Operational Assessment of Shell and Tube High Pressure Heater in PT Sumber Segara Primadaya's 300 MW Unit 2 Power Plant

Mulyono[(1)], Erwan Tri Efendi*[(2)], Rayhan Muhammad Faqi Fikar Setiyawan [(3)], Dianisa Khoirum Sandi[(4)], Dhiyaussalam [(5)]
[1,2,3,4]*Department of Mechanical Engineering, Politeknik Negeri Semarang*, Semarang, Indonesia
[5]*Department of Electrical Engineering, Politeknik Negeri Banjarmasin*, Banjarmasin, Indonesia
Email address : ***erwan.triefendi@polines.ac.id**

***Abstract*— Electricity is a fundamental necessity, with Indonesia's per capita consumption reaching 1.73 kWh/capita in 2022—a 4% increase from 2021 and the highest in five decades. Projections indicate demand will surge to 1,885 TWh by 2060, with per capita consumption exceeding 5,000 kWh, underscoring the need for efficient power generation. In coal-fired power plants (PLTU), high-pressure shell-and-tube heat exchangers are critical for optimizing efficiency, recovering waste heat to preheat boiler feedwater, reducing fuel use by 5–10%, and minimizing emissions. This study evaluates the performance of these heat exchangers at PT Sumber Segara Primadaya PLTU Cilacap, a major Indonesian PLTU with units totaling 2,260 MW capacity. By analyzing operational effectiveness, this research aims to enhance maintenance strategies and maximize energy output, supporting Indonesia's growing electricity demands while improving thermal efficiency in coal-dependent power systems.**

***Keywords*— High-pressure heater, shell-and-tube heat exchanger, thermal efficiency, PLTU.**

Electricity is one of the most crucial components in life. Based on ESDM report data, Indonesia's per capita electricity consumption in 2022 reached 1.73 kWh/capita. This consumption level increased by around 4% compared to 2021 (year-on-year), and also became a new highest record in the last five decades. Quoting from the press release of the Ministry of Energy and Mineral Resources of the Republic of Indonesia, Indonesia's electricity needs in 2060 are projected to be 1,885 Terawatt Hours (TWh), where PLN demand is around 1,728 TWh, and non-PLN demand is around 157 TWh. Meanwhile, the projected per capita electricity consumption will reach more than 5,000 KWh/capita in 2060[1].

In thermal power plants, heat exchangers play a vital role in optimizing energy efficiency and reducing operational costs. The high-pressure heater (shell and tube type) specifically serves as a critical component in the feedwater heating system, recovering waste heat from turbine extraction steam to preheat boiler feedwater. This process significantly improves overall plant efficiency by reducing fuel consumption and minimizing thermal stress on boiler components. Properly maintained heat exchangers can contribute to 5-10% improvement in power plant thermal efficiency, making their performance evaluation essential for sustainable operations. The effectiveness of these heat exchangers directly impacts coal consumption rates and greenhouse gas emissions, particularly crucial for Indonesia's coal-dominated power sector [2].

PLTU is the power plant with the highest capacity in Indonesia. One of them is PT Sumber Segara Primadaya PLTU Cilacap. PT Sumber Segara Primadaya has 4 units, namely units 1 & 2 with a capacity of 2 x 300 MW, unit 3 with a capacity of 1 x 660 MW, and unit 3A with a capacity of 1 x 1000 MW. To maintain the continuity of the electricity generation process in the PLTU, especially at PT Sumber Segara Primadaya PLTU Cilacap, maintenance should be carried out on each of its equipment, in addition, the author also needs to know the efficiency value of each equipment in order to know the maximum value that can be produced. One of the important components in the Cilacap PLTU is the Heat Exchanger. The Heat Exchanger, especially in the cooling water system, functions as a heater for demineralized water before it is put into the boiler so that combustion in the boiler does not take a long time and uses a lot of coal. This is the basis for choosing this research topic [2][3].

I. Methods

Heat exchangers are process support tools that are often used to transfer heat, can function as heaters or coolers. Heat exchangers are designed in such a way as to obtain heat transfer between fluids that occurs efficiently. In heat exchangers, heat exchange occurs because there is back contact between the fluids there is a separating wall or both are mixed directly or direct contact[4], [5].

