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Improvement of Thermal Performance for Shell and Tube Heat Exchanger withDifferent Baffles

Enass A. Sattar[1, a], Ahmed A. Ouda[2, b], Mohammed D. Salman[2, c]
[1] College of Engineering, University of ThiQar, M.S. Student, ThiQar, 64001, IRAQ
[2]College of Engineering, University of ThiQar ,ThiQar, 64001, IRAQ

Abstract:**This paper deals with the effect of adding baffles at different shapes (half circle, triangle and rectangle)to enhance shell and tube heat exchanger with different flow rates, mathematical model was designed in ANSYS FLUINT CFD 2020 R1. The flow rate of water in the tube is constant at 0.5 kg/s with a varied flow rate at the shell (0.5, 1, 1.5, 2 kg/s). The results shows that the Adding baffles increases the heat transfer rate, which reaches to 19% in circle baffle, 5% in triangle baffle, and 6% in rectangle baffle (appear circle baffle best performance compared with triangle and rectangle baffles).**

Keyword:Baffles, Heat exchanger, Shell and tube, Thermal performance.

1 Introduction

Heat transfer from process fluids is an essential part of most chemical processes. A shell and tube heat exchanger is a class of heat exchanger designs it is the most common type of heat exchanger and is suitable for high-pressure applications [1]. Tube Bundle Heat Exchanger offers a relatively large ratio between heat transfer area and volume and weight. Optimal design of shell and tube heat exchangers is an active area for new technology research. There are conventional optimization techniques that are more applicable. Conventional optimization techniques are the best resource when sufficient data, mathematical models. If the above cannot be guaranteed, as is the case with many real-world optimization problems. [1]

Baffles are laid within shell of the HE firstly to preventing tube vibration and sagging, to support the tubes, and secondly to have a higher heat transfer coefficient by directing the flow.Thermophysical properties especially thermal conductivity is the most important property that has to be taken into account for this purpose [1].

We can classify baffles in two category: spiral and plate baffles. Spiral baffles offer improved heat transfer compared to conventional heat exchangers. Due to theessential advantages of spiral baffles over segment baffles, Plate baffles can be single segment,double segment, or triple segment. Thesingle segment deflector shape is the most common. The dual segment baffle reduces the velocity of thecross flow for a given baffle spacing. The triple segment baffle reduces cross flow and long flowvelocities and has been distinguish as a "window cut" baffle. [3]

The following is a summary of some of the numerical and experimental research of previous researchers.

E. Akpabio et al. (2009) numerically analyzed for the shell and tube heat exchangers with the baffles, the purpose of this article is to find the partition distance where the solid partition is cut, which will provide us with the best value for the total heat transfer coefficient. The Microsoft Excel 2003 software package was used for this. Research. The best overall heat transfer coefficient is obtained. In the comparison, the calculated total heat transfer coefficient (Uc) is consistent with the assumed total heat transfer coefficient (Ua), which is within 0.006 0.09%, compared to 25% in the literature. There is shows that the change of the baffle spacing can determine the efficiency of the heat exchanger. [16]

Yang et al. (2014) numerically investigated to simulate the effects of thenumber and width of the sealing strips on shell side flow and heat transfer of atube bundle heat exchanger (STHX) with shaped baffles. The results show that with the same mass flow rate M and the width ofsealing strips W, with an increasing number of sealing strips, the Nusselt number on the shell side is 9.3-41.7% higher than without sealing strips. The wider the weatherstrip, thebetter heat transfer performance. Numerical simulation results also show thatsealing strips improve the heat transfer performance of CHSTHX more effectively.

