FLOW PREDICTION ON THE EFFECT OF BAFFLE CUTS IN A SHELL AND TUBE HEAT EXCHANGER DESIGN

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ABSTRACT
The exchange of heat between fluids is one of the most important features of machineries, industrial and chemical processes for improving product quality. A counter flow shell path was considered for the computational shell and tube heat exchanger model, which was designed and implemented with SOLIDWORKS 2020 flow simulation software at different baffle cut ratios of 15%, 25%, 35%, and 45%, while other design parameters such as the shell and tube side (pressure, temperature, and mass flow rate) were kept constant for all four models of Shell and Tube Heat Exchanger (STHE). These models were utilized to analyse the pressure gradient and heat transfer coefficient of the shell side within the heat exchanger, which revealed a drop in both heat transfer coefficient and pressure gradient as the baffle cut ratio increased. The results show that computational fluid dynamics (CFD) modelling may be used to estimate the shape of shell and tube heat exchangers.

Keywords: CFD, STHE, Heat transfer, Pressure drop, Heat transfer coefficient, Baffle cut.

1.0 INTRODUCTION
STHE is a type of heat exchanger device which consist of a shell and a tube bundle inside it. This shell and tube heat exchanger has one fluid flowing through the tubes while another fluid flows over the tube (through the shell) in order to transfer heat between the two working fluids. It is usually used when large volume of fluid requires cooling or heating. Due to its design principles it provides a large heat transfer area and offers high heat transfer efficiency. The fluids flowing in the STHE can either be gases or liquids on either the tubes or the shell side. There are many different types of heat exchangers, such as Plate heat exchangers, STHEs and spiral heat exchangers. The major components that makes up a shell and tube heat exchanger are, shell, tubes, front end head, rear end head, baffles and tube sheet. The tube sheet comprising of tube bundle, baffles, and tie rods is fitted into the exchanger shell and closed up at both ends with heads. Shell side geometry such as tube layout, tube pitch, number of tubes, number of baffles length. Baffles are primarily used to in shell and tube heat exchangers to forces the shell side fluid to move in a cross flow arrangement. Thereby, improving the shell side transfer coefficient. Baffle design (Lei et al., 2017), baffle cut ratio and baffle spacing (Nemati Taher, Zeyninejad Movassag, Razmi, & Tasouji Azar, 2012) are factors to consider in order to achieve result on how effective baffles can be on the performance of shell and tube heat exchangers (Nemati Taher et al., 2012). Its secondary purpose (baffles) is to support the tube bundles therefore, the overall impact of the baffles is to enhance the heat transfer capability but with an increase in pressure drop. Increasing the number of baffles; increases the heat transfer coefficient and pressure drop on the shell side, while it decreases the value of

correction factor due to unequal baffle spacing (Ambekar, Sivakumar, Anantharaman, & Vivekenandan, 2016). The pressure drop increases at a higher rate with the number of baffles (Abdelkader & Zubair, 2019). Baffles, placed on the shell side space, are providing the cross flow direction of shell side fluid and so the more concentrated heat exchange between fluids could be realized (Kallannavar, Mashyal, & Rajangale, 2020). Besides, baffles are carriers of tube bundle, which helps them to decrease the deflection and vibration in apparatus. The effectiveness of segmental baffle which was been investigated proved that the heat exchange in a shell and tube heat exchanger strongly depends on the shell side geometry (no of baffles, baffle cut, size, baffle spacing, baffle position, and the inlet and outlet nozzle) (Vukić, Tomić, Živković, & Ilić, 2014). Pressure gradient increases with the decrease of baffle spaces at the same mass flow rate and the same working conditions. Longer baffle spaces result in lower heat transfer coefficient at the same pressure gradient, longer baffle spaces have higher heat transfer coefficient (Nemati Taher et al., 2012). Some of the significant factors responsible for the performance of a heat exchanger are the baffle design, baffle spacing and its cut ratio. Mainly baffles create a cross flow velocity component which increases the heat transfer coefficient (Abeykoon & Transfer, 2020). Basically one of the objective of baffles is to support the tube bundle against weight, high flow rates, and pressure to mitigate the vibrations however their presence also influences the shell side thermal hydraulic performance by obstructing the flow of fluid (Jamil, Goraya, Shahzad, Zubair, & Management, 2020). Various work on effect of baffle cuts on the design of shell and tube heat exchanger have been investigated by authors in literature.

