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Research Article

The Effect of Inlet Water Intake Temperature on the Thermal Efficiency of Timor 1 Coal-Fired Power Plant (2x50 MW)

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Abstract: In a thermal power plant, evaluating the performance of plant can be seen from the thermal efficiency value. Thermal efficiency is the percentage of heat energy entering the system that is actually converted into electrical energy. One way to increase the thermal efficiency of the plant is to reduce the temperature of the cooling water at the water intake inlet. From the research results, a graph shows the relationship between the increase in inlet water intake temperature from 30℃ - 33℃ to the condenser heat transfer rate, condenser pressure, and thermal efficiency of power plant. From the results of the calculations carried out, it was found that an increase in the inlet water intake temperature of PLTU Timor 1 (2x50 MW) from 30℃-33C, caused a decrease in the heat transfer rate in the condenser from 81,875 kJ/s – 81,873kJ/s, causing an increase in condenser pressure from 0, 0744 bar – 0.0872 bar and causes a decrease in thermal efficiency from 43.62% – 43.23%. So it can be said that the higher inlet water intake temperature, the lower the thermal efficiency of power plant. Lowering thermal efficiency from 43.62% – 43.23% will cause an increase in Levelized Generating Cost Value (LGCV) from IDR 1,284/kWh – 1,302/kWh. If LGCV multiplied by the annual kWh production, every 1℃ increase in water intake inlet temperature will increase production costs by 5 billion rupiah per year.

Keywords: *thermal efficiency, water intake, cooling temperature, condenser pressure*

1. Introduction

PLTU Timor 1 (2x50 MW) is one of the power plant projects under the 35,000 MW program, which, according to the RUPTL (Electricity Supply Business Plan) 2021-2030, is targeted to achieve COD (Commercial Operation Date) in 2023. PT PLN UIP Nusa Tenggara, as the project owner, faced challenges in the construction of the Sea Water Intake (SWI) pipe, where, as of August 2022, the physical progress showed a deviation of 30.57%.

The initial intake design used RCCP (Reinforced Concrete Steel Cylinder Pipe) with a length of 565 m extending from the SWI pond. However, the contractor proposed a design modification to shorten the intake pipe from STA 565 to STA 320 to avoid an excessively long excavation in the offshore area. This adjustment affected the thermal dispersion of the PLTU Timor 1 outfall, leading to an increase in the inlet water intake temperature.

Thermal dispersion studies revealed that the maximum temperature at the inlet water intake of PLTU Timor 1 (2x50 MW) rose from the initial design of 30℃ to 31.48℃ due to the shortening of the intake pipe from STA 565 to STA 320. The rise in inlet water intake temperature is expected to reduce the heat transfer rate and condenser vacuum, ultimately lowering the thermal efficiency of PLTU Timor 1 (2x50 MW).

Research by Syed Haider Ali in 2014 indicated that an increase in water intake temperature from 12℃ to 42℃ resulted in a condenser pressure rise from 0.10 bar to 0.48 bar. This pressure increase caused a decrease in the thermal efficiency of the power plant from 36% to 34.5%. Similarly, a study by Gamal Yassin and Abdualrazzaq in 2021 on a 300 MW capacity power plant in West Doha simulated cooling water temperature variations between 25℃ and 36℃. Their findings showed that an increase in cooling water temperature from 25℃ to 36℃ resulted in a condenser pressure rise from 0.06 bar to 0.1 bar.

Based on the findings above, an analysis of the thermal efficiency of PLTU Timor 1 (2x50 MW) is necessary to evaluate the impact of changes in inlet water intake temperature from 30℃ to 33℃.

2. Materials and methods

2.1. Research Design

In general, the stages of this research are carried out by identifying the problem of the influence of inlet water intake temperature on the thermal efficiency of PLTU Timor 1 (2x50 MW), followed by collecting data on the Heat & Mass Balance at 100% TMCR, condenser and CWP pump datasheets, and boiler datasheets.