M.M. Elias et al. (2014) numerically performed for the effects of various particle shapes (plate, cylindrical brick, and spade) on the total heat transfer coefficient in shell and tube heat exchanger, heat transfer rate and entropy of tube bundle heat exchangers with different baffle angles and other shapes of segmented baffles. They found that the overall heat transfer coefficient of cylindrical particles with a guide plate angle of 20 are improved by 12%, 19.9%, 28.23% and 17.85%, which are 17.85% higher than the guide plate angles or segmented guide plates of 30, 40, 50. It is also found that the heat transfer rate of the cylindrical shape with a deflection angle of 20° is higher than that of other deflection angles and segmented baffles. Yet, the generation of entropy decreases with the increase of all baffle angles and the volume concentration. [17]

J. Wen et al. (2015) numerically simulated to propose an improved baffle structure for the heat exchanger. There results show that the heat transfer coefficient of the improved heat exchanger is increased by 82.8-86.1%. Due to the pressure drop on the shell side, the power loss is about 21-549 W, an increase of. The thermal efficiency factor increased by 28.4-30.7%, which shows that the trapezoidal folded wall effectively improves the heat transfer performance of the heat exchanger with spiral baffles. There results of this simulated are of great significance to the optimal design of the heat exchanger. [18]

Swati Singh et al. (2016) experimentallyanalyzed the carried out with water nanofluids made from CuO to evaluate the effect of nanoparticle concentration on Nusselt number and on heat transfer properties with or without inserting baffles. After examining the results of, it was concluded that the Nusselt number and the heat transfer properties of increased after the baffles were inserted. [6]

A.K. Surana et al. (2017) numerically discussed the effect nanofluids (Al_2O_3) on the heat transfer by introducing water along tubes and nanofluids along the side of shell. They were investigated the effect of pipe number, pipe diameter and unequal spacing on pressure drop and heat transfer. ANSYS CFX 15.0 was used to the numerical calculations with nanofluids volumetric fraction equal to (0.5, 0.75, 1.0, 1.25 and 1.5 percent) and different velocities to find the best pressure drop at each volumetric fraction. There results obtained that the pressure drop decreases and heat transfer coefficient increases with unequal baffle spacing and they increases with increasing the number of tubes. But the decreases with the increasing of the pipe diameter. [9]RamtinBarzegarian et al. (2017) studied empirically the thermal action for heat exchanger of typical shell and tube with three segmental type baffles of employment Al_2O_3-water nanofluid in an empirical investigation.

This empirical work utilizes the Al_2O_3-γ nanoparticles at (15) nm mean diameter at different volume fractions of nanoparticles (φ = 0.03, 0.14 and 0.3%) and using sodium dodecylbenzene sulfonate as a surfactant, the heat transfer characteristics, friction coefficient, Reynolds number and thermal performance coefficient of the shell and tube heat exchanger under the limit of laminar flow with the volume concentration of nanoparticles were studied. Their results explainthat the general heat transfer coefficient and Nusselt number of nanofluids increase with the increase of Reynolds number, friction factor, slightly forfeiture was observed by utilization nanofluid in the analyses part, in conclusion the highest improvement in thermal performance were recorded at a concentration of 0.3% was 21.5%. [13]

Sunil Shinde et al. (2018) performed experimental and numerical a study of the performance of shellandtube heat exchanger used continuous helical barriers at different angles instead of the segmental barriers that are often used. The material used for the barriers were STHX-FCHB and SB-STHX. There results was the possibility of utilization spiral-barriers to improve the performance of the heat exchanger. The experimental and numerical results were verified to know the thermal performance of the STGX material at deflection angle of 25, the results were found to be compatible, and the deviation is about 6-11%, although the initial cost is more expensive, but the cost of producing continuous barriers is much easier and less complex. An alternative to barrier material is FRP, which is considered a good material. Replaceable materials are available, which will further reduce the initial cost and heat operating cost. [19]

A. Karima et al. (2018) tested numericalthe effect of the new baffle design on the efficiency of tube bundle heat exchangers. These are throttle valves that are inserted into a cylindrical tubular heat exchanger. Focus on the effects of baffle shape, distance between baffles (pitch ratio), and baffle size (blockage rate) on heat transfer and flow behavior. The test is run against Reynolds numbers in the range 3000-8000. All analyzes are performed using CFD Fluent software. There results obtained show that the butterfly baffles with pitch ratio = 4 and blockage rate = 0.1 are the best structures to ensure optimal flow mixing and increase the thermal gain factor by 1.7 times with a moderate pressure drop of. [9]