In PLTU, heat exchanger is one of the components that has an important role in the production process, the main task of the heat exchanger is to transfer heat from a fluid flow to another fluid using the basic principle of conduction. The type of fluid operated by the heat exchanger can vary, from high viscosity to low viscosity, but its use must be in accordance with the appropriate heat exchanger material, the material usually found in heat exchangers is carbon steel and alloy steel which can be used for liquids such as water, oil, water glycol, to sea water. But for special fluids (corrosive, acidic) such as salt, acids, etc. require special materials such as stainless steel and titanium[3], [4], [6].

The calculation of the effectiveness value is carried out using the Number Of Transfer Units (NTU) method with the stages of heat balance calculation, Log Mean Temperature Difference (LMTD) calculation, overall heat transfer coefficient calculation, heat capacity rate calculation, and heat effectiveness calculation using the NTU method[7], [8], [9], [10], [11], [12], [13], [14], [15] .

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Table 1. HPH Heat Exchanger Specifications Shell and Tube Type

Parameter	Discription
Type	Shell and Tube
Serial Number	NO. W19-408
Max. Design Pressure tube	28 MPA
Max. Design Pressure Shell	4.7 MPA
Max. Test Pressure Tube Side	35 MPa
Max. Test Pressure Shell Side	6,64 MPa
Max. Design Temperature Tube	280°C
Max. Design Temperature Shell	350/260°C
Vessel WT	38678
Heat Exchanger Area	1050 m^2
Baffle Space	700 mm
Medium Tube Side	*Water*
Medium Shell Side	*Steam*
Production	Dongfang Boiler Co.LTD
Tube Diameter	10 mm

A. Heat Transfer Rate

Heat duty to determine the amount of heat that can be transferred from hot fluid to cold fluid in a heat exchanger is calculated using the formula:

$$Q=\dot{m}.C_{p}.\Delta T \tag{1}$$

Description:
Q = Amount of heat transferred (Watt)
ṁ = fluid flow rate (kg/s)
ΔT = difference between inlet and outlet temperatures (K)
Cp = heat capacity (J/kg.K)

B. LMTD

LMTD (Log Mean Temperature Difference) to determine the value of the temperature difference that occurs in a heat exchanger, can be calculated using the following formula:

$$LMTD=\frac{\Delta th-\Delta tc}{\ln\frac{\Delta th}{\Delta tc}} \tag{2}$$

Description:

Δth (T2 hot-T1 hot) = delta hot temperature(K)
Δtc (T2 cold-T1 cold) = delta cold temperature(K)

C. Mass Flow Rate of Water

$$Gt=\frac{\dot{m}c}{at} \tag{3}$$

Description:
Gt= mass flow velocity of water (kg/m2.s)
At= cross-sectional area (m2)

D. Reynolds Number

Reynolds number is the ratio of inertial force to viscous force that qualifies the relationship of both forces to a particular flow condition. It is usually used to identify different types of flow (lamellar and turbulent).

$$Re=\frac{di\ x\ Gt}{\mu} \tag{4}$$

Description:
di = pipe diameter (m)

E. Overall heat transfer coefficient

$$U=\frac{Qmax}{A\ x\ LMTD} \tag{5}$$

Description:
U = overall heat transfer coefficient (W/m2.°C)
Q = Heat transfer rate (Watt)
A = cross-sectional area (m2)
ΔLTMD = average temperature difference (°C)

F. Calculation of Heat Capacity Rate

Calculation of Heat Capacity Rate for Hot Fluids

$$Ch= \dot{m}h\ x\ Cph \tag{6}$$

Calculation of Heat Capacity Rate for Cold Fluids

$$Cc= \dot{m}c\ x\ Cpc \tag{7}$$

Comparison of Heat Capacity Rate of Hot and Cold Fluids

$$C''= Cmin/Cmax \tag{8}$$

Description:
ṁ = mass flow rate (kg/s)
Cp = heat capacity (J/Kg°C)
Cmin = minimum heat capacity rate
Cmax = maximum heat capacity rate
C” = heat capacity rate