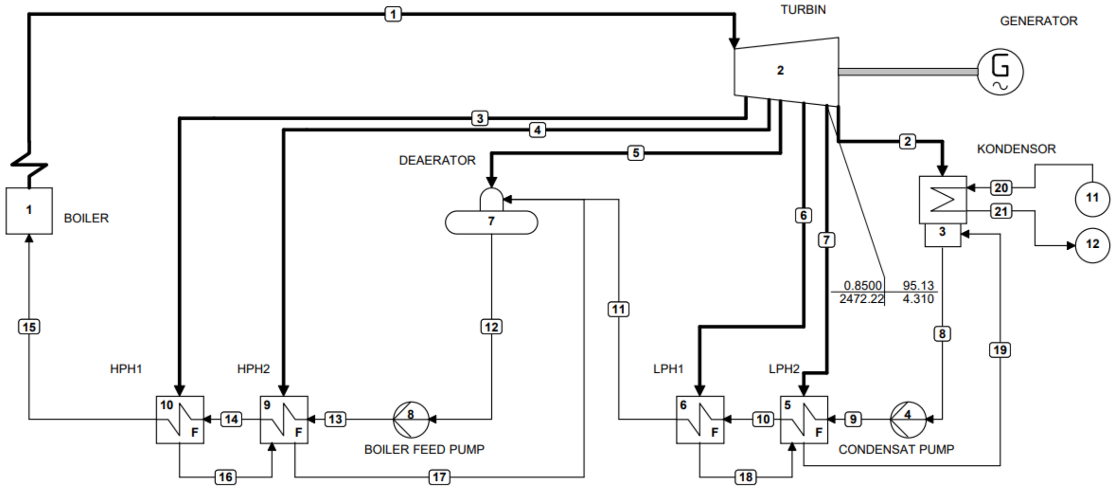

Figure 1. Process Flow Diagram PLTU Timor 1 (2x50 MW)

2.2. Data Calculation

The data calculation begins with the following steps: calculating the heat transfer rate in the condenser, determining the steam temperature entering the condenser, calculating the heat & mass balance and turbine work from the results of the cycle tempo simulation for each variation of inlet water intake temperature (30℃ - 33℃), and calculating the thermal efficiency for each variation of inlet water intake temperature (30℃ - 33℃).

2.3. Equation for Heat Transfer Rate in the Condenser

The basic principle of a condenser's operation is the First Law of Thermodynamics, where the heat transfer rate on the hot side is equal to the heat transfer rate on the cooling water side.

$$\dot{Q} = \dot{m}_c \, C_{pc} \, (T_{c,out} - T_{c,in}) \text{ ....} \mathbf{(2.1)}$$

Description:

$\dot{m}_c = mass\ flow\ rate$ (kg/s)
C_{pc} = Spesific heat (J/kg°C)
$T_{c,out} = Outlet\ temperature$ (°C)
$T_{c,out} = Inlet\ temperature$ (°C)

$$\dot{Q} = U\ A_s\ \Delta\ T_m \ \ldots\ldots\ldots\ldots\ldots\ldots \ \mathbf{(2.2)}$$

Description:

$U = Overall\ heat\ transfer\ coefficient\ (W/m^2)$
$\dot{A}_s = Surface\ area\ of\ condenser\ pipes\ (m^2)$
$T_m = Temperature\ difference\ between\ two\ fluids$(°C)

2.4. Equation for Steam Temperature at the Condenser Outlet

The temperature difference between the steam and the cooling water is relatively higher at the condenser inlet and decreases exponentially toward the condenser outlet. The cooling water temperature will never exceed the temperature of the hot fluid (condensed steam), regardless of the cooling time. Therefore, the **Log Mean Temperature Difference (LMTD)** equation is suitable for analyzing heat transfer in the condenser. Here, $\Delta\ T_1$ dan $\Delta\ T_2$ represent the temperature differences between the two fluids at different points in the condenser.

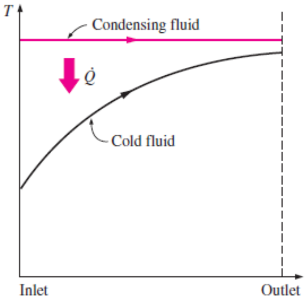

Figure 2. Heat Transfer Diagram of the Condenser

$$\Delta\ T_{lm} = \frac{\Delta\ T_1 - \Delta\ T_2}{\ln(\Delta\ T_1/\Delta\ T_2)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(2.3)}$$

2.5. Turbine Work Equation

Turbine work is greatly influenced by the magnitude of the heat drop. If the enthalpy of the steam leaving the turbine to the condenser decreases, the power generated by the turbine will increase. The enthalpy of the steam exiting the turbine is influenced by the isentropic efficiency. Under ideal conditions, the entropy of the steam entering the turbine is the same as the entropy of the steam leaving the turbine.