P. Bichkar et al. (2018) introduced numerical simulations performed with types of baffles helix baffle, double segment and Single segment. They were show the effect of the baffle on the pressure drop of the shell and tube heat exchanger. The spiral baffle eliminates the dead zone and reduces pressure loss. The fewer dead zones, the better the heat transfer. Double-segment baffles reduce vibration damage compared to single-segment baffles. Single-segment baffles reveal the formation of dead zones where heat transfer is not effective. A small pressure drop reduces the pump capacity and improves the overall efficiency of the system. Comparison results of obtain that the spiral baffle is more beneficial than the other two baffles. [13]

Saleh Etaig et al. (2019) numerically investigated three-dimensional of heat exchanger with inclined baffles. The coolant fluid was used CuO-water and MgO-water nano-fluid. The hybrid nanofluid is on approach as single phase model ANSYS CFD 18 was used to designed and calculate the temperature variation numerically at differenet volume fractions were examined in the present study at (0% to 4%). Their resulteof this paper found increment in the volume fraction of the nanoparticle led to thermal conductivity upturn, accordingly diminish the temperature of the hot fluid. [20]

A.A. AbbasianArani and R. Moradi (2019) numerically described of the fluid flow and heat transfer of water in a three types of baffles are segmented baffle, disk baffle and segmental-disk baffle heat exchanger with a combined baffle and longitudinal finned tube configuration. The SOLIDWORKS Flow Simulation (2015) fluid domain is simulated. There results obtained are compared with experimental data and numerical results in the literature. According to the results obtained at the maximum mass flow rate (2 kg/s), the average shell-side heat transfer coefficient of DBTR and CSDBTR are 26.6% and 31.9% higher than that of DBCR and CSDBCR, respectively. In another standard called the performance evaluation standard, the performance of is 39%, 37%, and 13% different from traditional baffles, which are represented by disc baffles and tubes with longitudinal triangular fins. [25]

M. S. Kassim et al. (2020) calculated numerical evaluation of the performance of a shell and tube heat exchanger with the ANSYS program. In the current design process, the water is used in both the shell and sides of the tube. Modeling the heat exchanger without and with dielectric plates was performed to study the effect on the performance of the device. The domain of the work is to calculate the distribution of temperature on the side of the shell and tube to calculate the rate of transfer, as well as the effectiveness of both configurations. It is demonstrated that the use of the deflectors can significantly improve device performance and increase the total heat transfer rate. The effectiveness of the heat exchanger increases from 0.68 to 0.76 after using the deflector plates around the pipes. The baffle of the plates has increased a turbulence of a custody fluid and minimized variances of tube temperature and thermal tensions due to Cross-Flow. [30]

M. Bahiraeiet al. (2021) numericallyexamined the thermohydraulic properties and flow index of nanofluids, which contain different forms of particles including cylinder, brick, plate and flattened spheroid in a shell heat exchanger and tubes (STHX). The STHX is equipped with the new single-sided spiral baffles to develop spiral flow within the shell side. The flow pattern developed by the baffles has a notable effect on the performance of the STHX. Increasing the Reynolds number by on the shell side increases the heat transfer rate, the total heat transfer coefficient, the effectiveness, the number of transfer units (NTU), and the pressure drop, while that the performance index decreases. [14]

2 Methodology

This part deals with the geometry and mathematical model that solves with the assumptions at the boundary conditions and the needed formula and equations.

2.1 Model description

Figure 1 shows the schematic structure of the heat exchanger with baffles examined. It was designed with ANSYS FLUINT CFD 2020 R1. Table 1 shows the size and specifications of the heat exchanger. Cold liquid through in shell and hot liquid through in tubes.

