with excess air measured at the same location (moles/kg fuel)

$HrNOx$ = Heat of formation of NO = 89950 (kJ/g mol)

H_f = High heating value of coal (kJ/kg)l

2.5.3 6. Heat Credit

a. Credit from Air Inlet to Boiler

$$Q_{pBDA} = \frac{MFrWA \times HWv}{H_f} \times 100\%$$

Where: $MFrDA$: Amount of air entering the boiler (kg/kg-fuel)

HDA: Enthalpy of dry air at AH inlet air (kJ/kg)

Hf: High heating value of coal (kJ/kg)

b. Credit from Water Moisture in the Air

$$Q_{pBWA} = \frac{MFrWA \times HWv}{H_f} \times 100\%$$

Where:

$MFrWA$: Moisture at AH inlet wet air (kJ/kg)

HWv : Enthalpy of dry vapor at AH inlet air (kJ/kg)

Hf : High heating value of coal (kJ/kg)

c. Credit from Sensible Heat in the Coal

$$Q_{pBF} = \frac{Hdb}{H_f} \times 100\%$$

Where:

Hdb: Enthalpy of dry air fuel at boiler inlet temperature (kJ/kg)

Hf: High heating value of coal (kJ/kg)

In calculating boiler efficiency using the heat loss method, the input energy can be written as:

EF = 100 SmQpL + SmQpB, (%)

$SmQpl$ = QpLDFg + QpLWF + QpLH2F + QpLWA + QpLUbC + QrLSrc + QpLUn + QpLRs

$SmQpB$ = QpBDA + QpBWA + QpBF, (%)

Where:

$SmQpL$: Total losses calculated based on fuel input (%)

$SmQpB$: Total credits calculated based on fuel input (%)

3. Methodology

Research methodology refers to the stages of research that must be established before problem-solving can be undertaken. This allows for focused research and facilitates the analysis of problems (Kapur, 2018). The following flowchart of the research method used is shown in Figure 3.

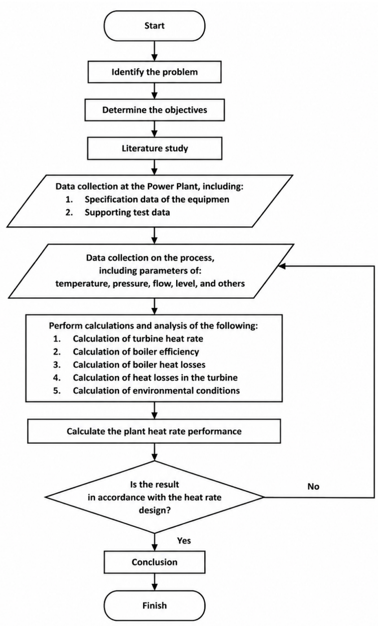

Figure 3. Research Flowchart

Based on Figure 3, the flowchart illustrates the step-by-step process of calculating the plant heat rate performance. It starts with identifying the problem and determining the objectives, followed by a literature study. Data collection at the power plant is then conducted, including specification data of the equipment and supporting test data. This is followed by the collection of process data such as temperature, pressure, flow, and other parameters. The next step involves performing calculations and analyses, including turbine heat rate, boiler efficiency, boiler heat losses, heat losses in the turbine, and environmental conditions. After these analyses, the plant heat rate performance is calculated. Finally, the results are checked against the heat rate design, and if they align, the process concludes with a summary. If not, further adjustments are made before concluding.

3.1 Data Collection Procedure

The required parameters were measured using data from the initial design of the steam turbine. These data were used as comparative data to test the actual performance of the steam turbine (Medica-Viola et al., 2020). After the design data are processed using the equations discussed in the previous section, the next step is to consider several parameters that will be used for data processing. Data is taken every 1 week for 4 hours, namely in the third week of May 2020 until August 2020 in accordance with the minimum data collection from ASME PTC 6. In addition, data collection was performed when the system was in the base-load state.

The base load is the condition in which the steam turbine produces the maximum electrical output. This was done to ensure that the data processing results had consistent values under the same conditions, ensuring consistent results.

3.2 Data Specifications and Calculations

The data explained in this chapter are the data resulting from the commissioning of Babelan, Bekasi PLTU, and actual data. based on the monitoring and measurement results.

