Analysis of the Impact of Load Change on the Efficiency of the Heat Exchanger on Closed-circuit Cooling Water with a Capacity of 300 MW

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***Abstract*— Electricity has become one of the most crucial components of life. The steam power plant (PLTU) is the most significant contributor to the power supply process in Indonesia, with an installed capacity of 29.57%. A review of each component is required to support the sustainability of the production process at PLTU. This research discusses the heat exchanger's components in the cooling system at PT. XYZ. The cooling system in PLTU plays a vital role in preventing overheating of the power plant components, which can cause an interruption of the energy generation process. Following this, research was carried out on the influence of load changes on the efficiency of heat exchangers in PT. XYZ cooling systems using observation methods, interviews, and literature studies. Such methods produced data that could be used to calculate the efficiency value. From the results of the investigation, it was concluded that the performance of the PT. XYZ heat exchanger was at its best at maximum load with an effectiveness presentation of 68.29% and at its lowest at minimum load with an effectiveness presentation of 59.95%. However, the value was still below the standard value of efficiency of the heat exchangers, which is 75%, so it required more intensive treatment to improve its efficiency value.**

Keywords— Closed circuit cooling water, effectiveness, heat exchanger.

I. Introduction

Electricity has become one of the most crucial components of life. Many attempts to explore renewable sources of electricity have been developed, and their potential has been investigated by some researchers, including fuel cells [1], biogas [2], solar power plants [3], micro-hydro-plants [4], wind turbine plants [5], and so on. However, steam power plants (PLTU) are still Indonesia's most significant contributor to electricity generation, with a percentage of installed capacity of 29.57% [6].

PLTU is a power plant developed using steam from combustion as a turbine driver to generate electricity [7]. One PLTU that contributes to the national power supply is PLTU PT. XYZ, with a capacity of 300 MW. As supplementary information, according to the Ministry of Energy and Mineral Resources (ESDM) report of the Republic of Indonesia, per capita electricity consumption in Indonesia in 2022 reached 1,173 kWh/capita.

To maintain the continuity of the power generation process in PLTU, especially in PT. XYZ, monitoring of the performance of power components should be carried out so that when there is a decrease in performance, it can be addressed immediately. The crucial element in the plant is the cooling system, where the system keeps the temperature of the power plant components safe from overheating, which may interfere with the production process. Generally speaking, such a cooling system is a heat exchanger (HE) used as a chill system in PT. XYZ is a type of plate heat exchanger.

Many studies have already investigated the performance of HE as a cooling system, as done by [8], [9], [10]. It is generally concluded that routine approval of the HE condition is necessary to ensure optimal HE performance. Besides, the operating conditions also affect the performance of the HE and the power system. Saputri and Hasnira conducted a study that discussed the effect of treatment on the heat exchanger system on heat transfer efficiency in the lubrication system using demineralised water [11]. Research shows that treatment can increase lubricant cooling by 3°C and heat transfer by 20,968 joules. This suggests that heat exchanger treatment can improve the cooling system's performance and heat transfer in the lubrication system.

Soegijarto and Arsana studied the influence of the temperature of the incoming fluid on the heat transfer rate and efficiency of the shell and tube heat exchangers using the TiO2 nanofluid [12]. The results show that the rate of calorie transfer and efficiency increase as the temperature of the inlet fluid increases. The most optimal efficiency and speed of heat transfer occur at 80°C, with efficiency increasing to 50% and heat transfer speed reaching 75614488 watts. In addition, Teguh et al. found in their study that the efficiency of steam power plants increases with a decrease in the heat rate value as the power plant's operating load changes. Fuel consumption also increased in line with the increase in load [13].

Based on this background, this study aims to study the performance of HE on closed-circuit cooling water that exists in PT. XYZ. The HE efficiency values are evaluated under different load conditions. The results of this investigation are expected to be used as a reference in efforts to prevent overheating of power components so as not to interfere with the energy generation process.

II. Methods

In this study, the methods used to investigate the performance of HE are interviews, observation, and literature study methods. The interview method obtains detailed information about HE Closed Circuit Cooling Water used in PT. XYZ, where the interview is conducted with the operator of the power generation unit of PT. XYZ. The observation

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method is performed by looking directly at the operational state of HE to get actual data. While the literature study is carried out to get an essential theoretical reference related to the focus of the investigation.