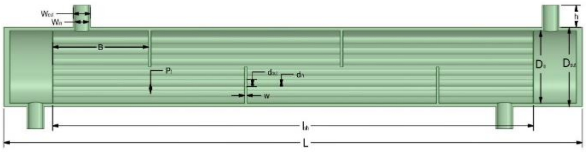

Fig. 1 Schematic of the shell and tube heat exchanger

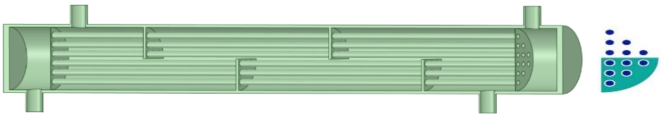

Fig. 2. Schematic of the shell and tube heat exchanger without baffles

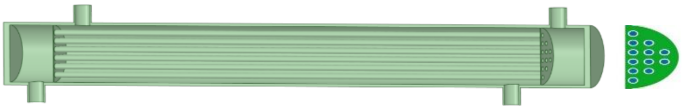

Fig. 2 Schematic of the shell and tube heat exchanger with half circle baffles

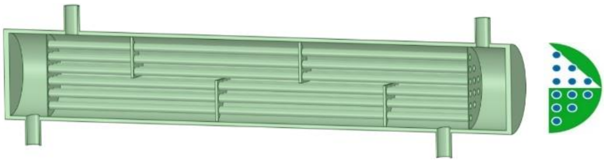

Fig. 4 Schematic of the shell and tube heat exchangerwith triangle baffles

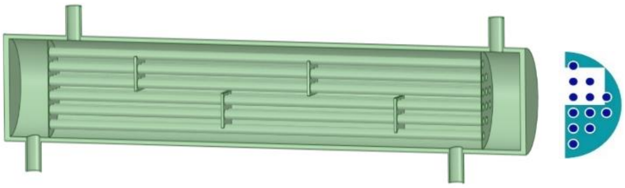

Fig. 3 Schematic of the shell and tube heat exchanger with rectangle baffles

Table 1. Dimensionsof shell and tube heat exchanger

Dimension	symbol	Value
Length of heat exchanger	L	1351mm
Length of shell	l_{sh}	1123mm
Outer shell diameter	D_{out}	167mm
Inner shell diameter	D_{in}	153mm
Outer pipe diameter	d_{out}	15.17mm
Inner pipe diameter	d_{in}	11.4mm
tube pitch	P_t	22.5mm
Outer inter shell diameter	W_{out}	40mm
Inner inter shell diameter	W_{in}	33.7mm
High inter shell	h	46.5mm
Number of tube	N	24
Baffle spacing	B	224mm
Baffle width	w	6mm

2.2 Assumptions

The assumptions that are utilized in this mathematical model are as follow:

1- Steady state, laminar and turbulent flow.
2- The physical properties of water are change with temperature and concentration.
3- Non slip.
4- Incompressible flow with change properties

2.3 Governing Equations

The foundation of computational fluid dynamics is the equations of control fluid dynamics, continuity equations, momentum equations and energy equations. Because all CFD are based on these equations, every student must understand and understand these equations before continuing to study. For shell and tube heat exchanger are briefly below as: [24]

The continuity equation:

$$\frac{\partial(\rho u_i)}{\partial x_i} = 0 \qquad (1)$$

Momentum equation:

$$\frac{\partial(\rho u_i u_j)}{\partial x_i} = -\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left((\mu + \mu_t)\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right) \qquad (2)$$

Energy equation:

$$\frac{\partial(\rho u_i T\,)}{\partial x_i} = \frac{\partial}{\partial x_i}\left(\left(\frac{\mu}{pr} + \frac{\mu_t}{pr_t}\right)\frac{\partial T}{\partial x_i}\right) \qquad (3)$$

2.4 k-epsilon turbulence model

The k-epsilon (k-ε) turbulence model is the most commonly used model in (CFD), which is used to simulate the average flow characteristics under turbulent conditions. It is a two-equation model that uses two transport equations to give an overview of turbulence [25]

Turbulence kinetic energy (k):

$$\frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left(\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right) + G_k + G_b - \rho\varepsilon \qquad (4)$$

Rate of turbulent energy dissipation (ε):

$$\frac{\partial}{\partial x_i}(\rho\varepsilon u_i) = \frac{\partial}{\partial x_j}\left(\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right) + C_{1\varepsilon}\frac{\varepsilon}{k}(G_k + C_{3\varepsilon}G_b) - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} \qquad (5)$$

Gk represents the turbulent kinetic energy generation due to the gradients of mean velocity, andGb is the turbulent kinetic energy generation due to bouncy. C1ε, C2ε, and C3ε are model constants. σε and σk are turbulent Prandtl numbers for diffusion of ε and k. The turbulent viscosity is:

$$\mu = \rho c_\mu \frac{k^2}{\varepsilon} \quad (6)$$

$where c_\mu$ = 0.09, $c1$ε = 1.44, $c2$ε = 1.92, σk = 1, $\sigma\varepsilon$ = 1.3

2.5 Boundary conditions

The model examined was exposed to the boundary conditions used to complete the model.

