The Influence of Baffle Inclination on Fluid Flow and Temperature Distribution of HPH Heat Exchanger

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Abstract. High Pressure Heater is one of the heat exchanger type shell and tube in the plant consisting of a shell on the outside and a tube on the inside where the temperature of a fluid in the shell is different from the temperature inside the tube, resulting in heat transfer between fluid flows. The use of baffle inclination on the shell side serves to direct the fluid flow so that the flow occurs turbulence that can affect the temperature distribution on the shell side. This study aimed to determine the influence of baffle inclination angle on temperature distribution and fluid flow. The results showed that using variations in the angle of baffle inclination can increase the outlet temperature value and the higher temperature at a 20° variation in baffle inclination angle of 349.74 K, the pressure on the shell side decreases at each variation lowest value of 793.19 pa at 0° variation of baffle inclination and the velocity value produced is higher with the increasing angle of the baffle. Given the variation in baffle angle, the change in value in the high-pressure heater is caused by turbulence caused by baffle inclination on the shell side.

1. Introduction

The production process of the power plant is influenced by the leading equipment in the Steam Power Plant, for example, boiler, turbine, condenser and generator. Research in the field of power plants is critical. Research Trisnayanthi et al. and Satrio et al. discusses the kinds of fuels such as LNG, HSD, MFO and coal to power plant performance [1,2]. There is research Kurniawati et al. discuss condenser investigation on power plant [3]. This study examines the angle of baffle inclination in HPH to obtain a high temperature value.

High Pressure Heater has a vital role in maintaining the water temperature that will enter the boiler and is one example of a heat exchanger. The process occurs by utilizing the heat transfer process from a high-temperature fluid to a low-temperature fluid. The main components of shell and tube type heat exchangers are tube, baffle, shell, front head, rear head, and nozzle. Generally, shell and tube type heat exchangers have parallel flow, counter flow and cross. From the flow is given baffle on heat exchanger so that in the working fluid there is considerable turbulence to improve the performance of the heat exchanger. One of the many baffles in use is the segmental baffle type that has the advantage of easy installation, affordable price, and high heat transfer. Segmental type baffle also has some disadvantages that are prone to high flow speed that results in vibration in heat exchanger [4].

The performance of the heat exchanger can be said to be good if it gets a considerable heat transfer coefficient value where this value is obtained from the Reynolds number. The greater the Reynolds
number it will affect the value of the coefficient of heat transfer rate. The type of heat exchanger used in this simulation using shell and tube is then given a baffle on the shell side that has the primary function to direct the fluid flow evenly to obtain a more excellent heat transfer value caused by turbulence.

S. R. Bhandurge, et al. [5] researched the effect of baffle tendency on the shell and tube with a variation in angle 0°, 15°, 30°, and 45° to find out the coefficient of heat transfer rate. The result obtained by the coefficient of heat transfer and heat transfer rate increased by 10% to 17% when the baffle angle changed from 0° until 45°.

P. A. Kiyasudeen, et al. [6] researched shell and tube heat exchanger using baffle inclination variations of -20°, 0° and 20°. The heat exchanger simulates using FLUENT CFD software, in which the researchers obtained the outlet temperature value shown in Table 1.

| Baffle Inclination Angle | Total Temperature (K) | Min   | Max   |
|--------------------------|------------------------|-------|-------|
| -20                      |                        | 267   | 347   |
| 0                        |                        | 300   | 338   |
| 20                       |                        | 260   | 377   |

From the results obtained, the considerable angle of baffle used, the heat transfer is increasing so that at the angle of inclination baffle 20° has the best results compared to the angle of inclination -20° and 0° because of the lack of support for the shape of the tube on the shell and baffle cannot be used effectively.

The purpose of this research was to determine the influence of baffle inclination on temperature distribution, pressure on inlets and outlets, pressure drop, velocity, and streamline on the shell side affected by the angle of baffle inclination. With baffle inclination, it is expected to increase the value of heat transfer in high pressure heater. In this study, heat transfer occurs due to friction between the fluid on the shell side and heat on the tube wall with the co-current flow, so the final result in this study is focused on shell side heat transfer only.

2. Numerical Method
This study aims to analyze fluid flow in the shell which includes the distribution of temperature, pressure, and velocity will then be simulated using CFD software. The angle of inclination of the baffle used is intended to determine the comparison of heat transfer produced in each variation of the baffle inclination. This stage consists of three stages, namely pre-processing, processing and post-processing.

2.1. Geometry Modelling
In this study, the observed geometry is high pressure heater in the subcooling zone. The required data in the form of geometry in high pressure heater obtained from the reference [7] is shown in Table 2.
Table 2. Geometry specifications of High Pressure Heater.

| Named                              | Description |
|------------------------------------|-------------|
| Shell inner diameter               | 180 mm      |
| Tube outside diameter              | 40 mm       |
| Shell length                       | 1220 mm     |
| Number of tubes in the shell       | 7           |
| Pitch tube                         | 60 mm       |
| Number of baffles in shell         | 6 mm        |
| Baffle diameter                    | 180 mm      |
| Baffle thickness                   | 6 mm        |
| Baffle spacing                     | 172 mm      |
| Diameter inlet                     | 80 mm       |
| Baffle cut                         | 25%         |

The process of drawing High Pressure Heater from CFD software uses a type of design modeller. By using the data in Table 2 so that you can see the results of images created with a design modeller such as Figure 1.

