Calculation of Heat Exchanger as Demineralized Water Cooler in C3W

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Abstract: ***The cooling system in a steam power plant is a closed-process cooling system that uses a heat exchanger with a cheap heat receiver transfer medium such as seawater. The closed cooling system heat exchanger has problems, namely frequent tube leaks and decreased effectiveness. This condition is fascinating to re-analyze by studying and calculating essential variables in the heat exchanger. Heat Exchanger (HE), a demineralized water cooler in the C3W system, uses a shell and tube heat exchanger. This heat exchanger, on the shell side, is passed by demineralized water fluid with an input temperature of 37 ° C and an output temperature of 30 ° C, and on the tube side, is passed by seawater fluid with an input temperature of 28 ° C and an output temperature of 31 ° C. The design standard will refer to the dirt factor value. HE is critical in the process that occurs in the plant, so it needs good design. This design will be carried out by calculation and simulation methods. The design standard refers to a dirt factor value of 0.0015 and a pressure drop of 10 psi (TEMA standard). The design calculation produces a dirt factor value of 0.0015 with a pressure drop of 6.32 psi (shell side) and 3.17 psi (tube side).***

Keywords: C3W system**,** cooler, demineralized water, heat exchanger, seawater

1. Introduction

The Steam Power Plant has three units with a capacity of 315 MW each. To achieve this capacity, the Steam Power Plant uses auxiliary equipment and a cooling system with demineralized water as a heat transfer medium. The production cost of demineralized water is high. Therefore seawater is chosen as a cheaper alternative medium[1-3]. Heat exchange between demineralized water through the shell and seawater through the tube in a closed cooling system after a long operation usually experiences several problems, such as leakage and dirt buildup. Leaks in the line can result in demineralized water and seawater mixing if the pressure on the shell side is higher [4]. Plugging is done to seal leaking tubes but with a maximum plug usage limit of 25% of the total line [5]. Plugs that exceed the limit require tube replacement (retubing), which can also lead to problems such as cracks in the tube sheet and require the replacement of the entire HE unit.

HE is considered one of the most critical systems that help solve various energy cycles, as it is based on solving heat transfer from different parts of the system without the need for physical mixing. HE design calculations need to pay attention to the operating boundary conditions, namely dirt factor and pressure drop and must pay attention to the materials used related to operating pressure [6].

2. Closed Cooling System

Shell and tube type HE is a heat exchanger with pipes installed in a cylindrical shell. Fluid flow occurs inside and around the pipes' outer surface. The internal construction of HE can vary according to the needs of heat transfer, pressure drop, thermal stress reduction, leakage prevention, ease of cleaning, temperature, and pressure. Standards such as TEMA, DIN, and ASME are used to classify and design shell and tube HE types. TEMA uses a three-letter notation system to name the designed heat exchangers. There are various shell and tube HEs, such as AES for the font type with removable canals and covers, the one-pass shell type, and the rear type with floating heads and equipment behind them.

Figure 1 shows the line diagram of a closed refrigeration cycle in a steam power plant. The heat exchanger (HE) is used with demineralized water on the shell side and seawater on the tube side. The demineralized water comes from the expansion tank that obtains water from the water treatment plant. A C3W pump is used to pump the demineralized water to the shell side of the HE. Seawater is taken directly from the sea with the help of a cooling water (CW) pump and a Cooling Water Booster (CWB). Heat exchange occurs in the HE between the demineralized water and seawater, where heat from the demineralized water is transferred to the seawater, causing a decrease in demineralized water temperature and an increase in seawater temperature. After passing through the HE, the demineralized water is distributed as a coolant, while the seawater that has absorbed the heat from the demineralized water is distributed as a coolant.