1- Mass flow rate inlet tube is constant at 0.5m/s and temperature 328K.

2- Mass flow rate inlet shell is variation from 0.5-2m/s and temperature 298K.

3- Outlet pressure of shell and tube at gauge pressure equal to zero.

2.6 Water thermal properties equations

Maximum deviation of 3.5% applicable in the range 0 ≤ T ≤ 100. Where T is the water temperature expressed in ° C. [26]

1-$\rho_w = 1000 * \left(1 - \frac{(T_w-4)^2}{119000+1365*T_w-4*T_w^2}\right)$ (7)

2- $c_{pw} = a + bT + cT^2 + \mathrm{d}T^3 + eT^4 + fT^5$ (8)

$a = 4217 \cdot 629. b = -3 \cdot 20888. c = 0 \cdot 09503. d = -0 \cdot 00132.$

$e = 9 \cdot 415 * 10^{-6}. f = -2 \cdot 5479 * 10^{-8}$

3-$k_w = a + bT + cT^2 + dT^3$ (9)

$a = 0 \cdot 56112. b = 0 \cdot 00193. c = -2 \cdot 60152749 * 10^{-6}. d = -6 \cdot 08803 * 10^{-8}$

4-$\mu_w = a + bT + cT^2 + dT^3$ (10)

$a = 0 \cdot 00169. b = -4 \cdot 25263 * 10^{-5}. c = 4 \cdot 9255 * 10^{-7}. and$

$d = -2 \cdot 09935 * 10^{-9}$

2.7 The calculated parameters

To studied the characteristic of shell and tube heat exchanger with and without baffles some parameters are require to be determined: [29]

heat transfer rate

$$Q = mC_p\Delta T \quad (11)$$

Heat transfer coefficient

$$h = \frac{Q}{A*(T_w-T_b)} \quad (12)$$

cross section area

$$A = \frac{\pi}{4}d^2 \quad (13)$$

$$Re = \left(\frac{m_f}{A_{cfs}}\right)\frac{D_e}{\mu_f} \quad (14)$$

Where D_e: equivalent diameter(m) calculated from equation

$$D_e = \frac{4\left(p_t^2 - \frac{\pi d_\circ^2}{4}\right)}{\pi d_\circ} \quad (15)$$

A_{cfs}: cross flow area (m^2)

$$A_{cfs} = (D_s * C_t * B)/p_t \quad (16)$$

C_t: tube clearance

$$C_t = p_t - d_\circ \quad (17)$$

3 Validation

The empirical and numerical models of Sunil Shinde and UmeshChavan validated this model. To verify the validity of the numerical model, the results are compared with those already in the literature [16]. The calculation of the heat transfer coefficient at thelimit is compared. Figure 1 shows a good match between the results of this model and the results available in the literature.

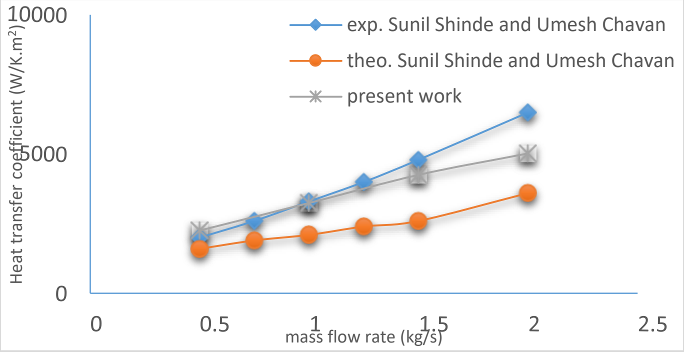

Fig. 4variation of the heat transfer coeficient versus mass flow rate for water.