Abdelkader and Zubair (2019) concluded in their work that increase in the baffle spacing, decreases the pressure drop along the shell side. With a model been developed to calculate the highest heat transfer of an STHE without exceeding the given pressure drop. Nonetheless, if the tube pressure drop is not within allowable limits, decreasing the number of flow passes or increasing the total number of tubes, results in a desired pressure drop on the tube side.

Vukić et al. (2014) investigated the effectiveness of segmental baffles on its performance and their studies concluded that baffles changes the fluid flow characteristics of the STHE. Increase in segmental baffles number has higher influence to the STHE effectiveness. Their results show that, the heat exchanged strongly depends on the shell side geometry that is the number of segmental baffles, baffle cut, size, baffle distance. In addition, the first and the last baffle position to the inlet and outlet nozzle, and size of the constructive clearance).

Nemati Taher et al. (2012) investigated the effect of baffle spacing in the shell side flow using numerical and theoretical methods. It was discovered that the optimal baffle spacing to shell diameter ratio is between 0.4 and 0.6 of the shell diameter, and that the output for heat transfer coefficient is minimal when baffle spacing is reduced.

Bichkar, Dandgaval, Dalvi, Godase, and Dey (2018) investigated the effects of baffles on the performance of shell and tube heat exchanger using CFD and concluded that of the three types of baffle tested the helical baffle pose a better performance compared to the double and single segmental baffles. However, the single segmental baffle had the worst heat transfer performance with the highest pressure drop also pressure drop increased with the increase in number of baffles.

Zheng and Wang (2019) carried out a CFD model on the shell-and-tube phase change energy storage heat exchanger to study the effects of diameter, number of inner tubes and inlet temperature on the heat transfer characteristics of the heat exchanger during charging process. Their results obtained indicated that the thermal disturbance between heat pipes were improved by natural convection, and significantly enhance. From the result on the size of 25 mm tube diameter, the melting time is nearly 25% shorter than that of the 34 mm tube diameter. However, when the small diameter heat tubes are used, the heat transfer intensity decreases obviously and the flow resistance increases. Therefore, the heat transfer tube should be selected reasonably in the design of heat exchanger.

Biçer et al. (2020) in their study investigated the design of three new zonal baffle. A CFD analysis of the heat exchangers with conventional and three zonal baffles were performed and the results of the analysis were compared with the experimental result obtained under the same operating conditions. The shell and tube heat exchanger with the newly developed three zonal baffles was then optimized using the taguchi method. Their results showed that the application of a three zonal baffle resulted in major increase in temperature differences and very low pressure drops at the shell-side as compared to conventional baffles.

This work presents the flow pattern and the effect of segmented baffle cuts on the heat transfer coefficient and the pressure drop in STHE. This simulation gives a preview of the flow domain at the shell side and would enhance the design of the STHE facility.

2.0 COMPUTATIONAL METHODS

SOLIDWORKS FLOW SIMULATION version 2020 is used to visualize how fluid flows as well as how fluid behaves under certain conditions. It is based on numerical methods like the Navier-Stokes equation which are solved either iteratively or using some empirical relations. The flow domain in the shell side of the heat exchanger is assumed to be fully turbulent; therefore the k-□ model was adopted for the calculation process because it takes less computation time and memory than other models ("ANSYS FLUENT 14 Theory Guide," 2011; Fluent, 2011).

