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Material Selection for Shell and Tube Heat Exchanger Using Computational Fluid Dynamics Method

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Abstract. Shell and Tube Heat Exchanger (STHE) is equipment generally assembled from a bundle of round tubes mounted in cylindrical shell parallel to the tube axis to exchange the heat energy between the two fluids. The selection of material plays an important role in optimizing the STHE design. By using Computational Fluid Dynamic (CFD) method in ANSYS FLUENT software, distribution of temperature was obtained due to the usage of some different materials. In this research, the heat exchanger was studied with the number of baffle of one, three, and five pieces using aluminum, steel, and copper as the materials. From this research, it was found that copper with baffle number of five pieces produced the highest rate of heat transfer, the highest heat transfer coefficient and the lowest the pressure drop.

BACKGROUND

Heat transfer is one of the most important phases in a mechanical system. Heat transfer has a significant role due to the demand of energy that keeps increasing and almost every aspect of an industry requires heat transfer. Heat transfer is available in many different forms, particularly for the current use in the industrial sectors, one of them is the shell and tube heat exchanger (STHE) [1].

A STHE consists of a shell and a tube located inside the shell. On the surface of the shell, liquid is forced to flow through the surface of the tube in order to transfer the heat between the two different liquids. One set of tube is referred as the tube bundle consisting of several tubes. To support a long lasting heat transfer process, excellent materials is needed. If the selected materials are less appropriate, it will impact on the production rate due to the equipment failure. Therefore, a good engineer has to comprehend the details of the entire aspects of an equipment, such as the most suitable material for the assembly, as well as the maintenance and operation of heat transfer to prevent any equipment failures and corrosion in the shell and tube [1].

RESEARCH METHODS

Research Step

In this study, there were three steps of simulation using Computational Fluid Dynamics (CFD), which were [2]:

1. Pre-processing
   The first step was to make a model in CAD (Computer Aided Design), create the right mesh, and subsequently apply the limits and the properties of the fluid.
2. Problem Solving
   Problem solving was a step for using Solvers (Program for finding a solution) of CFD to calculate conditions when the pre-processing was being carried out.

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3. Continued Process
   Continued process was the last step in CFD analysis. This stage was the organization and interpretation of data derived from CFD simulation, which were in the forms of image, curve, animation, etc.

Computational Model

Computational model of STHE is shown on Fig. 1, and it was simulated with 5 (five) cycle from baffle to the shell side with 24 numbers of tube. The calculation domain as a whole was constricted by the inside of a shell and any other objects located inside the tube within the domain. The inlet and outlet domain were connected to the same tube.

To simplify the numerical simulation, the following assumptions were made [3]:

- Fluids on the shell side has a properties of constant thermal;
- Convection occurred by nature due to density variety of the fluid can be ignored;
- Heat exchange is well-isolated, therefore heat loss to the surroundings is completely ignored;
- Leak in flows between tube and baffle, meanwhile leak between baffle and shell is ignored ;
- No change in temperature on the wall of the tube at shell side and baffle side;
- Flow of fluids and heat exchange process is a turbulent flow in a steady state.

Geometry and Mesh

Specifications of STHE:

- Type of STHE is the straight type
- Diameter inside shell is Φ 90mm with length of 600mm
- Total number of tubes are 7 (seven) pieces, with the layout of rotated triangular and tube pitch of 30mm
- Dimension of outside diameter is Φ 20mm
- Material of shell and tube is made of steel, aluminum and copper [4]
- Baffle cut dimension is 22%
- Fluids in Shell is cold water and inside tube is warm water
- The baffles are 5 pieces (NP5), 3 pieces (NP3) and 1 piece (NP1).

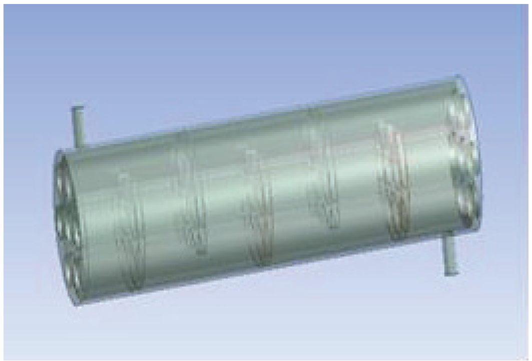


FIGURE 1. Isometric on STHE baffle

Discretize Model

Three-dimension model was discretized on CFD by using accurate hexahedral mesh element and involving some calculations. A good control on hexahedral mesh near the surface would lead to high accurate capture of gradient layer boundary.

