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Simulation and Study of Shell and Tube Type Heat Exchangers

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Abstract.

Design of the shell and tube heat exchanger using comsol multiphysics application. The calculation of the dimensions of the heat exchanger aims to determine the quality of the heat exchanger based on the overall heat transfer coefficient, impurity factor, and the pressure drop that will occur. The heat exchanger that is made and designed is a shell and tube type heat exchanger 1 (one) pass shell and 1 (one) pass tube made of stainless steel 304 and copper with fluid flow in the form of air and water. The analysis results obtained that the heat exchanger that is designed already meets the requirements of the effectiveness coefficient of the baffle, understands the factors that exist in the shell and tube type of heat exchanger and understands the factors that affect efficiency and effectiveness. Calculations using the LMTD method, obtained that receive heat released has a large unity with time Q , then the heat received by cold fluid is $Q = 4565.16$ W, LMTD produced also shows the number 20, with a proven factor (F) is 1. Reynolds Number of the tube side is greater than shell side.

1. Introduction

Heat exchangers are widely used in daily life and in industry. Heat exchanger is a device used to exchange energy in the form of heat between fluids of different temperatures, which can occur through direct contact or indirect contact. Energy exchanging fluids can be in the same phase fluid as liquid to liquid or gas to gas. There are a lot of heat exchangers in the industry such as boilers, super heaters, oil coolers, condensers. In the chemical process industry the problem of transferring energy or heat is very much done. It is well known that heat can take place in three ways in which the heat transfer mechanism itself is different. The purpose of this study is to understand the factors that exist in shell and tube heat exchangers and to understand the factors that affect efficiency and effectiveness.

2. Method and materials

The method used is a simulation method with comsol multiphysics software. This test is conducted with the aim of knowing the fluid flow in the heat exchanger (shell exchanger) with the type of shell and tube.



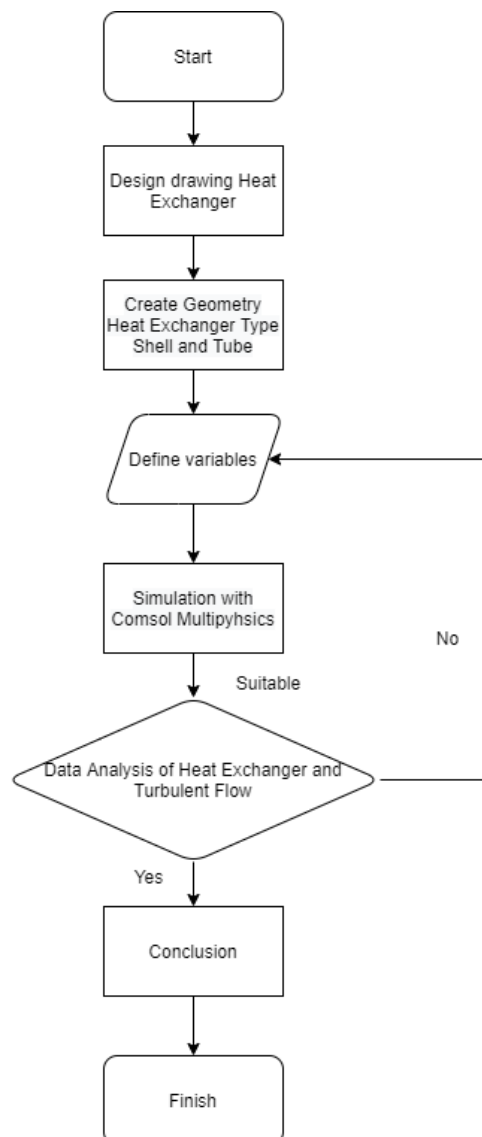


Figure 1. Flow Chart

In making components made using the Fusion 360 application first and then importing them into the Comsol application, the process starts with the manufacture of geometry to make the tube body type heat exchanger shell and tube, each surface, both the body and the shell, has the same size. Initially made in advance in the baffles part of a complete circle with a total of 34 pipes and a total of 2 baffles with a size of 120 mm, having a thickness of 10 mm, Then after that, half of the baffles are made to be installed on the components on the shell and tube heat exchanger, with a total of 9 baffles. Making a body with a diameter of 125 mm and a thickness of 5 mm, made slightly wider than the size of the baffle so that the placement of the baffle with the body can match, After that, combine the baffles from the full circle baffles to the circle baffles that are not full or half. And lastly is the manufacture of a cover or surface for this shell and tube heat exchanger with a diameter of 150 mm and a thickness of 40 mm, and also with the cover filled with a 30 mm radius (tangent). The fluids used are air and water. the number of pipes used is 34 pieces, the material used is

stainless steel 304 and copper. The length dimension of the pipe used is 110 cm and also the type of heat exchanger that is used shell-and-tube.