Meshing is the process of dividing geometry that has made into small elements. The accuracy of the simulation results depends on the density of the geometry when meshing. The smaller the size of the elements in the geometry used, the more elements are formed and affect the length of the computational process. In this study, the meshing used was global mesh on the shell side body, inlet shell body and outlet shell body. In addition, the meshing stage gives the naming of the location for the boundary condition. the results of meshing created in CFD software, such as Figure 2.
Grid Independent aims to find the best mesh and results. Independent grid uses the difference between mesh element and outlet temperature. On the independent grid, it is necessary to data the outlet temperature that will be destabilized so that it can be said that there will not be an increase or decrease in the outlet temperature. The addition of element size at the right point can change the element value, orthogonal quality, and temperature value. So that the change in outlet temperature to element size can be seen in Figure 3.

2.2. Simulation Process
The next step is simulating using a fluent solution setup solver using pressure-based and steady-state. In the selection of models, several are activated, among which are energy and viscous using realizable k-\(\varepsilon\). In addition to operating two types of materials for fluids using water and solid using aluminium. In boundary conditions, inputted parameters can be seen in Table 3.

![Figure 2. Meshing of the High Pressure Heater.](image)

![Figure 3. Grid Independent test.](image)
Table 3. Boundary conditions.

| Named           | Description       |             |             |
|-----------------|-------------------|-------------|-------------|
| Inlet Shell     | Type              | Velocity Inlet |             |
|                 | Mass Flow Rate    | 0.1997 m/s  |             |
|                 | Temperature       | 300° K      |             |
| Outlet Shell    | Type              | Outflow     |             |
| Wall Tube       | Type              | Stationary Wall |         |
|                 | Temperature       | 450° K      |             |

The selection of methods in the simulation in this study using coupled and change the second-order upwind scheme on momentum, turbulent kinetic energy, Turbulent dissipation rate and energy, in addition to the default standards. Next, on the initialization solution using hybrid initialization, then click initialize. After that, do run calculation with 5,000 iterations and click calculate.

3. Result and Discussion

3.1. Validation Data
In this study, variations of 0°, 10°, 20° are by the geometry contained in the journal after obtaining the desired value. Validation is required to know if the simulation results are by the reference used using temperature outlet.

Table 4. Validation data.

| Variation | Tout Shell from Reference [7] | Tout Shell from Simulation | Error (%) |
|-----------|-------------------------------|---------------------------|-----------|
| 0°        | 336.377 °K                    | 348.989 °K                | 3.74%     |
| 10°       | 337.285 °K                    | 347.549 °K                | 3.04%     |
| 20°       | 335.968 °K                    | 346.33 °K                 | 3.08%     |

From the data in Table 4 can see the difference between tout shell data in journals and simulations is highest in 0° variation, namely with the value in the journal of 335.377 °K and the simulation of 348.989 °K.

Figure 4. Comparison of Tout data of the simulation and the reference [7].
The error value caused by the difference in outlet temperature value between the simulation result and the simulation results in the journal shows that the 0° variation has a higher error value of 3.74% and the 10° deviation has the lowest error value of 3.04%. There is no change in temperature on the side of the tube wall, so it has no error. The simulation result can be said to be appropriate because the present error is less than 5% [8].

3.2. Effect of Baffle Inclination angle on temperature distribution
The temperature distribution that occurs on the side with the baffle inclination variation can see in Figure 5.

![Temperature distribution](image)

(a)

(b)

(c)

**Figure 5.** Temperature distribution for (a) baffle inclination 0° (b) baffle inclination 10° (c) baffle inclination 20°.

Based on the contours of the temperature distribution found in Figure 5 on the shell side, all variations of baffle inclination angle have an inlet temperature value in Table 5 and Figure 6.

| Baffle Inclination Angle | Total temperature (K) |
|--------------------------|------------------------|
|                          | Thi (K) | Tho (K) |
| 0°                       | 300     | 348.98  |
| 10°                      | 300     | 349.33  |
| 20°                      | 300     | 349.74  |

**Table 5.** Temperature on shell side.
The temperature contour in Figure 5 obtains an outlet temperature value on the shell side with a considerable outlet temperature value at a variation of 20° baffle inclination angle and the lowest temperature at a variation of 0° baffle inclination angle. Temperature changes on the shell side are caused by heat transfer between the fluid on the shell side with a tube wall with a constant temperature value. The baffle variation used on the shell side is used to direct the fluid moving on the shell side, causing turbulence on the shell side. So, the change in turbulence value on the side of the shell will affect the temperature change in the simulation.

So with the increasing variety of the angle of baffle inclination, the resulting outlet temperature value increases with a considerable outlet temperature value at a variation of the baffle inclination angle of 20° and the lowest temperature at the variation of the baffle inclination angle of 0°. Temperature changes on the shell side are caused by heat transfer between the fluid on the shell side with a tube wall with a constant temperature value. The baffle variation used on the shell side is used to direct the fluid moving on the shell side, causing turbulence on the shell side. So, the change in turbulence value on the side of the shell will affect the temperature change in the simulation.