Heat exchanger that has been discretised in terms of solid and fluid domain will have a better control above node numbers. Fluid mesh is better made with solid mesh to simulate the combination of heat transfer. The 26 fluid domain as shown on Fig. 2. The result of the model that has been discretised is up to the required standard, which later will be exported to ANSYS.

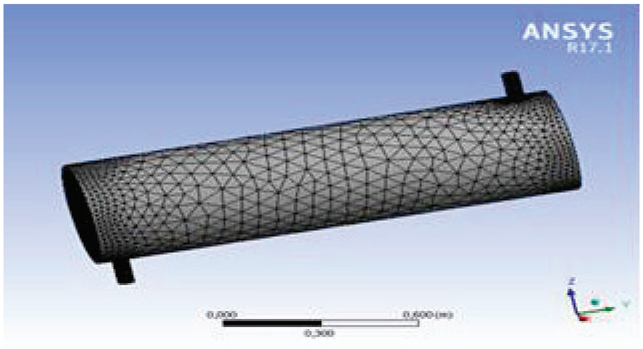


FIGURE 2. The Mesh of STHE

Meshing

At first mesh, a large mesh size was created containing of mixed cells (tetra cell and hexahedral cell) with the shape of triangle and rectangle. This method was acquired through the use of structured cell (hexahedral) as much as possible through automatic method that is available on ANSYS meshing client. It was intended to reduce the amount of numerical diffusion as much as possible with an exceptional setup of mesh, most importantly near the wall area in shell. Afterwards, for independent mesh model, a fine mesh was created for the edges and the gradient area that had high temperature and pressure, as shown in Fig. 2.

The produced model was transferred to ANSYS workbench. Furthermore, physic preference of CFD and solver preference of fluent were chosen.

Solution Set-up

Simulation was done using ANSYS FLUENT software. In the simulation, the preference of type pressure was based, velocity formulation was absolute, and time was transient at the solver part. In the calculation phase, the model with Energy - on, viscous, standard $k - \varepsilon$, standard wall Fn, was preferred.

Solution Initialization

Solution method used the pressure of velocity coupling with SIMPLE scheme. In Spatial discretization, the preferences were the gradient of least squares cell based, pressure of second order, momentum of second order upwind, turbulent kinetic energy of second order upwind, and turbulent dissipation rate of first order upwind. In the solution control, momentum of 0.7, turbulent kinetic energy of 0.8, turbulent dissipation rate of 0.8, turbulent viscosity of 1 and energy of 1 were opted [5].

RESULTS AND DISCUSSION

Convergent simulation

By using limited conditions, initializing solution was set for 500 iterations. The convergence from this simulation was needed to obtain the parameter on the outlet of STHE. It was also expected to provide more accurate values for the used parameter of the rate of heat transfer. Continuity, X-Velocity, Y-Velocity, Z-Velocity, energy, k, epsilon are the elements of residual scale estimators that have to be converted into a specific area. For this simulation, the values of Continuity, X-Velocity, Y-Velocity, Z-Velocity, k-epsilon should be less than 10^{-4} and the energy value should be less than 10^{-7}.

Streamline Plot

The illustration of a speed contour streamline (for baffle cut/BC of 22%) along STHE is demonstrated on Fig. 3. Fluid flows from the above of the inlet side and exits at the bottom to the outlet side going through a few baffles. The colors change at the inlet, flowing through the first baffle, second baffle and so on to the outlet of shell. The color shows a decrease in speed of the fluid due to the installation of baffle inside the shell. On the shell side, the fluid flows through baffle cut goes to the outlet of the shell can be noticed.