3. Results and discussion

Meshing is the process of continuous discretization of the fluid domain into a discrete computational domain so that equations (in this case the fluid flow) can be solved in it and produce a solution. Mesh is also useful for dividing the geometry of the model into many elements used by the solver to build volume controls. The following process of meshing on *comsol multiphysics* has been made:



Figure 2. Final *Meshing*

In the result there are several components that have been made such as velocity, the following image that has been formed in the comsol multiphysics application:

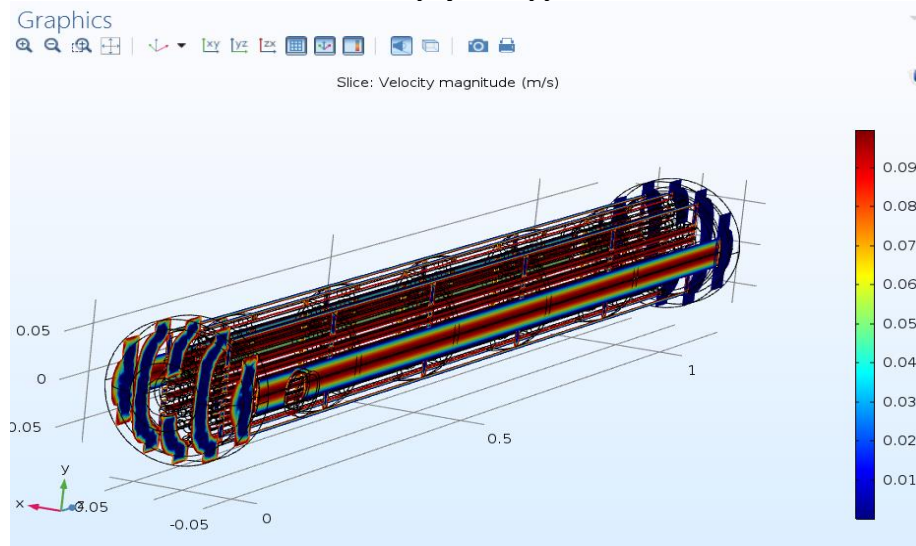


Figure 3. *Velocity*

This section is a form of components that have entered the result stage in the COMSOL application, the numbers contained in the figure show that the speed from 0.01 to 0.09 is the highest in the component. The result part after velocity is pressure, this pressure aims to show that there is pressure on each of these components, the following pressure image has been made:

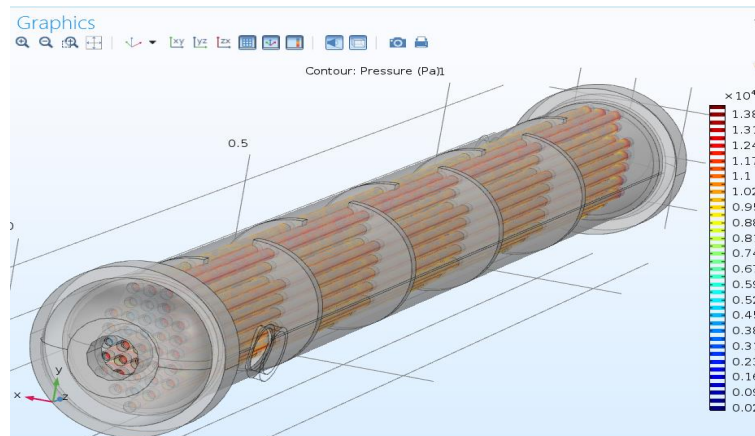


Figure 4. Pressure

Pressure or pressure generated on each component to determine the value of the amount of pressure starts from 0.02 to 1.38×10^4 .

Theoretical calculation

- ✓ If the heat released has a magnitude equal to Q unity of time, then the heat received by the cold fluid equal to Q is equal to:

Information:

Q = Heat released / received (W)

U=Comprehensive heat transition coefficient (W / m² 0 C)

A = Heat transfer area (m²)

ΔT = Difference in average temperature (0C)

- ✓ $Q = U \cdot A \cdot \Delta T$

$$Q = 16,2 \text{ W / (m.K). } 14,092 \text{ m}^2. (1000 - 800)$$

$$Q = 4565,912 \text{ W}$$

$$LMTD = (\Delta T_{max} - \Delta T_{min}) / (\ln \Delta T_{max} / \Delta T_{min})$$

$$\Delta T1 = T_{Hot_In} - T_{Cold_Out}$$

$$= 100.00 - 92.00$$

$$= 8.00$$

$$\Delta T2 = T_{Hot_Out} - T_{Cold_In}$$

$$= 100.00 - 80.00$$

$$= 20.00$$

$$LMTD = 13.10$$

- ✓ This is the LMTD result of calculations using the LMTD Calculation application. For the type of heat exchanger 1 fitting shell and 1 fitting tube correction factor (F) = 1.