G. Pressure Drop

$$\Delta P=\frac{f\ x\ Gt^2 x\ L\ x\ n}{2\ x\ g\ x\ di\ x\ \rho} \tag{9}$$

$f=(1,58x\ln(Re)-3,28)^{-2}$

Description:
Gt = Mass flow rate of water (kg/m2.s)
L = tube length (m)
N = number of tubes
G = gravity (m/s2)
Di = inner diameter (m)
P = flow density (kg/m3)

H. Factor Correction

$$R=\frac{T1-T2}{t2-t1} \tag{10}$$

$$S=\frac{t2-t1}{T1-t1} \tag{11}$$

Description:

T_1= Hot fluid inlet temperature (K)
T_2= Hot fluid outlet temperature (K)
t_1= Cold fluid inlet temperature (K)
t_2= Cold fluid outlet temperature (K)

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I. Effectiveness Value

The effectiveness of a heat exchanger can be found by comparing the heat transfer coefficient during the operating process, with the overall heat transfer coefficient, so that the following results are obtained:

$$\mathcal{E}=\frac{1-\exp[-NTU(1-C)]}{1-c.\exp[-NTU(1-C)]} \quad (12)$$

Description:
$\mathcal{E}$= effectiveness value (%)

II. Results and Discussion

Table 2. Actual Data Calculation Results

Data	Hasil
Q_c (W/m^2.°C)	24808022,14
$\dot{m}_c$ (kg/s)	175,555
$\dot{m}_h$ (kg/s)	147,313
C_c (J/s)	772354,362
C_h (J/s)	295286,993
C”	0,382
ΔLTMD (K)	334,954
ΔP (Mpa)	1,9095156
Fouling factor	0,86
Q_{max} (watt)	110693827,3
U (W/m^2.°C)	1416,536129
NTU	1,103
Efektivitas (%)	58%

Table 2. Overhaul Data Calculation Results

Data	Hasil
Q_c (W/m^2.°C)	23567104,7
$\dot{m}_c$ (kg/s)	172,0227
$\dot{m}_h$ (kg/s)	142,003
C_c (J/s)	787670,612
C_h (J/s)	284694,715
C”	0,362
ΔLTMD (K)	346,03
ΔP (Mpa)	1,80878
Fouling factor	0,70
Q_{max} (watt)	134329346,3
U (W/m^2.°C)	1549,768237
NTU	1,3
Efektivitas (%)	66%

After the calculation and data obtained, it can be analyzed if the heat transfer rate Qc is the same as Qh, which in this event is called energy balance so that the heat transfer rate in the actual heat exchanger is Qc = Qh = 24808022.14 Watts, while the data after the overhaul is obtained Qc = Qh = 23567104.7 Watts, this can happen because there is contact between hot and cold fluids with the same medium so that comparable values are obtained.

The Reynolds number is used to determine the type of flow that is flowing, the Reynolds number obtained on the actual tube side heat exchanger is 74474.594 and the Reynolds number on the heat exchanger after overhaul is 67725.54, the numbers obtained from the two heat exchangers are greater than re> 4000 so that it can be determined if the type of flow that flows is turbulent flow, turbulent flow is a type of flow where the movement of fluid particles is very uncertain because it experiences mixing and rotation of particles between layers, the Reynolds number can be influenced by the speed of fluid flow, diameter, and viscosity of the fluid. So that the increasing speed of the fluid, the greater the Reynolds number obtained. The type of fluid flow greatly affects the heat transfer that occurs, the more random the fluid, the better the heat transfer that occurs, this randomness of the fluid plays a role in heat transfer in the tube.

Correction Factor used to adjust the difference in average logarithmic temperature in heat exchangers that do not operate in countercurrent flow. In the actual heat exchanger, the obtained dirt factor value is 0.86, while in the heat exchanger after overhaul, the obtained dirt factor value is 0.70, indicating that the Correction Factor of dirt in the actual heat exchanger on the tube side is higher than the heat exchanger after overhaul. It can also be calculated that the pressure drop that occurs in the actual shell and tube type heat exchanger is 1.9095156 MPa while the shell and tube heat exchanger after overhaul is 1.96911 MPa. The pressure drop between the actual data and after overhaul has a difference of 3.02%, this can affect the tube outlet pressure which can inhibit the rate of heat transfer by reducing the Reynolds number value.