$$W_{Turbin} = (m_1 x\ h_1) - (m_2 x\ h_2) - (m_3 x\ h_3) - (m_4 x\ h_4) - (m_5 x\ h_5) - (m_6 x\ h_6)\ \ (m_7 x\ h_7)$$
$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(2.6)}$$

Description :

W_{Turbin} = *Turbine Work* (kJ)
m_1 = *Steam flow rate entering the turbine* (kg/s)
h_1 = *Enthalpy of steam entering the turbine* (kg/s)
m_2 = *Steam flow rate entering the*

h_4 = *Enthalpy of steam entering* HPH 1 (kg/s)
m_5 = *Steam flow rate entering the Deaerator* (kg/s)
h_5 = *Enthalpy of steam entering the Deaerator* (kg/s)
m_6 = *Steam flow rate entering* LPH 2 (kg/s)

condenser(kg/s)

h_2 =*Enthalpy of steam entering the condenser* (kg/s)

m_3 =*Steam flow rate entering HPH 2* (kg/s)

$h_3 = Entalpi\ uap\ masuk\ HPH\ 2$ (kg/s)

$m_4 = Steam\ flow\ rate\ entering\ HPH\ 1$ (kg/s)

h_6 =*Enthalpy of steam entering LPH 2* (kg/s)

$m_7 = Laju\ uap\ masuk\ LPH\ 1$ (kg/s)

h_7 =*Steam flow rate entering LPH 1* (kg/s)

2.6. Thermal Efficiency Equation

The thermal efficiency of a power plant is the ratio of the work produced by the turbine to the heat absorbed from the coal fuel.

$$W_{Feed\ pump} = (m_1 x\ h_1) - (m_2 x\ h_2) \quad \textbf{(2.7)}$$

$$W_{condensat\ pump} = (m_1 x\ h_1) - (m_2 x\ h_2) \quad \textbf{(2.8)}$$

$$Q_{boiler} = m_1 (h_1 x\ h_{15}) \quad \textbf{(2.9)}$$

$$Efisiensi_{Thermal} = \frac{w_{turbin} - w_{pompa}}{Q_{boiler}} \quad \textbf{(2.10)}$$

Description:

$W_{Turbin} = Turbine\ Work$ (kJ)

$W_{Feed\ pump} = Work\ of\ Boiler\ Feed\ Pump\ (kJ)$

$W_{condensat\ pump} = Work\ of\ Condensate\ Pump\ (kJ)$

$Q_{boiler} = Heat\ input\ to\ the\ boiler\ (kJ)$

2.7. Plant Heat Rate Equation

In performance calculations for power plants, parameters from the boiler, turbine, and generator sides are involved. The value of the plant heat rate provides an indication of the overall efficiency of a power plant. The plant heat rate calculation can be determined using the following formula (ASME PTC 4, 2008):

$$GPHR = \frac{Turbin\ heat\ rate}{Efficiency\ boiler} \quad \textbf{(2.14)}$$

$$NPHR = \frac{GPHR}{1 - (\frac{Aux\ Power}{Gross\ Output})} \quad \textbf{(2.15)}$$

2.8. Levelized Cost of Electricity (LCOE) Equation

$$LCOE = \frac{NPV\ of\ Total\ Cost\ Over\ Lifetime}{NPV\ of\ Electrical\ Energy\ Produced\ Over\ Lifetime} \quad \textbf{(2.16)}$$

$$LCOE = \frac{\sum \frac{(Komp\ A_t + Komp\ B_t + Komp\ C_t)}{(1+r)^t}}{\sum \frac{E_t}{(1+r)^t}} \quad \textbf{(2.17)}$$

Description

Component A: Initial Investment Cost (Capex) (IDR)

Component B&D: Maintenance, Operational (O&M), and Consumable Costs (IDR)

Component C: Fuel Cost (IDR)

E: Electrical Energy Produced (kWh)

t: Year t (year)

r: Discount Rate (%)