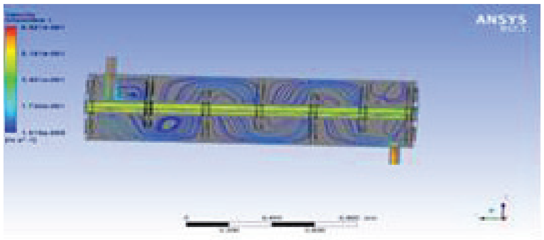
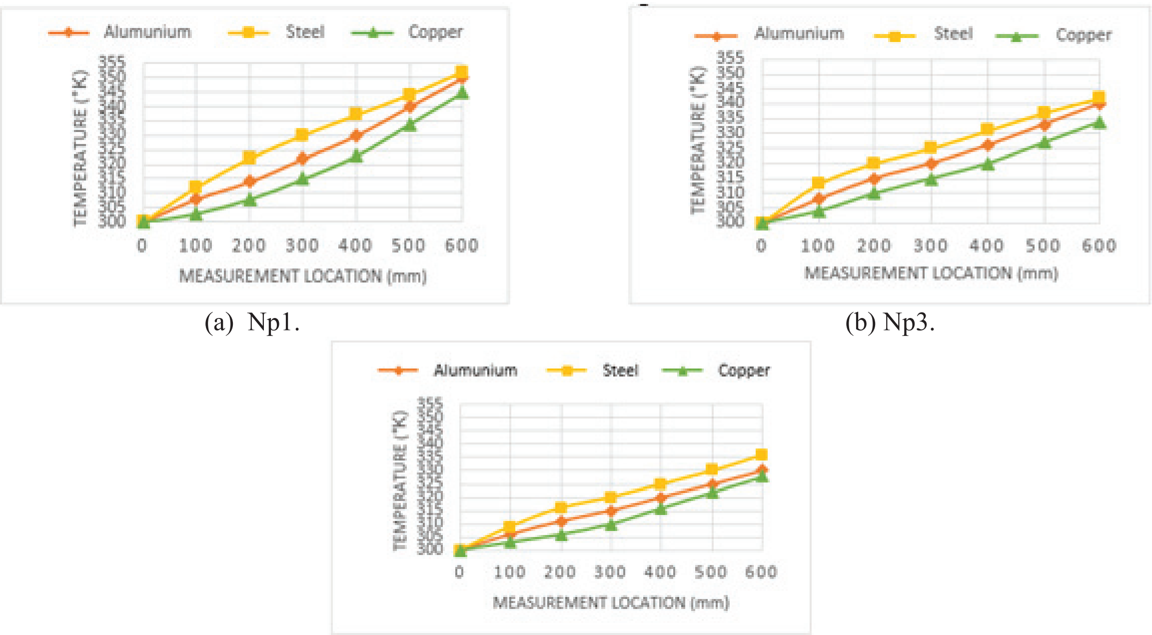


FIGURE 3. Velocity streamline at baffle cut of 22% with five baffles.

The Effect of Material on Temperature along the Axis of STHE

Fig. 4(a) shows the usage of five baffles in which the simulation produced different temperatures between the area of going out and going in of the shell. The highest difference occurred on steel material with temperature of 52K. Fig. 4(b) shows the usage of three baffles, in which the highest difference in temperature between area of going out and going into the shell occurred on the steel as the material with temperature of 42K. Meanwhile, Fig. 4(c) shows the usage of 1 (one) baffle, in which the highest difference occurred on steel material with temperature of 36K. From those graphics, it can be seen that Δt of steel has the highest difference while the resistance becomes higher and the coefficient of the heat transfer (U) is smaller. Therefore, it can be concluded that steel material with Np 5 on STHE produces the highest differences temperature.



(a) Np1.

(b) Np3.

(c) Np5.

FIGURE 4. Temperature distributions of materials with diverse numbers of baffle.