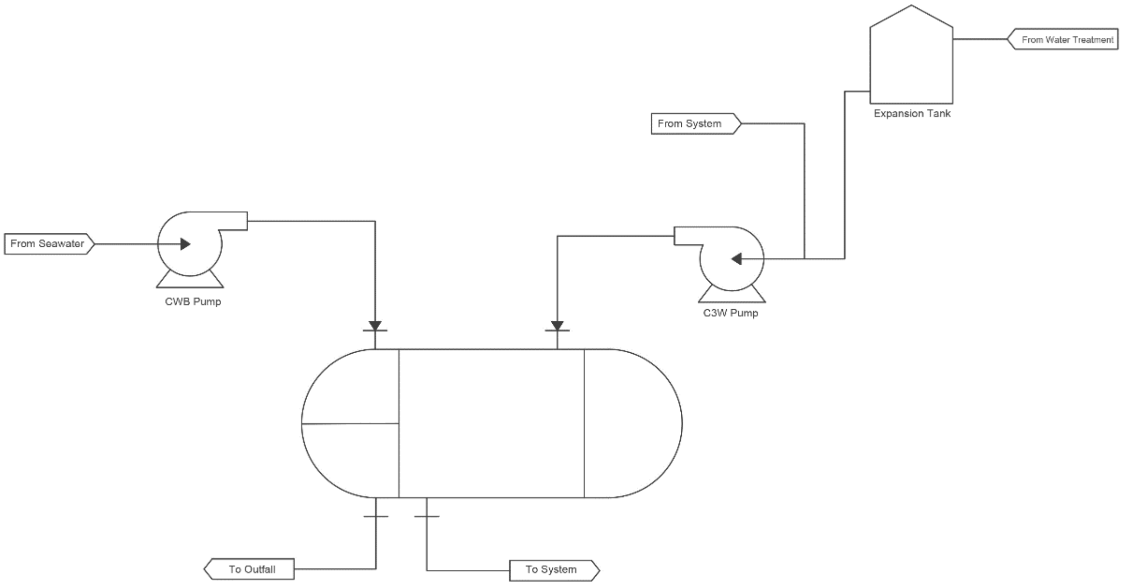
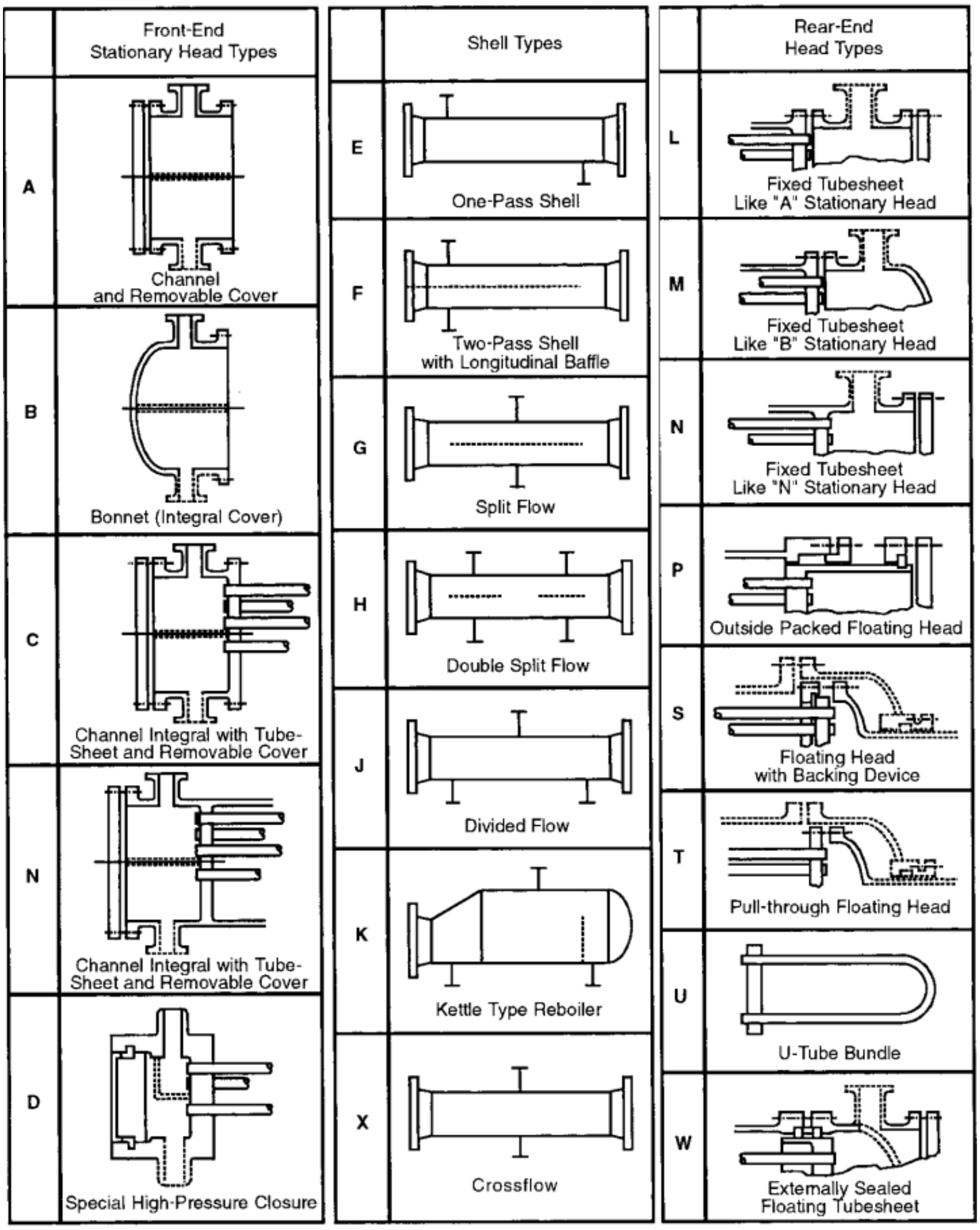