3. Results and discussion

3.1. Heat & Mass Balance Modeling with Cycle Tempo

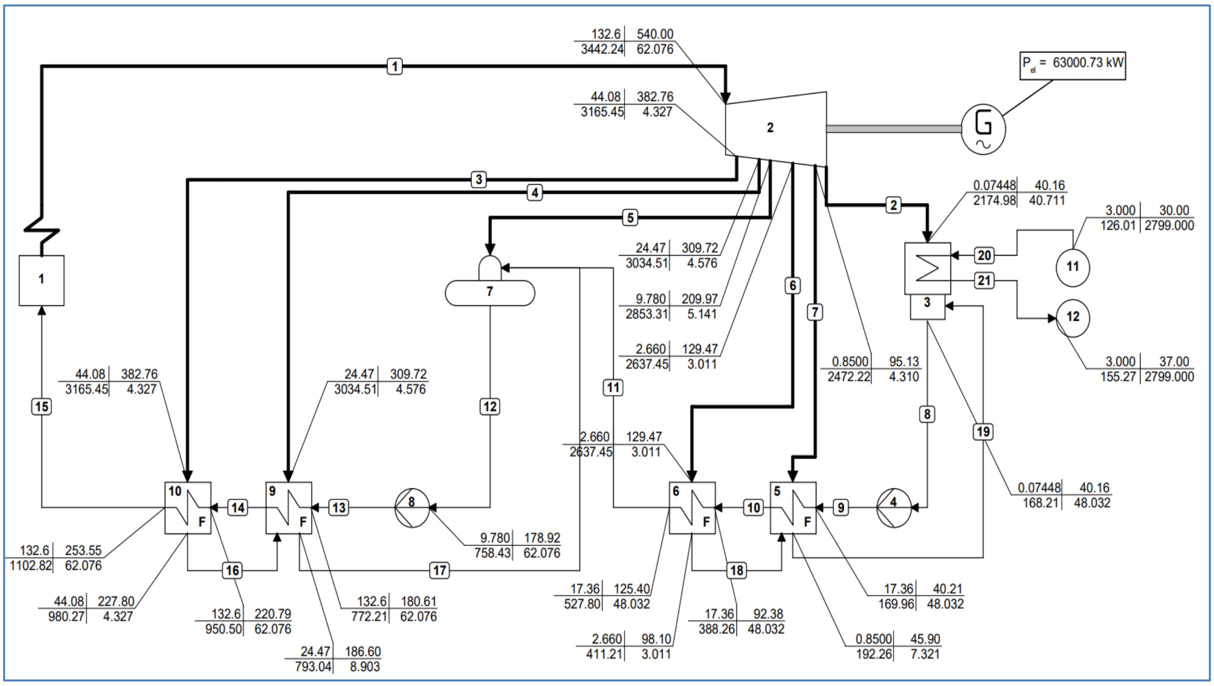

Figure 3. Original Heat Balance Diagram 100% TMCR of PLTU Timor 1 (2x50 MW)

Based on the thermal dispersion study results, the scenario of modifying the water intake pipe design by shortening the pipe from STA 565 to STA 320 leads to an increase in the water intake temperature from 30°C to 33°C. The results from the simulation at 100% TMCR will be used to calculate the thermal efficiency of the power plant. These results will then be simulated with variations in water intake temperature from 30°C to 33°C.

The parameters kept constant in the Heat Balance simulation with variations in inlet water intake temperature from 30°C to 33°C are as follows:

A. Temperature difference between cooling water inlet and outlet of the condenser: 7°C
B. Mass flow of Circulating Water Pump (CWP): 2.799 kg/s
C. Constant Auxiliary Power: 6.377 kW

3.2. Analysis of Turbine Outlet Pressure and Temperature

The heat transfer rate in the condenser is calculated using equation 2.2, and the logarithmic temperature difference (ΔT_{lm}) is calculated using equation 2.3.

Table 1. Data from Turbine Outlet Pressure and Temperature Calculation

Temperatur Water Intake	$\dot{m}_c$ (kg/s)	C_{pc} (kJ/kg°C)	Q (kJ/s)	T_1 (°C)	$p_{kondensor}$ (bar)
In : 30 **Out : 37**	2.799	4,1788	81.875	40,160	0,0744
In : 31 **Out : 38**	2.799	4,1788	81.875	41,159	0,0785
In : 32 **Out : 39**	2.799	4,1787	81.873	42,159	0,0828