4 Resultsand discussions

First, ANSYS FLUINT CFD 2020 R1 used the numerical isperformed usingwater as base fluid. Next,different shape of baffles is used and the results werecompared:

Fig. 7explain the variation of the heat transfer coefficient versus mass flow rate for different baffles, hence higher flow rate, higher the heat transfer rate ultimately heat transfer coefficient. Also, explain the effect of adding baffles increases heat transfer coefficientthe main characteristic of using baffles was to guide the flow of fluid withinthe tube bundle, which increased the thermal efficiency and the heat transfer coefficient. The baffles added more local motion and turbulence and reached fresh fluid to all the hot surfaces of the tube bundle.

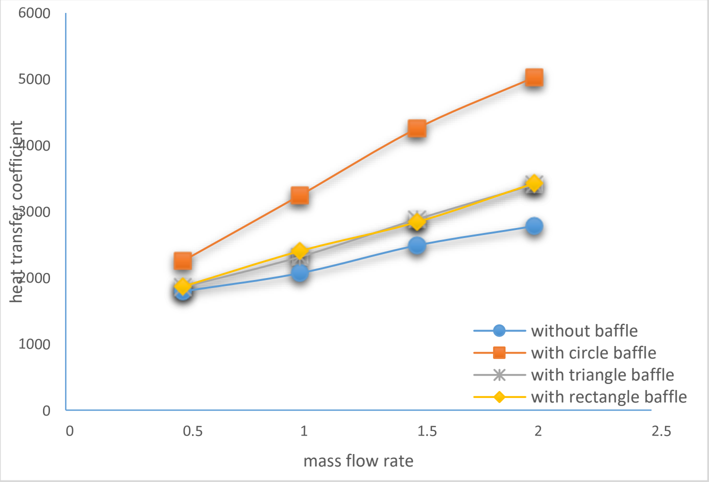

Fig. 5 variation of the heat transfer coefficient versus mass flow rate

Fig.8explains the variation of the enhancement in heat transfer versus mass flow rate for different baffles, this figure shows the enhancement in heat transfer rises with increment mass flow rates, higher flow rate indicates higher generation of eddies. These eddies are responsible for heat transfer. Also explains the effect of adding baffles increases heat transfer rate the baffles increase heat transfer in two ways firstly increase residence time. Secondly, they increase the shell-side velocity, which corresponds to more turbulence and increased heat transfer. This figure shows the circle baffle is the better from them.

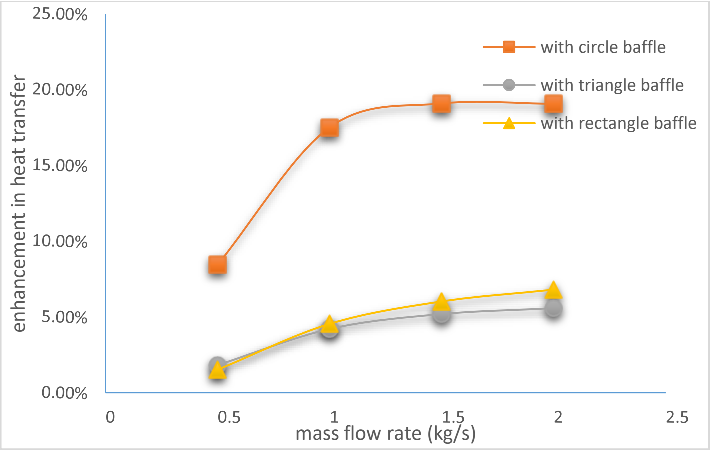

Fig. 6 variation of the enhancement in heat transfer versus mass flow rate

Fig. 9represents the variation of heat exchanger effectiveness against Reynolds number for without baffles and with baffles (half circle, triangleand rectangle). This figure explain that the effectiveness reduction with increased Reynolds number for all cases, because increasing of the maximum heat transfer is larger than increasing in the actual heat transfer with increasing Reynolds number, which leads to lowering in effectiveness. In addition, the half circle baffles case appears more effectiveness between them.