The HE system at the PT XYZ power plant, with a capacity of 300 MW, is being investigated. Operational data is taken from the DCS, while temperature data on the pipe is measured using a thermometer. Data is taken as the temperature output and temperature input data on hot and cold fluids, the mass of hot and cold types of fluid, as well as the discharge of cold and hot fluid. Hot fluids are used as mineral water. For cold fluids, use seawater. HE is evaluated as the HE-type plate heat exchanger.

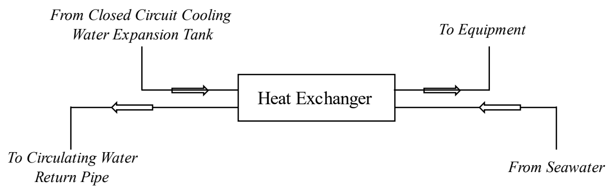

Fig. 1. Schematic cooling water heat exchanger

The dew water used to cool the oil components will enter the closed-circuit cooling water expansion tank and then be drawn to the heat exchanger. On the heat exchanger, the dew will be cooled with seawater to reach a targeted temperature of less than 40 °C and pulled back to the power plant component to cool the oil. Schematic details of the system are shown in Figure 1, while technical data related to HE is shown in Table 1.

In the HE system investigation process (in this work), manual calculations related to performance analysis were performed with the help of Microsoft Excel applications based on equations 1–12. Details of the heat exchange parameters calculated in this HE system performance evaluation are shown in Table 2.

TABLE 1. DATA COOLING WATER HEAT EXCHANGER PT. XYZ

Parameter	Information
Type	T35-PFM
Serial Number	30118-88-872
Max. Design Pressure (bar)	10,3
Max. Design Temperature (°C)	180
Plate Length (mm)	2875
Plate Width (mm)	1174
Length of Heat Transfer Area (mm)	1933
Width of Heat Transfer Area (mm)	1174
Free Channel (mm)	3,4
Materials of Flange Connections	Carbon Steel
Materials of Frame and Pressure Plate	Carbon Steel, Epoxy Painted
Seawater Pipe Diameter (mm)	500
Demin Water Pipe Diameter (mm)	500
Seawater Pipe Thickness (mm)	10
Demin Water Pipe Thickness (mm)	10
Rubber Lining Seawater Pipe (mm)	4
Rubber Lining Demin Water Pipe (mm)	4

TABLE 2. HEAT EXCHANGER PARAMETER CALCULATION

Parameter	Equation	Eq.	Ref.
Grashof Number (Gr)	$Gr = \frac{g.\beta.(Tw - T\infty).L^3}{v^2}$ where: g = gravitational acceleration (m/s^2) β = coefficient of thermal expansion (K^{-1}) Tw = surface temperature of the object (°C) T∞ = temperature of fuid at an infinite distance from an object (°C) L = characteristic length (m) v = kinematic viscosity (m^2/s)	(1)	[14]
Rayleigh Number (Ra)	$Ra = Gr\ x\ Pr$	(2)	[14]