- ✓ Tube Side Calculation

Reynolds number (Re, h)

Information :

ρ = density (kg / m³)

Vs = flow velocity (m / s)

L = Tube diameter length (m)

μ = Viscosity of fluid (N.s / m³)

$$Re = \rho V_s L / \mu$$

$$Re = (1000 \times 0.1 \times 0.15) / (3 \times 10^{-4})$$

$$Re = 50,000$$

- So, the type of flow that occurs in the tube is turbulent flow because Re, h > 2300, Convection Heat Transfer Coefficient (hi)

The convection heat transfer coefficient (h_i) can be found from the Nusselt (Nu) equation as follows:

- Information :
 - Re = Reynold number
 - $n = 0.8$
 - Pr = Prandtl Number (Provision of water fluid)
 - $m = 0.4$ (hot fluid)
 - ✓ $Nu = 0.023 (Re^n) (Pr^m)$
 $Nu = 0.023 (50.0000.8) (0.6880.3)$
 $Nu = 118.0811$
 - ✓ So that:
 $h_1 = (Nu \times K) / d$
 $h_1 = (118.0811 \times 16.2) / 0.15$
 $h_1 = 12752.76 \text{ W / m}^2 \text{ }^\circ\text{C}$ (Cold Fluid)
 $R_{\text{total}} = R_{\text{hot fluid}} + R_{\text{pipe}} + R_{\text{cold fluid}}$
 $R_{\text{hot fluid}} = 1 / (h_1 \times d)$
 $R_{\text{hot fluid}} = 1 / (113.7468 \times 0.15)$
 $R_{\text{hot fluid}} = 0.05861$
 - $R_{\text{cold fluid}} = 1 / (118.0811 \times 0.15)$
 $\text{Cold fluid } R = 0.05645$
 - ✓ $R_{\text{pipe}} = \frac{\ln \left(\frac{r_{\text{out}}}{r_{\text{in}}} \right)}{2 \times \pi \times K}$
 - ✓ $R_{\text{pipe}} = \frac{\ln \left(\frac{65}{20} \right)}{2 \times 3.14 \times 16.2}$
 $\text{Pipe } R = 0.01159$
 - ✓ $\text{Total } R = 0.05861 + 0.05645 + 0.01159$
 $\text{Total } R = 0.12666$
- Shell Side Calculations
 - Reynold's number (Re , c)

$$Re = \rho V_s L / \mu$$

$$Re = (1000 \times 0.1 \times 0.05) / (12.33 \times 10^{-6})$$

$$Re = 405,515$$

So, the type of flow that occurs in the tube is turbulent flow because $Re, h > 2300$ (Incropera: 1996), Convection Heat Transfer Coefficient (h_i) The convection heat transfer coefficient (h_i) can be found from the Nusselt (Nu) equation as follows:

$$Nu = 0.023 (Re^n) (Pr^m)$$

$$Nu = 0.023 (4055150.8) (0.6880.4)$$

$$Nu = 606,972$$

Result:

$$h_0 = (Nu \times K) / d$$

$$h_0 = (606,972 \times 16.2) / 0.05$$

$$h_0 = 65552.99 \text{ W / m}^2 \text{ }^\circ\text{C}$$
 (Hot fluid)

$$Nu = 0.023 (Re^n) (Pr^m)$$

$$Nu = 0.023 (4055150.8) (0.6880.3)$$

$$Nu = 630,1$$

Result:

$$h_0 = (Nu \times K) / d$$

$$h_0 = (630.1 \times 16.2) / 0.05$$

$$h_0 = 204152,6 \text{ W / m}^2 \text{ }^\circ\text{C}$$
 (Cold fluid)

$$R_{\text{total}} = R_{\text{Hot fluid}} + R_{\text{pipe}} + R_{\text{cold fluid}}$$

$$R_{\text{hot fluid}} = 1 / (h_0 \times d)$$

$$R_{\text{fluid heat}} = 1 / (65552.99 \times 0.05)$$

$$R_{\text{hot fluid}} = 3.05 \times 10^{-4}$$

$$R_{\text{cold fluid}} = 1 / (204152.6 \times 0.05)$$

$$R_{\text{cold fluid}} = 9.79 \times 10^{-5}$$

$$R_{\text{pipe}} = \frac{\ln \left(\frac{r_{\text{out}}}{r_{\text{in}}} \right)}{2 \times \pi \times K}$$

$$R_{\text{pipe}} = \left[\ln \left(\frac{62.5}{62} \right) \right] / (2 \times 3.14 \times 16.2)$$