The governing equations for continuity, momentum, energy, k and □ in the computational domain are shown as follows:

Continuity:

$$\frac{\partial}{\partial X_i}\left(\rho\overline{u_i}\right)=0 \qquad (1)$$

Momentum:

$$\frac{\partial}{\partial X_i}\left(\rho\overline{u_i}\rho\overline{u_k}\right)=\frac{\partial}{\partial X_i}\left(\mu\frac{\overline{\rho u_k}}{\partial X_i}\right)-\frac{\partial P}{\partial X_k} \qquad (2)$$

Energy:

$$\frac{\partial}{\partial X_i}\left(\rho\overline{u_i}\bar{t}\right)=\frac{\partial}{\partial X_i}\left(\frac{K}{C_p}\frac{\partial\bar{t}}{\partial X_i}\right) \qquad (3)$$

Where

$U=\overline{u_i}+u'$

$t=\bar{t}+t'$

Turbulent kinetic energy:

$$\frac{\partial}{\partial t}\left(\rho k\right)+\frac{\partial}{\partial X_i}\left(\rho k u_i\right)=\frac{\partial}{\partial X_j}\left(\alpha_k u_{eff}\frac{\partial k}{\partial X_j}\right)+G_k+\rho c \qquad (4)$$

Turbulent energy dissipation:

$$\frac{\partial}{\partial t}(\rho\varepsilon)+\frac{\partial}{\partial X_i}(\rho\varepsilon u_i)=\frac{\partial}{\partial X_j}\left(\alpha_c\mu_{eff}\frac{\partial\varepsilon}{\partial X_j}\right)+C_{1\varepsilon}\frac{\varepsilon}{k}G_k-C_{2t\rho}\frac{\varepsilon^2}{k} \tag{5}$$

$$\mu_{eff}=\mu+\mu_{t,}\mu_t=\rho C_\mu\frac{k^2}{\varepsilon},C_{2\varepsilon}=C_{2\varepsilon}+\frac{C_{\mu\varepsilon}\eta^3\left(1-\eta/\eta_0\right)}{1+\beta\eta^3}$$

$$\eta=S\frac{k}{\varepsilon},G_k=\mu_t S^2,S\equiv\sqrt{2S_{ij}S_{ij}},S_{ij}=\frac{1}{2}\left[\frac{\partial u_i}{\partial X_j}+\frac{\partial u_j}{\partial X_i}\right]$$

Where μ_t and β are the turbulent viscosity and coefficient of thermal expansion respectively. $t^{'}$, $u^{'}$ are the fluctuating components and $\overline{u_i}$, $\bar{t}$ are time mean values of the velocity and temperature. G_k denote the generation of turbulence kinetic energy due to the mean velocity gradients (Nemati Taher et al., 2012).

For this study, the simulations were performed for the inlet channels, inside and the flow development regions in tubes and within the shell side and tube heat exchanger with single-pass construction. The geometry of the physical model indicates that the hot Fluid enters from the elevated green end and flows through the tubes exiting at the datum green end while the cold fluids enter the shell from the top indicated in orange colour and exit at the lower blue end. Properties of the hot fluid (water) and cold fluid (water) streams at their average temperatures are listed in Table 1.0. A Mesh study was carried out to ascertain the required mesh size to run the simulation. The thermodynamic properties of the hot fluid (water) and cold fluid (water) streams are shown in Table 1.0. Table 2.0 shows the geometry specification of the shell and tube heat exchanger.

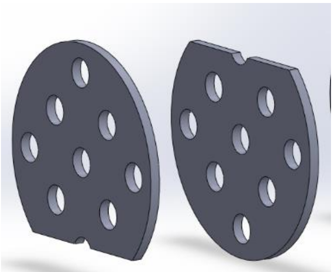
Table 1.0 Properties of the fluid

Parameters	Tube side (hot inlet)	Shell side (cold inlet)
Main fluid temperature (K)	363	298
Mass flow rates (kg/s)	0.047	0.047
Working Fluid	Water	Water
Pressure (Pa)	3000	3000

