Fernando A. Pascual
Fap2122
Heat Transfer Spring 2018
Quiz 2 Report

List of all final parameters listed at end of report

I decided to use a shell and tube heat exchanger for this project as opposed to a plate heat exchanger. Shell and tube heat exchangers are good for operating at higher temperatures and good for non viscous fluids. To build the condenser, the Kern method found on page 14 of Process Design of Heat Exchangers (https://nptel.ac.in/courses/103103027/pdf/mod1.pdf) was used. Many design considerations were taken with respect to GE's 1000 MW condenser (https://www.gepower.com/steam/heat-exchange/condenser). The cooling water will flow in the shell side while the fluid to be condensed will flow within the tubes. Multiple iterations were used before final values were determined. The first iteration assumes 1 shell 2 tube passes and no pressure drop in the tubes to get a rough estimates of the inlet and outlet thermodynamic properties. Essentially, this first iteration will be a pure counterflow exchanger, so a correction factor of 1 will be used.

The rate of heat transfer in the condenser is 1.35 GW. This was calculated by determining the heat input from the efficiency and net work. The efficiency was taken from the World Coal Organization's website to be 40% for coal - fired power plants. Equation 1 was rearranged to therefore determine heat input to the power plant.

$$(1) \quad \eta = \frac{W_{net}}{Q_{in}}$$

From the 1st law of thermodynamics, we know the difference of heat and work of a closed system is equal to 0, so we can determine the heat removed from the cycle. This value, Q_{out}, is equivalent to the rate of heat transfer in the condenser, which shall simply be called Q from now on.

The temperature at the inlet and outlet of the condenser was determined using the PropsSI function in CoolProp based on the initial pressure of 8 kPa and steam quality of 90%. The temperature was found to be 314 K at the inlet and also at the outlet due to the initial assumption of no pressure drop. From this values of enthalpy were determined at the inlet and outlet to be 2,335,969 J/kg and 173,839 J/kg.

Next, UA of the condenser was determined. Looking at Equation 2, we can see we must find some more values before proceeding.

$$(2) \quad Q = UA\Delta T_{LMTD}^{(CF)}F$$

In Equation 2, U is the overall heat transfer coefficient, A is the are for heat transfer, $\Delta T_{LMTD}^{(CF)}$ is the log-mean temperature difference for a counterflow configuration, and F is a correction factor for the shell and tube design. Equation 3 was used to determine $\Delta T_{LMTD}^{(CF)}$.

$$(3) \quad \Delta T_{LMTD}^{(CF)} = \frac{(T_1(0)-T_2(0))-(T_1(L)-T_2(L))}{ln\left(\frac{T_1(0)-T_2(0}{T_1(L)-T_2(L)}\right)}$$

The correction factor was found using correlations between two dimensionless parameters and figure 4 in HeatExchangersAndThermalFins.pdf - Narayanaswamy. For the first iteration, a correction factor of 1 was used.

Dividing the heat transfer rate in the condenser by $\Delta T_{LMTD}^{(CF)} F$, we get UA. Based off data found in Appendix VI of http://www.chemstations.com/content/documents/Technical_Articles/shell.pdf, it was determined the minimum and maximum overall heat transfer coefficient for water was 800 and 1500 W/m^{2}K. The average of these two values were taken for the first iteration and therefore an assumed value of U, 1150 W/m^{2}K, was used. The initial heat transfer area based on this coefficient was found to be 82,791.3 m^2.

To obtain the mass flow rate of the fluid to be condensed, the heat transfer out of the tubes was divided by the change in enthalpy and determined to be 624 kg/s.

Next, the pressure drop within the tubes was calculated. By calculating the pressure drop, we can go back and iterate on our outlet temperature of the condenser to obtain more realistic numbers compared to what was previously determined and then determine properties of the shell side of the exchanger. To do this, the number of tubes and fluid velocity was determined. Based on equations found on page 14 of Process Design of Heat Exchanger (shown below), we could determine these values and then determine the pressure drop as noted on page 124 of A Heat Transfer Textbook.