3.2.1 Heat Rate

By taking one of the research samples, the calculation is carried out as follows:

$$m_{in} = 134\,\text{kg/s}$$
$$h_{in} = 3450.5\,\text{kJ/s}$$
$$m_{fw} = 130.304\,\text{kg/s}$$
$$h_{fw} = 924.4\,\text{kJ/s}$$
$$m_{blow} = 0.33\,\text{kg/s}$$
$$h_{blow} = 2662.9\,\text{kJ/s}$$
$$m_{desu} = 4.021\,\text{kg/s}$$
$$h_{desu} = 722.3\,\text{kJ/s}$$

The heat rate is calculated as follows:

$$HR = \frac{Q}{P_{\text{generator}}} \times 3600$$

$$Q = (m_{in} \times h_{in}) - (m_{fw} \times h_{fw}) - (m_{blow} \times h_{blow}) - (m_{desu} \times h_{desu})$$

$$HR = \frac{(134 \times 3450.5) - (130.304 \times 924.4) - (0.33 \times 2662.9) - (4.021 \times 722.3}{138000} \times 3600 = 8865 \frac{kJ}{kWh}$$

3.2.2 Turbine Efficiency

Variable	Value
m_{in}	134 kg/s
T_{in}	540°C
P_{in}	125 Bar
h_{in}	3450.5 kJ/kg
m_{fw}	130.304 kg/s
h_{fw}	924.4 kJ/kg
m_{blow}	0.33 kg/s
h_{blow}	2662.9 kJ/kg
m_{desu}	4.021 kg/s
h_{desu}	722.3 kJ/kg
T_{ex1}	30.5°C
P_{ex1}	22.41 Bar
h_{ex1}	3025.4 kJ/kg
m_{ex2}	5.61 kg/s
T_{ex2}	56.1°C
P_{ex2}	249.9°C
h_{ex2}	927.83 kJ/kg
m_{ex3}	8.32 kg/s
T_{ex3}	18.3°C
P_{ex3}	7.41 Bar
h_{ex3}	2805.6 kJ/kg
m_{ex4}	8.7 kg/s
T_{ex4}	134°C
P_{ex4}	3.04 Bar
h_{ex4}	2725.55 kJ/kg
m_{ex5}	6.93 kg/s
T_{ex5}	92.6°C
P_{ex5}	0.77 Bar
h_{ex5}	2663.81 kJ/kg
P_{out}	0.15 Bar
T_{out}	54.5°C
h_{out}	2382.5164 kJ/kg

To obtain the value of the isentropic enthalpy, we use the Mollier diagram or steam table to plot the steam quality (x) against the exhaust pressure (P_{out}):

$$X = 0.83, H_{\text{Hisent}} = 2194.99\,\text{kJ/kg}$$

$$\eta_T = \frac{W_{\text{total actual}}}{W_{\text{total isentropic}}} \times 100\%$$

WTeks1 = min(hin - heks1)
WTeks2 = (min - meks1). (heks1 - heks2)
WTeks3 = (min - meks1 - meks2). (heks2 - heks3)
WTeks4 = (min - meks1 - meks2 - meks3). (heks3 - heks4)
WTeks5 = (min - meks1 - meks2 - meks3 - meks4). (heks4 - heks5)
WTeks6 = (min - meks1 - meks2 - meks3 - meks4 - meks5). (heks5 - hout)
WTisent = (min - meks1 - meks2 - meks3 - meks4 - meks5). (heks5 - hisent)

WTeks 1 = 134. (3450.5 - 3025.4) = 56963.4 kW
WTeks 2 = (134 - 6.14). (3025.4 - 2927.83) = 12475.3 kW
WTeks 3 = (134 - 6.14 - 5.61). (2927.83 - 2805.6) = 14942.62 kW
WTeks 4 = (134 - 6.14 - 5.61 - 8.32). (2805.6 - 2725.55) = 9210.1 kW
WTeks 5 = (134 - 6.14 - 5.61 - 8.32 - 8.7). (2725.55 - 2663.81) = 6496.9 kW
WTeks 6 = (134 - 6.14 - 5.61 - 8.32 - 8.7 - 6.93). (2663.81 - 2382.516) = 27651.16 kW
Wisent = (134 - 6.14 - 5.61 - 8.32 - 8.7 - 6.93). (2663.81 - 2194.99) = 46085.006 kW