In : 33 **Out : 40**	2.799	4,1787	81.873	43,159	0,0872

3.3. Analysis of Mass Balance and Turbine Work with Inlet Water Intake Temperature Variations of 30°C - 33°C

A. Water intake inlet temperature 31°C:

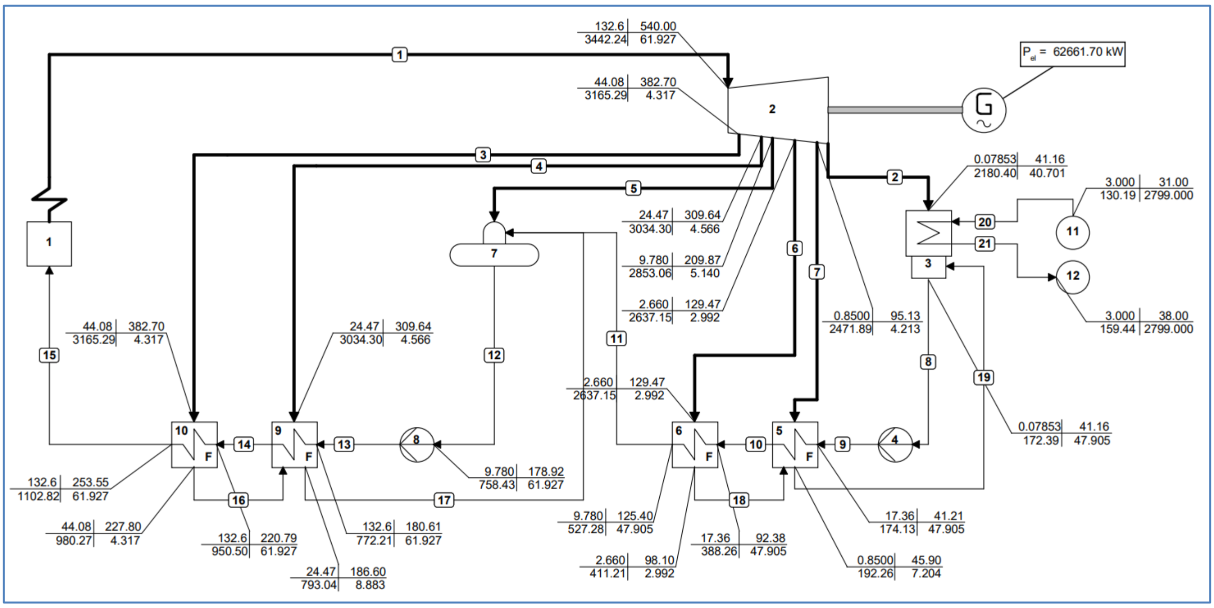

Figure 4. Heat & Mass Balance Modeling of Water Intake Inlet Temperature 31°C with Cycle Tempo