$$(4) \quad n_{tubes} = \frac{A}{\pi d_o L}$$

$$(5) \quad u = \frac{4m\left(\frac{np}{n_t}\right)}{\pi \rho d_i^2}$$

$$(6) \quad \Delta P = f\left(\frac{L}{d_i}\right)\frac{\rho u^2}{2}$$

d_o is the outer diameter of the tubes, d_i is the inner diameter, L is the length per tube pass (16.5 meters, based off GE), n_p is the shell-tube-pass ratio (determined to be 2 as mentioned earlier), ρ is the density (the mean was used since the density between inlet and outlet changes significantly). ‘f’ is the Darcy friction factor (64/Re). According to Process Design of Heat Exchanger, The Reynolds number should be above 10,000 for a velocity around 1m/s. To maintain the Reynolds number above 10,000, the calculation of velocity and Reynolds number was reiterated by adding 2 to the number of tube passes per iteration until an appropriate Re was reached. Then the pressure drop could be determined.

Once a pressure drop was determined, we can reiterate on the original outlet temperature to gain a more legitimate output temperature and recalculate all the previous values.

The following dimensions were used:

- Inner Diameter: 0.01 m
- Outer Diameter: 0.022 m

- Tube Length: 16.5 m

With these dimensions, the number of passes was optimized to 14 tube passes to give a Reynolds number of 13,585, flow speed of 0.88 m/s, and a pressure drop of 0.91 Pa. The tube dimensions were chosen based of previous designs found. The tube length was chosen based off a GE condenser.

With reiteration, not much of a difference was found since the tube pressure drop was so low. The correction factor F could be approximated to 0.99 and the final total heat transfer coefficient was 1161.68 W/m^2K as opposed to the guessed 1150 W/m^2K.

The mass flow rate of the cooling fluid was determined using a control volume analysis resulting in Equation 7.

$$(7) \quad Q = mcdT$$

We can assume c to remain the same for the inlet and outlet of the shell side due to the small change in temperature and no phase change. The mass flow rate was therefore 54,006.9 kg/s.

Individual Heat transfer coefficients were calculated using a form of the Sieder-Tate equation, Equation 8.

$$(8) \quad j_h = \frac{h_i d_i}{k}\left(\frac{\mu_{tube} C_{tube}}{k_{tube}}\right)^{-1/3}$$

For the shell heat transfer coefficient, an equivalent diameter had to be used as stated in Process Design of Heat Exchanger, which is shown in equation 9.

$$(9) \quad D_e = \frac{4*\left(pitch^2 - \frac{\pi}{4}d_o^2\right)}{\pi d_o}$$

The pitch in equation 9 is the spacing between tubes. This was determined using 10 m as an acceptable shell diameter and correlating the bundle spacing to this diameter. A square pitch pattern was used.

Once the coefficients were determined, they were added in series with the fouling factor and compared to the assumed U that was initially calculated. The overall U from the individual coefficients added up to 1015.8 W/m^2K which is very close to the assumed value of 1161.7 W/m^2K.

Final List of Parameters:

- Efficiency of power plant: 40%
- Area: 82,791 m^2
- U_{total}: 1161.7 W/m^2K
- Length Tube/Shell: 16.5 m
- Diameter Shell: 10 m
- Inner diameter tube: 10 mm
- Outer diameter tube: 22 mm
- Tube Pitch: square pitch 1mm
- Rate of condensation: 624.4 kg/s
- Mass flow rate cooling water: 54,006.9 kg/s
- H_{shell}: 1146.7 W/mK
- H_{tube}: 8892.4 W/mK
- UA: 96177347.72 W/K
- Thermal conductivity tube (Stainless Steel) = 10 W/mK
- Thermal conductivity shell (Stainless Steel) = 10 W/mK
- Number of Passes: 4
- Pressure drop in tube: 0.91 Pa
- Pressure drop in shell: 0 Pa (remains at atmospheric)
- Number of tubes: 72,598 tubes

I affirm that I did not plagiarize, use unauthorized materials, or give or receive illegitimate help on this assignment.

Sources:

- https://academy.paulmueller.com/different-heat-exchanger-types
- https://www.turnbull-scott.co.uk/about-us/types-of-heat-exchanger/
- http://www.hcheattransfer.com/selection.html
- GE Condenser: https://www.gepower.com/steam/heat-exchange/condenser
- Efficiency of coal power plants: https://www.worldcoal.org/reducing-co2-emissions/high-efficiency-low-emission-coal
- HeatExchangersAndThermalFins.pdf - Narayanaswamy
- A Heat Transfer Textbook
- https://www.engineeringtoolbox.com/thermal-conductivity-metals-d_858.html