3.3. Effect of Baffle Inclination angle on pressure and pressure drop

The mass flow rate influences pressure in the inlet shell and the angle of the baffle. The pressure contour can see in Figure 7.
The contour of pressure can see at each point baffle undergoes a change in pressure and continues to repeat the outlet on the side of the shell. At the baffle inclination angle, 0° has an inlet pressure value of 8.48 and an outlet pressure of -784.71. Furthermore, the angle of baffle inclination 10° has a pressure inlet value of 12.64 and pressure outlet of 792.46, and the angle of baffle inclination 20° has a pressure inlet value of 14,313 and pressure outlet of -802.66.

At the contour, pressure drop can be caused by the mass flow rate and baffle angle found on the side of the shell. If the cross-sectional area gets smaller, it increases the flow speed, and the pressure will decrease—the greater the rate of mass flow, the greater the pressure on the shell side.

In the heat exchanger, ΔP (Pressure Drop) is the pressure difference between the fluid in and out of the heat exchanger. ΔP is calculated to determine how much the process fluid can maintain its pressure as long as it flows inside the shell and tube sides of the heat exchanger. Pressure drop makes a loss of energy resulting in a non-constant change in temperature. The pressure drop from the simulation in Figure 7 can be seen compared to the inlet and outlet pressure values in Figure 8 to see the considerable pressure drop value in this simulation.

![Figure 7. Pressure contour (a) baffle inclination 0° (b) baffle inclination 10° (c) baffle inclination 20°.](image)

![Figure 8. Effect of velocity on pressure drop.](image)

Pressure drop flow of the shell side increases with the increase in the mass flow rate and the shrinking distance between the baffle used. The smaller the pressure drop value will make the pressure that will enter greater so that the relationship between the flow rate and pressure drop is directly proportional. A deficient bundle bypass factor and a deficient baffle leakage factor will lead to a reduced pressure drop, but the shell side will correspondingly decrease drastically in heat transfer coefficient [9]. The more baffles installed, the smaller the cross-sectional flow of the fluid. The trajectory taken by cold air is getting longer, and for the same mass flow rate, compared to if the number of baffles is small, it will make the speed of cold air increase so that the pressure decreases.
3.4. Effect of Baffle Inclination angle on velocity

The simulation has an inlet speed value of 0.1997 m/s, then conducted simulation with three kinds of variations baffle inclination angle. The simulation results can see in Figure 9.

![Figure 9](image)

**Figure 9.** Velocity Contour (a) baffle inclination 0° (b) baffle inclination 10° (c) baffle inclination 20°

From Figure 9, the inlet mass flow rate value at the three variations is 0.1997 m/s and then at the outlet speed value in Table 6.

| Baffle Inclination Angle | \( \dot{m}_{in} \) (m/s) | \( \dot{m}_{out} \) (m/s) |
|--------------------------|--------------------------|--------------------------|
| 0°                       | 0.1997                   | 0.2526                   |
| 10°                      | 0.1997                   | 0.2659                   |
| 20°                      | 0.1997                   | 0.27755                  |

So that with the baffle, the flow is increasingly formed and with the increase of angle baffle inclination on the side of the shell, the speed value produced is higher. Then the effect of baffle inclination angle on vertex in Figure 10.
The baffle on the shell side makes the fluid flow more directional and can make the flow more turbulent. Turbulence can randomly cause friction between the fluid and the tube wall in the resulting outlet temperature cold fluid to get hotter. The hotter the temperature will become colder with the influence of turbulence on the shell side. So in this simulation, the value of heat transfer between the fluid on the shell side and the tube wall is higher because of the time of turbulence. The friction between the fluid and the tube is getting longer.

4. Conclusion
Based on the results of the analysis on the influence of baffle inclination on the shell side of the High Pressure Heater can be concluded as follows:

1. The most significant temperature change is the 20° baffle inclination variation with an outlet temperature of 349.77 °K. In addition, baffle inclination can change the shape of the temperature contours in the shell. With baffle can accelerate the temperature increase on the side of the shell so that with increasing angle baffle inclination, the temperature increases.

2. The effect of baffle inclination angle on pressure contour is the pressure drop at each baffle point caused by mass flow rate caused by the angle of baffle inclination contained in the shell. So that the pressure drop is influenced by inlet pressure and shell outlet, in this simulation, get the lowest pressure drop result of 793.19 pa on the variation of baffle inclination 0°. The pressure drop difference on the inlet side of 8.48 pa and the outlet side of -784.71 pa.

3. With the baffle, the flow is more formed and with the increasing angle of baffle inclination on the side of the shell, the speed value produced is higher. At the angle variations performed to have the highest speed value at a variation of 20° of 0.2755 m/s, it makes the value of heat transfer between the fluid on the side of the shell and the temperature on the tube wall is higher. Because, at the time of more significant turbulence, the friction between the fluid and the tube is getting longer.
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