Find the actual total steam turbine power Actual total WT = WText1 + WText2 + WText3 + WText4 + WText5 + WText6
Actual total WT = 56963.4 + 12475.3 + 14942.62 + 9120.1 + 6496.9 + 27651.16
Actual total WT = 127649.48 kW

Find the total power of an isentropic steam turbine WTtotal isent = WText1 + WText2 + WText3 + WTex4 + WText5 + Wisent
WTtotal isent = 56963.4 + 12475.3 + 14942.62 + 9120.1 + 6496.9 + 46085.006
WTtotal isentropic = 146083.326 kW

$$\eta_T = \frac{W_{T,\text{total actual}}}{W_{T,\text{total isentropic}}} \times 100\% = \frac{127649.48}{146083.326} \times 100\% = 87.38\%$$

4. Results and Discussion

4.1 Comparison of Design Output Power, Commissioning Output Power and Actual Output Power

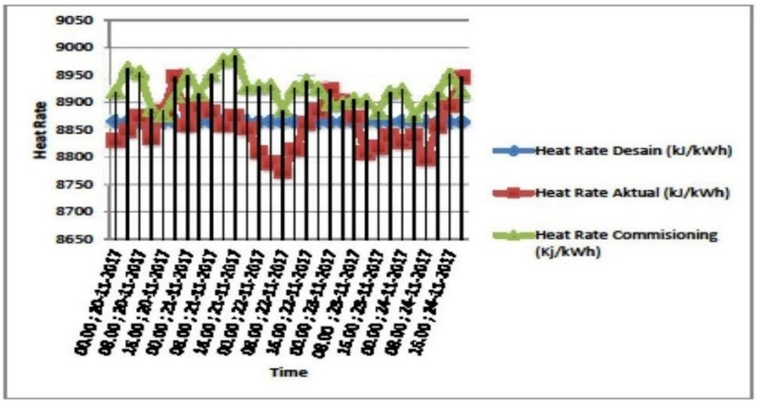

Figure 4. Output Power Comparison Graph

From Figure 4, it can be seen that the output power during commissioning is greater than the design output power and the actual data collection power. The design output power is 138,010 MW, while the output power at the time of commissioning is 139,295 MW or has a deviation of about 0.9% greater than the design data, and the output power at the time of actual data collection is 137,595 MW or has The deviation was 0.3% smaller than the design. The output power tolerance is given based on ASME PTC 6, which is 2%. Therefore, the output power at the time of commissioning and at the time of actual data collection was still within the given tolerance range. The output power at the time of commissioning is greater because during the performance test commissioning, the incoming steam energy is greater than the design data and at the time of actual data collection.

4.2 Comparison of Design Heat Rate, Actual Heat Rate, and Commissioning Heat Rate

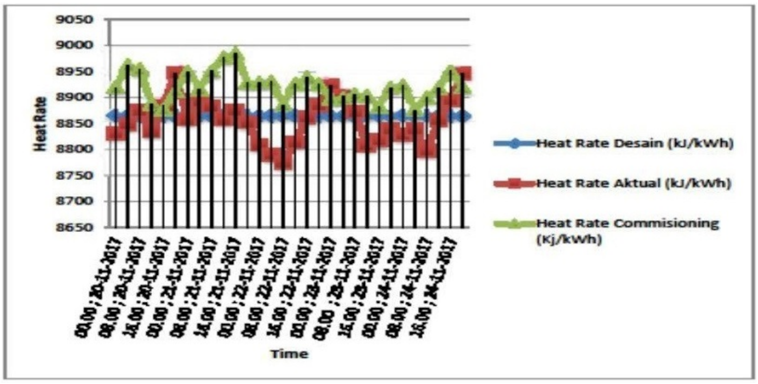

Figure 5. Heat Rate Comparison Graph

As shown in Figure 5, the heat rate during commissioning tends to be greater than the design heat rate and the heat rate during actual data collection. The design heat rate was 8865 kJ/kWh, whereas the commissioning heat rate was 8919 kJ/kWh, which deviated by 0.9% from the design heat rate. The heat rate during actual data collection was 8830 kJ/kWh, which had a deviation of 0.39% smaller than the design heat rate. The tolerance of the heat rate itself based on ASME PTC 6 was 2%. Therefore, the heat rate during commissioning and actual data collection was within the given tolerance range. The greater the heat rate value, the lower the turbine efficiency value, which causes the fuel consumption to heat water into steam to increase.