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	where: Pr = Prandtl number (obtained from table of thermophysical properties saturated water A.6)		
Nusselt Number (Nu)	$Nu = 0{,}15Ra^{1/3}$	(3)	[14]
Convection Heat Transfer Coefficient (h)	$Nu = \frac{h.L}{k}$ where: h = convection heat transfer coefficient (W/m.°C) L = plate length (m) k = thermal conductivity of materials (W/m.°C)	(4)	[14]
Convection Heat Transfer Rate (Q)	$Q = A.h.\Delta T$ where: Q = convection heat transfer rate (W) A = heat transfer rate area (m^2) ΔT = temperature different (°C)	(5)	[14]
Cold Fluid Outlet Temperature (To,c)	$Qconv = Qcond$ $Qcond = 2\pi.k.L\frac{(T_{o,c} - T_w)}{ln\frac{r2}{r1}}$ where: $T_{o,c}$ = cold water outlet temperature (°C) T_w = pipe surface temperature (°C)	(6)	[14]
Logarithmic mean temperature differenced (LMTD)	$LMTD = \frac{(T_{h,i} - T_{h,o}) - (T_{h,o} - T_{c,i})}{ln\frac{(T_{h,i} - T_{c,o})}{(T_{h,o} - T_{c,i})}}$ where: LMTD = logarithmic mean temperature differenced (°C)	(7)	[14]
Heat Balance (Q)	$Qhot = Qcold$ $Q = \dot{m}.cp.\Delta T$ where: ṁ = mass flow rate (kg/s) cp = heat capacity (J/kg.°C) ΔT = difference in temperature of hot and cold fluid (°C)	(8)	[14]
Overall Heat Transfer Coefficient (U)	$U = \frac{Q}{A\ x\ LMTD}$	(9)	[15]
Heat Capacity Rate (C)	$Ch = \dot{m}\ x\ Cph$ $Cc = \dot{m}\ x\ Cpc$ $C = \frac{Cmin}{Cmax}$ where: Cmin = minimum heat capacity rate (J/s. °C) Cmax = maximum heat capacity rate (J/s. °C)	(10)	[14]

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Number of Transfer Unit (NTU)	$$NTU = \frac{U.A}{Cmin}$$	(11)	[14]
Heat Exchanger Effectiveness (ε)	$$\varepsilon = \frac{1 - \exp\,[-NTU(1-C)]}{1 - C\exp\,[-NTU(1-C)]} x100\%$$ where: ε = heat exchanger effectiveness (%)	(12)	[14]

III. Results and Discussion

Some supporting data is used in the mathematical calculation of the performance of HE, as shown in Table 3.

TABLE 3. DATA SUPPORTS CALCULATIONS

Parameters	Results
Demin water density (kg/m^3)	900
Seawater density (kg/m^3)	1025
Demin water discharge (m^3/h)	1700
Seawater discharge (m^3/h)	2160

Table 4 shows that the water temperature will increase as the load increases. This is because as the weight increases, the device's performance will increase due to the increased pressure. As a result, the oil temperature on the components will also heat up, and the water temperature will rise. It is calculated that the change influences the highest efficiency of HE at the given load. This happens when the temperature of the hot fluid increases while the temperature and speed of the cold liquid and the HE performance are constant. The higher the temperature of the fluid, the higher the value of its effectiveness. This is because the overall heat transfer rate (U) is also increasing, which implies that the heat transfer speed is growing anyway [12].

TABLE 4. PERFORMANCE PARAMETERS OF HEAT EXCHANGERS DESIGNED BASED ON MATEHEMATICAL CALCULATIONS

No	Parameters	Results		
		50%	75%	100%
1	$T_{c\ out}$ (˚C)	32,95	35,74	38,46
2	$T_{film,h}$ (K)	309,63	311,08	313,12
3	$C_{p,h}$ (J/kg.K)	4178	4178,21	4178,62
4	$\dot{m}_h$ (kg/s)	425	425	425
5	$T_{film,c}$ (K)	302,23	303,83	305,1
6	Cp,c (J/kg.K)	4178,55	4178,23	4178
7	$\dot{m}_c$ (kg/s)	615	615	615
8	Ch (J/K)	1775650	1775739,25	1775913,5
9	Cc (J/K)	2569808,25	2569611,45	2569470
10	Cmin (J/K)	1775650	1775739,25	1775913,5
11	Cmax (J/K)	2569808,25	2569611,45	2569470
12	C (J/K)	0,6909	0,691	0,6911
13	Q (W)	16109091,39	19333854,35	23578211,57
14	LMTD	7,36	7,24	8,02
15	U (W/m^2.K)	968466,92	1181602,6	1300852,5
16	NTU	1,23	1,5	1,65
17	NTU-Effectiveness (%)	59,95	65,63	68,29

IV. Conclusion

Power system performance can be judged by the energy wasted to generate a specific desired power. Based on the investigations and calculations, the range of effectiveness values of heat exchanger closed circuit cooling water on PT. XYZ is in the range of 59.95–68.29%. The highest efficiency values are obtained at the time of maximum burning, and the lowest practical values are accepted at the minimum load. To improve the HE efficiency, the system needs to be regularly cleaned.

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