B. Water intake inlet temperature 32°C:

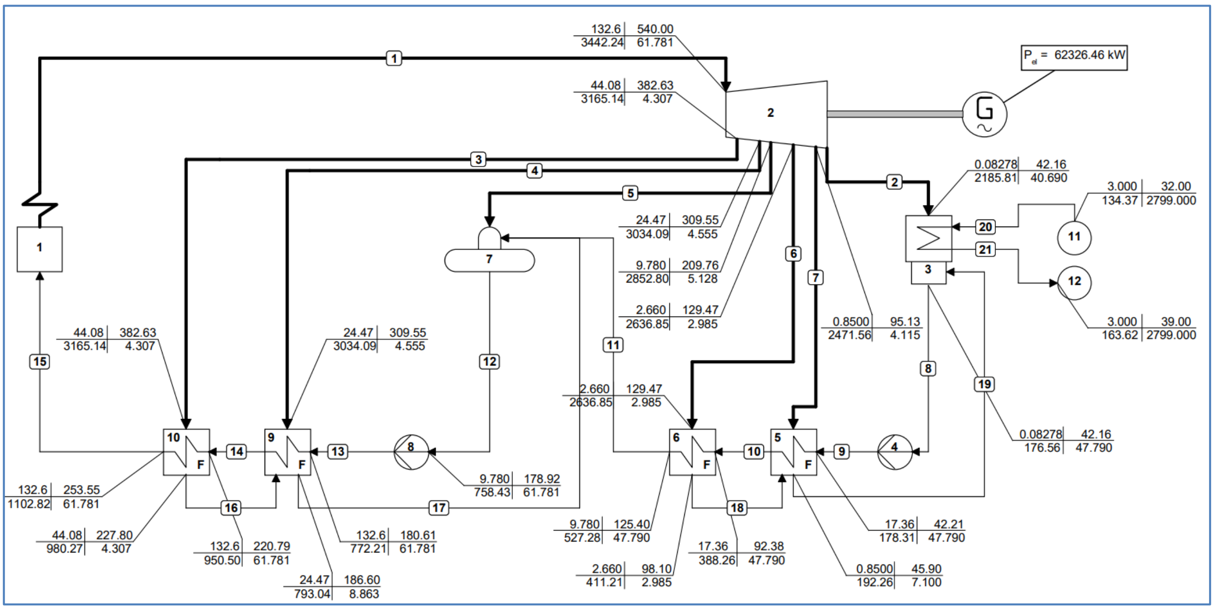

Figure 5. Heat & Mass Balance Modeling of Water Intake Inlet Temperature 32°C with Cycle Tempo

C. Inlet water intake temperature 33°C:

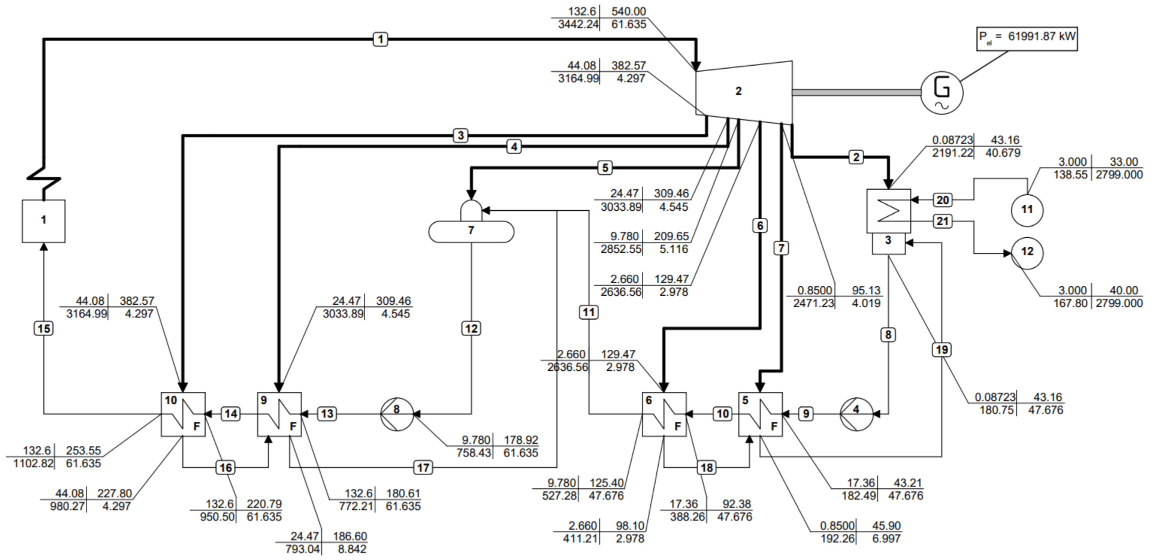

Figure 6. Heat & Mass Balance Modeling of Water Intake Inlet Temperature 33°C with Cycle Tempo Turbine Working

Table 2. Data on the results of generating thermal efficiency calculations

Temperatur cooling (°C)	Steam Flow (kg/s)	Q Boiler (kW)	W_{turbin} (kW)	W_{pompa} (kW)	*Gross Output Generator* (kW)	Plant Efficiency (%)
In : 30 **Out : 37**	62,076	145.222	64.287	939,46	63.000	43,62
In : 31 **Out : 38**	61,927	144.873	63.935	938,76	62.661	43,48
In : 32 **Out : 39**	61,781	144.532	63.602	934,97	62.326	43,36
In : 33 **Out : 40**	61,635	144.190	63.260	932,29	61.991	42,23

3.4. Levelized Generating Cost Value Analysis

Plant Heat Rate

Table 3. Data from Net Plant Heat Rate Calculation Results

Temperatur cooling (°C)	Steam Flow (kg/s)	Gross Output Generator (kW)	Turbine Heat Rate (kCal/kWh)	GPHR (kCal/kWh)	Aux Power (kW)	NPHR (kCal/kwh)
In : 30 **Out : 37**	62,076	63.000	1.983,32	2.347	6.377	2.611
In : 31 **Out : 38**	61,927	62.661	1.989,26	2.354	6.377	2.621
In : 32 **Out : 39**	61,781	62.326	1.995,24	2.361	6.377	2.630
In : 33 **Out : 40**	61,635	61.991	2.001,28	2.368	6.377	2.640