Figure 1: The line diagram of a closed refrigeration cycle in a steam power plant

Table 1: Shell and Tube Type



3. Calculation Methods

3.1 Calculation

Calculation of heat exchanger design using the following steps [7,8]:

i). Determine the temperature data and properties of the fluid used, the required data: inlet temperature (T_1), output temperature (T_2), mass flow (W), heat conductivity (k), specific heat (c), specific gravity (s), and viscosity (μ). The properties used are in the film temperature state of each fluid.

ii). Determination of heat duty (Q) required or desired. The designed HE must meet these heat requirements, and the heat the cooling medium receives must equal the heat released by the hot medium or fluid.

iii). Determining the size of the HE as an initial reference for design. This determination must be reasonable and consider the circumstances in the field.

(iv). Calculating the LMTD (Log Mean Temperature Diagram) of the temperature used and calculating the true LMTD due to the correction factor. LMTD calculation used the following equation:

$$LMTD = \frac{(T1-t2)-(T2-t1)}{\ln (T1-t2)/(T2-t1)} \quad (1)$$

where, T_1 is the inlet temperature of hot fluid (^{o} F); T_2 is an outlet temperature of hot fluid (^{o} F); t_1 is an outlet temperature of cold fluid (^{o} F), and t_2 is an inlet temperature of cold fluid (^{o} F).

(v). Calculating the impurity factor (Rd) of the designed heat exchanger, this factor significantly affects the heat transfer in the HE. The Rd value of the HE must be equal to or greater than the provisions of the fluid used. The Rd value is obtained with the following equation:

$$R_D = \frac{U_C - U_D}{U_C U_D} \quad (2)$$

Here, U_c is overall clean coefficient of heat transfer (Btu/hr ft^{2o}F); U_D is overall design coefficient of heat transfer coefficie*n*t (Btu/hr ft^{2o}F).

vi). Calculating the pressure drop, if the impurity factor value has met the conditions, the pressure drop value can be found. The pressure drop value has a limit of 10 psi; the pressure drop value cannot be more than ten psi. The following equation obtains pressure drop.

$$\Delta P_S = \frac{f G_s^2 D_e (N+1)}{5{,}22 \times 10^{10} D_{es} \emptyset_s} \quad (3)$$