Comparison between data after overhaul and actual data obtained different effectiveness, Factors that affect the effectiveness of the heat exchanger are the contact surface area, the temperature difference between the 2 fluids and the type of fluid flow rate, in this case it can be said that the contact surface area in the data after overhaul is more, namely 1351 tubes and getting a total surface area of 230.10 m^2, while for the actual heat exchanger gets a surface area of 230.102 m^2.

The temperature difference between the two fluids also affects the effectiveness, in the data after the overhaul, the difference in shell temperature (hot) inlet was 359.5°C while the shell outlet temperature was 221.57°C. for the tube inlet temperature (cold) the temperature was 201.7°C and the tube outlet temperature was 233.8°C. at the inlet temperature in the actual data, the shell inlet temperature (hot) was 345.02°C while the shell outlet temperature (hot) was 236.8°C, while for the tube inlet temperature (cold) the inlet temperature was 201.7°C and the tube outlet temperature (cold) was 233.8°C.

It can also be analyzed that the temperature inlet and outlet of the shell has an extreme temperature drop in the heat exchanger data after overhaul, reaching 137.93° C and in the actual heat exchanger 106.22° C, while the temperature increase in the heat exchanger data after overhaul is 19.92° C and the temperature in the actual heat exchanger in and out of the tube (demin) has a temperature increase of 32.1 ° C, in the theory of energy balance this is not appropriate because the

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energy exchanged is not comparable, this is a result of losses in the shell and tube, besides that in reality the heat in the shell will flow to the shell wall and will flow into convection heat to the environment, so that the heat that should be used to increase the temperature of the demin water but the existing heat causes losses in the form of steam heat transfer that flows towards the ambient temperature, the greater the difference in ambient temperature with the temperature of the outer wall of the shell, the more heat will be wasted.

The Heat Exchanger at PT Sumber Segara Primadaya unit 2 is used to increase the temperature on the tube side that will be used for boiler feed water, the effectiveness value ranges from 0-100%. The greater the effectiveness value, the better the performance of the heat exchanger because the actual heat transfer rate value is close to the amount of heat energy that can be transferred, an effectiveness of 59% is obtained on the actual heat exchanger and for the heat exchanger after overhaul, an effectiveness of 66% is obtained, performance in the form of effectiveness can be determined using the NTU graph of the effectiveness function.

In the actual heat exchanger, the NTU value is 1.001 and the C" value is 0.38 so that if a perpendicular line is drawn between the two, an effectiveness of ± 0.58 is obtained. While in the heat exchanger after overhaul, the NTU value is 1.3 and the C" value is 0.36 so that if a perpendicular line is drawn between the two, an effectiveness of ± 0.87 is obtained.

III. CONCLUSION

From the analysis and calculations, several conclusions can be drawn regarding the effective heat transfer rate, overall heat transfer coefficient, effectiveness value and the amount of pressure drop in the Shell and Tube HPH type Heat Exchanger:

1. The effectiveness value for actual data is 59% and for data after overhaul is 66% so that the decrease in performance can be caused by dirt factors, equipment age, and delays in maintenance that should be carried out routinely.
2. The pressure drop that occurs in the HPH includes pressure drop on the tube side, the amount of pressure drop in actual data on the tube side is 1.909 MPa, and in data after overhaul is 1.80 MPa, with the overhaul can reduce pressure drop by 5.7%.
3. A heat exchanger with a high ambient temperature can reduce the difference in temperature between the heat exchanger and the ambient temperature so that losses from convection temperature transfer to the environment can be minimized.
4. The increase in effectiveness of the HPH 2 heat exchanger is due to the increase in the hot fluid output from the turbine that has undergone an overhaul, which results in an increase in Q max.

By knowing the effectiveness of the Heat Exchanger and its problems, the author can suggest:

1. Perform routine cleaning so that the tube is free from scale and rust.
2. Repair clogged tubes so that the heat transfer area can increase and the heat exchanger can operate optimally.
3. Increase turbulent flow by increasing the flow rate, but it should be noted that if the pressure is too high it will affect the effectiveness of the heat exchanger.
4. Reduce pressure drop by controlling the flow rate because it can cause wear, deposit buildup, and can reduce the fluid flow rate, as well as controlling temperature and pressure.

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