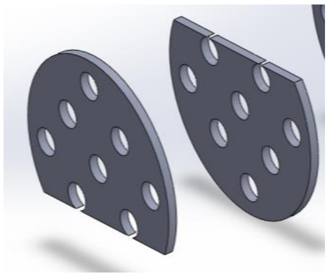
Table 2.0: Geometric Specifications of the heat exchanger

Parameter	Shell side	Tube side
Fluid	Water	Water
Material	Stainless steel	Copper
Inlet diameter	48mm	4mm
Outlet diameter	50mm	6mm
Inlet temperature	298K	363K
Mass flow rate	0.047kg/s	0.047kg/s
No of tubes		9
No of pass		1
Baffle cut	15%, 25%, 35%, 45%	

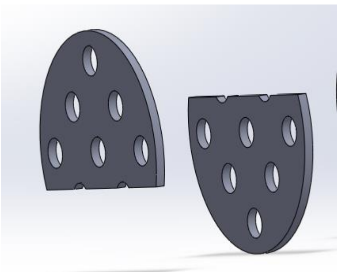
Fig 1.0 shows four different baffles which were designed at baffle cut values of 15%, 25% 35% and 45%. All thermodynamic parameters are placed at equal value for all baffle cut configurations.



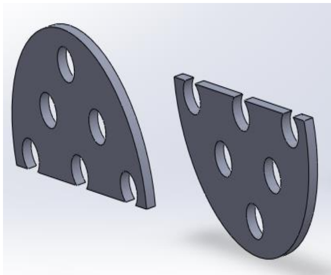
(a). 15% baffle cut



(b). 25% baffle cut



(c). 35% baffle cut



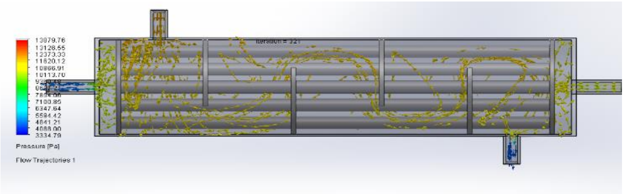
(d) 45% baffle cut

Fig 1.0 shows baffle cuts (a) at 15% (b) at 25% (c) at 35% and (d) at 45%.

Before setting the boundary condition the standard wall functions was employed for the near-wall region and the various fluid and solid domains are defined for all the inlet and exit of STHE to accurately simulate the thermo-hydraulic performance. All the solid walls are set with a momentum boundary condition of no slip. The inlet to the shell and tube is equally set as mass flow inlet and the fluid temperature is kept constant at the shell inlet at 298K.

3.0 RESULTS AND DISCUSSION

This simulation was conducted on segmental baffled shell and tube heat exchanger with different baffle cut ratios of 15%, 25%, 35% and 45%. In each CFD model, the heat transfer coefficient and pressure were measured across shell length to investigate the effects of different baffle ratios (15%, 25%, 35%, 45 %,) but with the exact number of tubes and baffles inside the shell and also by maintaining a constant mass flow rate. Fig 2.0 shows the fluid flow domain fluid on the shell side. Throughout the simulation, the flow rate of 0.047kg/s was maintained on both the shell and tube sides of the simulation. Fig 3.0 shows the pressure profile for different percentages of baffle cut at 15%, 25%, 35% and 45% respectively. All four baffle cut ratio proved to be effective in the transfer of heat across shell side. Due to the small number of baffles implemented in this design limited amount of time was taken for the exchange of heat by both fluid due to high flow velocity. Comparing the shell side heat transfer coefficient for all the four baffle cuts is depicted in Fig.4.0 where the pressure drop is lowest at a baffle cut of 45% with a reduced heat transfer coefficient. In previous study the recommended baffle cut ranges between 20-35% for optimum performance (Mukherjee, 1998).