Levelized Cost of Electricity (LCOE)

Table 4. Data from LCOE calculation results

Temperatur cooling (℃)	Net Output Plant (MW)	NPHR (kCal/kWh)	LCOE (Rp/kwh)
In : 30 **Out : 37**	63,000	2.611	1.284
In : 31 **Out : 38**	62,661	2.621	1.290
In : 32 **Out : 39**	62,326	2.630	1.296
In : 33 **Out : 40**	61,991	2.640	1.302

3.5. Analysis of Calculation Data

Calculation analysis of condenser heat transfer rate and condenser pressure

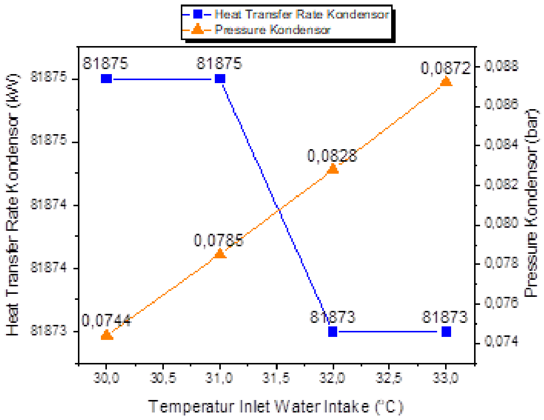

Figure 7. Comparison graph of water intake inlet temperature against heat transfer rate and condenser pressure

Analysis of Plant Thermal Efficiency Calculations

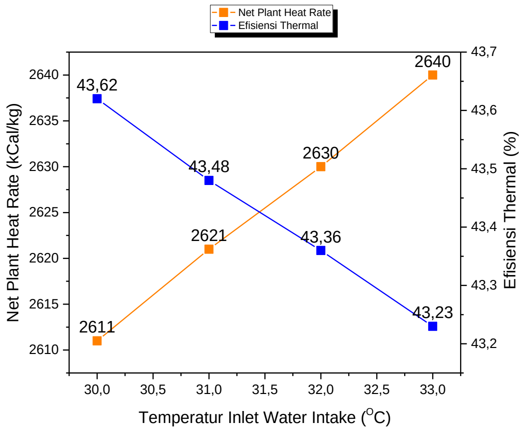

Figure 8. Comparison graph of water intake inlet temperature on NPHR and generator thermal efficiency

4. Discussion

1. A comparison of the simulation results with the operational parameters at 100% TMCR load is needed to compare the thermal efficiency of the PLTU Timor 1 (2x50 MW) cycle from the simulation results with actual operation.
2. The construction of a breakwater as a thermal barrier between the inlet water intake and the water outfall is necessary to prevent an increase in the inlet water intake temperature due to the redesign of the water intake pipe, thus maintaining the thermal efficiency at 43.62% as per the original design.

5. Conclusion

1. Based on the analysis of the effect of the increase in the inlet water intake temperature of PLTU Timor 1 (2x50 MW) from 30℃ to 33℃, there is a decrease in the heat transfer rate at the condenser from 81.875 kJ/s to 81.873 kJ/s.
2. Based on the analysis of the effect of the increase in the inlet water intake temperature of PLTU Timor 1 (2x50 MW) from 30℃ to 33℃, there is an increase in the condenser pressure from 0.0744 bar to 0.0872 bar and an increase in the turbine exhaust steam temperature from 40.16℃ to 43.15℃.
3. Based on the analysis of the effect of the increase in the inlet water intake temperature of PLTU Timor 1 (2x50 MW) from 30℃ to 33℃, there is a decrease in thermal efficiency from 43.62% to 43.23%.
4. Based on the analysis of the effect of the increase in the inlet water intake temperature of PLTU Timor 1 (2x50 MW) from 30℃ to 33℃, there is an increase in Net Plant Heat Rate (NPHR) from 2,611 kCal/kWh to 2,640 kCal/kWh and an increase in Levelized Cost of Electricity (LCOE) from Rp 1,284/kWh to Rp 1,302/kWh.

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