The Effect of the Number of Baffle on Temperature along the Axis of STHE

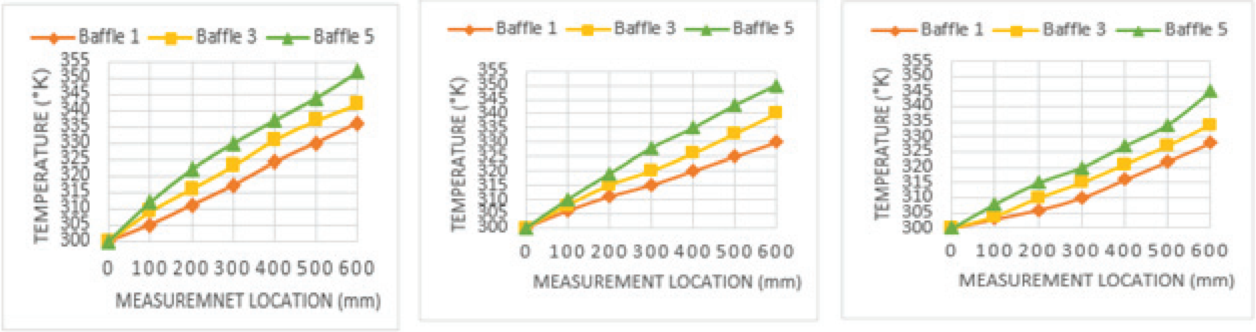
Fig. 5(a) shows the highest differences in temperature between the area of outlet and inlet of shell when the number of baffle was five (Np5) with temperature of 52K. Fig. 5(b) shows the lowest differences in temperature between the area of exit and entrance of shell when the number of baffle was three (Np3) with temperature of 50K. Meanwhile Fig. 5(c) shows the lowest differences in temperature between the area of exit and entrance of shell when the number of baffle is one (Np1) with temperature of 45K. The temperature of steel has the highest value, because it has the largest K from any other materials and on every baffle, it was found that Np5 experienced a significant change in temperature between Np1 and Np3. It occurred because Np5 has a high resistance, therefore the coefficient of heat transfer becomes lower when the Δt increases.

Temperature of the Outlet of Shell with Five Baffles

The temperatures of the outlet of the shell with five baffles for different STHE materials vary as can be seen in Table 1.

TABLE 1. Temperature outside of the shell for STHE material

STHE material	Temperature of the outlet of the shell (K)
Steel	352
Aluminum	350
Copper	345



(a) Steel (b) Copper (c) Aluminium

FIGURE 5. Temperature distributions of several materials with different numbers of baffle.

Pressure Drop of the Outlet of Shell with Five baffles

The values of pressure drop of the outlet of shell with five baffles for diverse STHE types vary as can be seen in Table 2.

TABLE 2. Pressure drop of the outlet of the shell for diverse STHE materials

STHE material	Pressure drop of the outlet of the shell (Pa)
Steel	239.60
Aluminium	234.09
Copper	227.82

The Entity of Heat Transfer Coefficient

Table 3 shows the highest rate of heat transfer (Q) and temperature going out (To) when the number of baffle was five for steel, aluminum and copper. At those conditions, the highest pressure drop occurred when steel was used as the material. To obtain an optimum value for STHE design which made up of variables of large value of Q and small value of Δp [6], the copper yields optimum design for STHE according to large value of Q and small value of Δp. Data of the heat transfer coefficient from the simulation can be seen in Table 3.

TABLE 3. Heat transfer coefficient

Material and baffle cut size	Number of Baffle	Outside Temperature, T_o (K)	Overall Heat Transfer Coefficient, U (W/m^2K)	Rate of Heat Transfer Q (W)
Steel, 22%	1	336	5.22	187.9
	3	342	5.46	229.3
	5	352	5.82	302.6
Aluminium, 22%	1	330	6.00	180.1
	3	340	6.44	256.7
	5	350	6.80	340.4
Copper, 22%	1	328	9.67	270.7
	3	334	10.4	353.6
	5	345	12.1	544.5

CONCLUSIONS

From this research, it can be concluded that:

1. The selection of material and the number of baffle have a significant impact in the change of coefficient and the rate of heat transfer from STHE.
2. The change in material and the number of baffle affect the temperature at the outside of the shell.
3. The change in material and the number of baffle inside the shell affect the value of pressure drop.
4. The most optimum design for STHE is by using copper as the material.

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