(a)


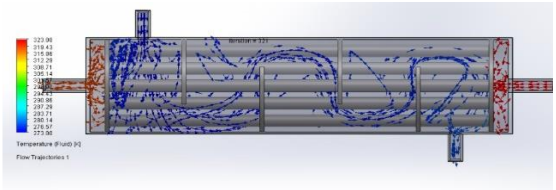
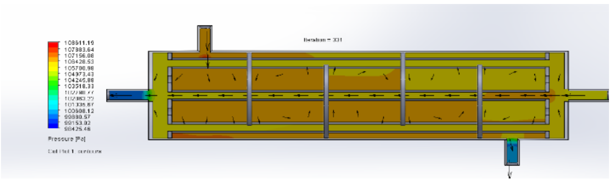
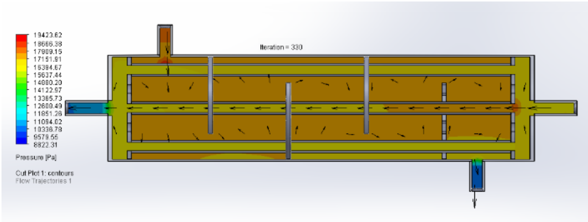
(b)


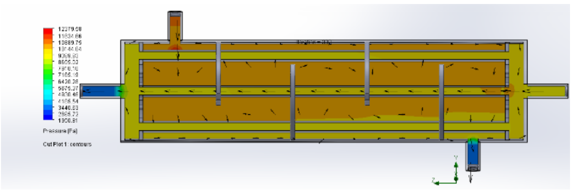
Fig 2.0 shows (a) the pressure drop across the STHE (b) the temperature profile



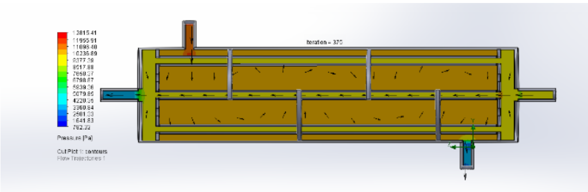
(a)



(b)



(c)



(d)

Fig 3.0 shows the pressure profile of the STHE with different baffle cuts (a) 15% baffle cut (b) 25% baffle cut (c) 35% baffle cut (d) 45% baffle cut.

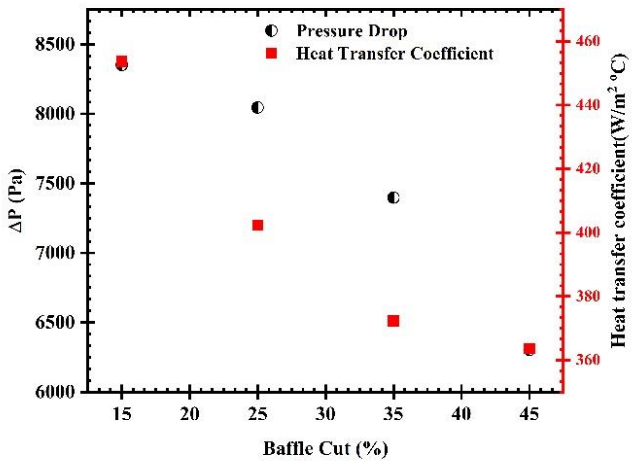


Fig 4.0 shows the plot of baffle cut against the pressure drop and heat transfer coefficient.

Fig 4 shows the plot of baffle cut against the pressure gradient and the heat transfer coefficient. It has shown that as the baffle cut increase, there is a decrease in the pressure on the shell side. Consequently, there is a reduction in the heat transfer coefficient as the baffle cut increases which is in line with what has been obtained in the literature(Abdelkader & Zubair, 2019).

4.0 CONCLUSION

In this study, a CFD simulation of segmental baffled shell and tube heat exchanger, with different baffle cuts ratio were conducted to study the effect of baffle sizing on the shell side of STHE. This simulation was done to calculate the shell side pressure gradient and heat transfer coefficient for four STHE that employ different baffle cuts, but with the same mass flow rate of 0.047kg/s by using SOLIDWORKS flow simulation 2020. From the result obtained, it can be concluded that baffle cuts have an important impact on the shell and tube heat exchanger performance. This notably showed that pressure gradient increases with a decrease in baffle cut ratio and also causes an increase in heat transfer coefficient in the shell side.

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