4.3 Comparison of Turbine Efficiency Design, Turbine Efficiency Commissioning, Actual Turbine Efficiency

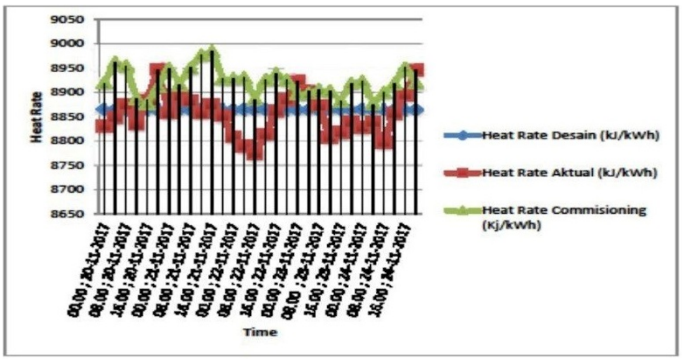

Figure 6. Turbine Efficiency Comparison Graph

From Figure 6, it can be seen that the actual turbine efficiency is greater than the turbine efficiency at commissioning and design turbine efficiency. The actual turbine efficiency was 88.21%. while the turbine efficiency at the time of commissioning was 87.1% and the design turbine efficiency was 87.38%. The actual turbine efficiency is greater because the exhaust pressure at the time of actual data collection is more vacuum than the design data during commissioning. The turbine efficiency is determined by the vacuum of the steam-turbine exhaust pressure. The data shows that the design exhaust pressure is 0.15 bar, while the commissioning exhaust pressure is 0.15 bar, and the actual data The exhaust pressure was 0.126 bar.

5. Conclusions

From the analysis and calculations that have been carried out on the condensing extraction turbine-type steam turbine, it can be concluded that:

1. The design output power was 138,010 MW, whereas the output power at the time of commissioning was 139,295 MW, and the actual output power was 137,595 MW. The tolerance of the output power based on ASME PTC 6 is 2% of the design data, so that both the commissioning output power and actual output power were still within the given tolerance.
2. The design turbine heat rate was 8865 kJ/kWh, whereas the turbine heat rate at the time of commissioning was 8919 kJ/kWh, and the actual turbine heat rate was 8831 kJ/kWh. The tolerance given based on ASME PTC 6 is 2%, so the turbine heat rate at the time of commissioning, and at the time of actual data collection, was still within the given range.
3. The design turbine efficiency was 87.38%, while the turbine efficiency at the time of actual data collection was 87.068%, and the turbine efficiency at the time of actual data collection was 88.65%. Turbine efficiency is greatly influenced by the vacuum of the turbine exhaust itself.
4. From the results of the steam turbine performance research during commissioning and actual data collection, all tested parameters were within the tolerances given based on ASME PTC 6.
5. Steam flow and incoming steam energy affect the efficiency of the turbine, this can be seen where the steam energy at the time of actual data collection is greater, namely 3463.4 kJ/kg with an efficiency of 88.65%, while the steam energy in the design data is 3450 kJ/kg with an efficiency of 87.38% and the steam energy at the time of commissioning is 3445.73 kJ/kg with an efficiency of 87.1%. Maintaining the vacuum from the turbine exhaust or the vacuum from the Air Cooled Condenser greatly influences the increase in turbine efficiency.
6. One of the causes of the decline in turbine efficiency is the increase in pressure on the air-cooled condenser, which can be seen in the comparison graph between the design, commissioning, and actual turbine efficiency; the higher the turbine exhaust vacuum pressure or air-cooled condenser pressure, the lower the turbine efficiency. One way to maintain the vacuum in the air cooled condenser so that the turbine exhaust pressure is low is to schedule the cleaning process of the tubes on the air cooled condenser to avoid the accumulation of dirt on the air cooled condenser tubes, which will affect the process of condensing the turbine output steam, including efforts to maintain the turbine exhaust vacuum and increase the efficiency of the turbine itself.

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Author Contributions

AS conceived the research idea and designed the methodology for the study, conducted the experiments, analyzed the data, and was primarily responsible for writing the manuscript. IS supervised the project, offering valuable guidance and critical insights.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this study. This research was conducted independently, and no financial or personal relationships influenced the results or interpretation of the findings.

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