The heat transfer coefficients h_o and h_{io}. Based on the R_D value, the best design is a rectangular pipe arrangement design because the R_D obtained from the calculation results is the same as the Rd provisions.

$$\Delta P_t = \frac{f G_t^2 L n}{5{,}22 \times 10^{10} D s \emptyset_t} \quad (4)$$

Pressure drop on the tube side is added to the return side pressure drop because, in heat exchangers that use two passes on the tube, there is this factor; later the tube pressure drop value is added to the return side pressure drop.

$$\Delta P_r = \frac{4n}{s} \frac{V^2}{2g'} \frac{62{,}5}{144} \quad (5)$$

where D_e is diameter of shell (m); f is friction factor; g' is gravitational acceleration (ft/sec^2); G_s is mass velocity (lb/hr ft^2), L is tube length (m); n is the number of flow passes, (N +1) is Number of crosses; s is specific gravity and V is velocity (m/s).

Pressure drop on the tube side is added to the return side pressure drop because, in heat exchangers that use two passes on the tube, there is this factor; later the tube pressure drop value is added to the return side pressure drop.

(vii). Calculating HE effectiveness requires the maximum heat transfer value (Q_{max}) that may occur. To get the maximum heat transfer, finding each fluid's heat capacity is necessary. The following equation determines the heat capacity of each fluid :

$$C_h = W \times C \quad (6)$$

$$C_c = w \times c \quad (7)$$

$$Q_{maks} = C_{min}(T_1 - t_2) \quad (8)$$

$$\varepsilon = Q/Q_{maks} \quad (9)$$

Where C_c, C_h are capacity rate cold fluid, hot fluid (J/s ^{o}C); c, C are specific heat of cold fluid, hot fluid (J/kg ^{o}C); w, W are mass flow for cold fluid, hot fluid (kg/s), ε is effectiveness.

The working fluids used are demineralized water and seawater, respectively 0.001 (Treated make-up) and 0.0005 (seawater), so the total RD value is 0.0015. The pressure drop for liquid limitation is ten psi or 0.068 MPa.

3.3 Determination of Heat Exchanger Calculation Data

Data obtained from the field (steam power plant) for demineralized water cooling is shown in Table 2. In addition to requiring plant data, HE calculations require dimensional data according to those in the field. The specified data is contained in Table 3.

Table 2: Data obtained from steam power plant for demineralized water cooling

Demineralized water	Seawater
T_{in} = 37°C = 98,6°F	T_{in} = 28°C = 82,4°F
T_{out} = 30°C = 86°F	T_{out} = 31°C = 87,8°F

Table 3: Dimensional data

Inner Diameter Shell (ID) = 60 inch	Out Diameter tube (OD) = 0,75 inch
Baffle space (B) = 20 inch	Thickness (Th) = 0,001633 ft
Passes (Shell) = 1	Pitch (Pt) = 1,05 inch (triangular)
Number of tube (n_t) = 2240	Passes (tube) = 2
Tube length (L) = 25ft	Clearance (C') = 0,3 inch

4. Results and Discussion

The design calculation is done by varying the HE dimensions affecting the R_D and pressure drop values. In HE design, each size or temperature parameter can be altered or changed to get the desired R_D and pressure drop values. Still, in this design, several parameter values are made fixed. The design is also carried out in 2 types; this type of difference is done because the tube placement configuration has two kinds: triangular [9] and square [10].

The R_D values in Tables 4 and 5 have different values because the U_D and U_C values influence the R_D value. Variations affect the U_D value in the value of a", the number of tubes, and the tube length. The Uc value is influenced by the heat transfer coefficients h_o and h_{io}. Based on the R_D value, the best design is a rectangular pipe arrangement design because the R_D obtained from the calculation results is the same as the Rd provisions.

After the design calculation, the next step is determining the material concerning "ASME" [11] Code: Section II Material PART D" as shown in Table 5. Material selection is determined based on dimensions (outside diameter and length) and temperature limitations. The highest temperature on the tube and shell in the HE design is 98.6 °F or 37 °C.