$$R_{\text{pipe}} = 9.82 \times 10^{-5}$$

$$R_{\text{total}} = 3.05 \times 10^{-4} + 9.79 \times 10^{-5} + 9.82 \times 10^{-5}$$

$$\text{Total } R = 5.01 \times 10^{-4}$$

Overall Design Heat Transfer Coefficient (Ud)

$$U_d = \frac{Q}{A \times LMTD}$$

$$U_d = \frac{4565,912}{14,09 \times 20}$$

$$U_d = 16,2 \text{ W/m}^2\text{ }^\circ\text{C}$$

Clean Whole Heat Transfer Coefficient (Uc)

$$U_c = \frac{1}{\frac{1}{h_1} + \frac{\ln \left(\frac{r_{out}}{r_{in}} \right)}{2 \times \pi \times K} + \frac{1}{h_0}}$$

$$U_c = \frac{1}{\frac{1}{0,001304} + \frac{\ln \left(\frac{65}{20} \right)}{2 \times 3,14 \times 16,2} + \frac{1}{9,82 \times 10^{-5}}}$$

$$U_c = 375,9361 \text{ W/m}^2\text{ }^\circ\text{C}$$

Fouling Factor (Rf)

$$R_f = \frac{U_c - U_d}{U_c \times U_d}$$

$$R_f = \frac{375,9361 - 16,2}{375,9361 \times 16,2}$$

$$R_f = 0,059068 \text{ }^\circ\text{C} \cdot \text{m}^2 / \text{W}$$

Pressure drop (ΔP)

- Side of *Tube* :

$$\Delta P_t = \frac{f \times G t^2 \times L \times n}{2 \times g \times d_i \times \rho \times \phi}$$

$$\Delta P_t = \frac{0,035 \times (0,01)^2 \times 0,15 \times 2}{2 \times 9,81 \times 0,04 \times 1000 \times 1}$$

$$\Delta P_t = 1,34 \times 10^{-9} \text{ kg/m}^2$$

- Side of *Shell* :

$$\Delta P_t = \frac{f \times G t^2 \times L \times n}{2 \times g \times d_i \times \rho \times \phi}$$

$$\Delta P_t = \frac{0,008 \times (1)^2 \times 0,05 \times 2}{2 \times 9,81 \times 0,01 \times 1000 \times 1}$$

$$\Delta P_t = 4,08 \times 10^{-6} \text{ kg/m}^2$$

Heat Capacity (C)

Cold fluid in the shell:

Information :

Cc = Cold Heat / Cold Fluid Capacity

mc = Shell weight

Cp.c = Air density

Cc = mc x Cp.c

Cc = 0.05 x 1000

Cc = 50 W / °C

Hot fluid in the tube:

Information :

Ch = Heat / hot fluid capacity rate

mh = Tube weight

Cp.h = Density of water

Ch = mh x Cp.h

Ch = 0.015 x 4200

Ch = 63 W / °C

From the rate of heat capacity obtained, Ch >

Cc then Cmax = Ch and Cmin = Cc

Maximum Heat Transfer Rate (max q)

Information :

Cmin = The smallest value of the results of the comparison of Ch and Cc

Th in = Temperature of hot fluid entering

Tc in = The temperature of the incoming cold fluid

Q max = Cmin (Th in - Tc in)

Max Q = 50 (1000 - 800)

Max Q = 1000 watts

Effectiveness of the Heat Exchanger (ϵ)

The effectiveness of a heat exchanger is obtained by comparing the actual heat transfer rate with the maximum possible heat transfer rate.

Information :

Actual Q = Actual rate of heat transfer

Q max = Maximum heat transfer rate

$\varepsilon = (\text{actual Q}) / (\text{Q max}) \times 100\%$

Actual Q = $C_c \times (T_{c \text{ out}} - T_{c \text{ in}})$

Actual Q = $50 \times (920 - 800)$

Actual Q = 600 watts

Q max = $C_{\text{min}} \times (T_{h \text{ in}} - T_{c \text{ in}})$

Max Q = $50 \times (1000 - 800)$

Max Q = 1000 watts

$\varepsilon = (\text{actual Q}) / (\text{Q max}) \times 100\% = (600 \text{ W} / (1000 \text{ W}) \times 100\% = 60\%$

4. Conclusion

The velocity section, shows that the smaller velocity section is found in the Stationary Head of a shell and tube type heat exchanger component. The effectiveness of the heat exchanger shows a value of 60% and impurity factor is 0.059068 $0C. m^2 / W$. The coefficient values (U_d) and the value of the heat transfer coefficient (U_c) are respectively $16.2 \text{ W} / m^2 \text{ }^0C$ and $375.9361 \text{ W} / m^2 \text{ }^0C$. The rate of heat capacity of the tube is greater than the heating speed of the shell. The convection heat transfer coefficient (h_0) produced by the tube is smaller produced by the shell.

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