Based on ASME, the temperature limits of each material listed have a value greater than the temperature used in HE. He has a baffle distance of 20 inches or 0.508 m, so there is a tube with a length of 0.541 m without support. The tube length limit with no help at a diameter of 0.75 inches is 60 inches or 1.524 m for the high and low alloy steel material groups. Considering material selection also believes the fluid used, the liquid on the tube side is seawater with a high corrosion rate. Fluids with high corrosion rates require materials that have high corrosion resistance.

Table 4: Design 1 with triangular pipe arrangement

TRIANGULAR			
Shell		Tube	
Mass flow	1102311 lb/h (500 ton/h)	Mass flow	2574634 lb/h (1167.835 ton/h)
Inside Diameter	60 inch (1.52 m)	Number of Tube (N_t)	2442
Baffle space	20 inch (0.508 m)	Tube length (L)	23 ft (7.01 m)
Passes	1	Passes	2
Coefficient of heat transfer (ho)	547.46 Btu/hr ft^{2o}F	Coefficient of heat transfer (h_{IO})	802.11 Btu/hr ft^{2o}F
Pressure Drop (ΔP_S)	6.37 psi	Pressure Drop (ΔP_T)	2.53 psi
U_C 325.38 Btu/hr ft^{2o}F			
U_D 218.42 Btu/hr ft^{2o}F			
R_D 0.001504 hr ft^{2o}F/Btu			

Table 5: Design 2 with square pipe arrangement

SQUARE			
Shell		Tube	
Mass flow	1102311 lb/h (500 ton/h)	Mass flow	2574634 lb/h (1167.84 ton/h)
Inside diameter	60 inch (1.52 m)	Number of Tube (N_t)	2240
Baffle space	20 inch (0.508 m)	Panjang Tube (L)	25 ft (7.62 m)
Passes	1	Passes	2
Coefficient of heat transfer (ho)	517.91 Btu/hr ft^{2o}F	Coefficient of heat transfer (h_{iO})	882.32 Btu/hr ft^{2o}F
Pressure Drop (ΔP_S)	6.32 psi	Pressure Drop (ΔP_T)	3.17 psi
U_C 326.35 Btu/hr ft^{2o}F			
U_D 219.07 Btu/hr ft^{2o}F			
R_D 0.0015 hr/ft^{2o}F/ Btu			

Table 6: Material design

Spesification	Tube	Shell
Composition	Ti-0,3Mo-0,8Ni	Mn-1/2 Mo
Form	Tube	Pipe
Spec No.	SA-672	SB-338
Type Grade	H75	12
Alloy Design	K12021	R53400

Finally, the dimensions and types of materials are shown in table 6 [12-13]. A comparison of the calculations of design 1 and design 2 is shown in Table 7. Based on Table 7, the final value of RD, which determines whether the design is qualified, is different.

Table 7: Comparison of design 1 and design 2

Unit	Design 1	Design 2
U_D (Btu/hr ft^{2o}F)	218.42	219.07
U_C (Btu/hr ft^{2o}F)	325.38	326.35
R_D (hr/ft^{2o}F/ Btu)	0.001504	0,0015
ΔP_S (Psi)	6.37	6.32
ΔP_T (Psi)	2.53	3.17

The best design is that the calculated Rd is equal to the required Rd, meaning that judging from the dirtiness factor, the rectangular pipe arrangement is better than the triangular pipe arrangement. Likewise, the pressure drop value for the quadrilateral account between the calculation and the requirements must be met is closer than the triangular pipe arrangement.

5. Conclusion

Referring to the results of the final project, the following conclusions were obtained:

i). The HE design calculation has a final result of R_D of 0.0015 and a pressure drop of 6.32 psi on the shell side and 3.17 psi on the tube side, with an effectiveness value of 77%.

ii). The materials specified for this design are alloy steel (SA-672) and titanium alloy steel (SB-338).

Conflicts of Interest

The authors declare no conflict of interest.

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