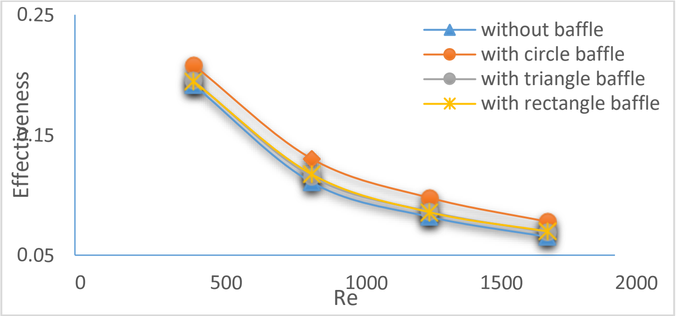

Fig. 9 variation of effectiveness versus Reynold number

Fig. 10, 11, 12, 13explain the longitudinal distribution temperature contour for water without baffles, with half circle, triangle, and rectangle baffles for counter flow at 2kg/s flow rate of shell and tube heat exchanger. This figures show the gradient temperature of heat exchange between the two liquids. As the temperature of the fluid in the tubes begins to decrease, this exchange occurs because of the temperature difference between two liquid. Where baffles play an important role in lowering the temperature more compared to the exchanger without baffles because increase the fluid residence time, which allow more heat exchange.We also note that the half circle baffle provided better thermal performancecompared to other baffles (triangle, rectangle), due to the large area of the half circle baffle,which makes it impede the passage of larger quantities and thus better performance.

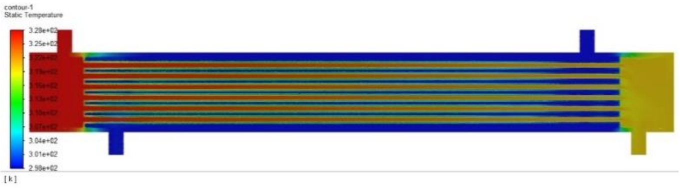

Fig. 10 longitudinal temperature contour for water without baffle

Fig. 11 longitudinal temperature contour for water with half circle baffle

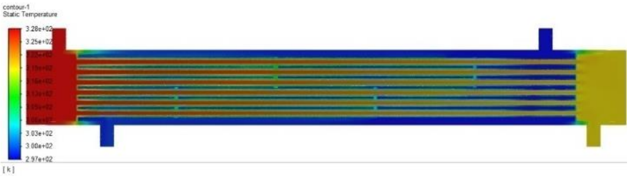

Fig.12 longitudinal temperature contour for water with triangle baffle

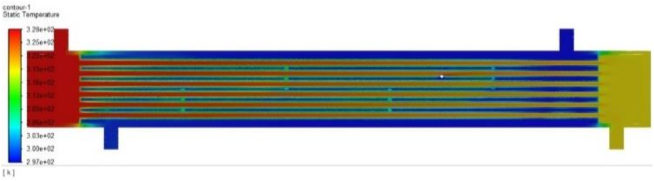

Fig. 7 longitudinal temperature contour for water with rectangle baffle

Fig. 14, 15, 16, 17reveal the longitudinal distribution velocity contour for water without baffles,half circle, triangle, and rectangle baffles for counter flow at 2m/s flow rate of shell and tube heat exchanger. We can notice velocity in inlet shell higher as possible because cross section area is small and begins spread in shell space and go down, also can be notice effect of baffles in increase velocity and action eddies subsequently enhance heat exchange.The guides the jacket side backflow and forwards over the pipe Field, increase the velocity of and the heat transfer coefficient. The half circle baffle gives higher average velocity at the contact region because of the large blockage area of this type, which reduce the cross section area of flow.

Fig. 14longitudinal velocity contour for water without baffle

Fig. 15 longitudinal velocity contour for water with half circle baffle

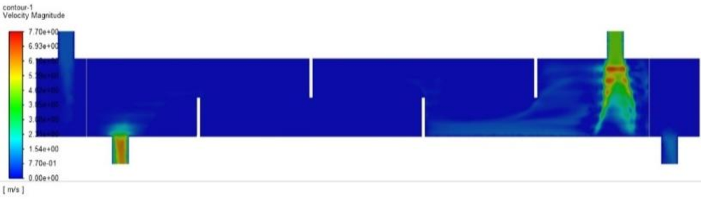

Fig. 8 longitudinal velocity contour for water with triangle baffle

Fig. 9 longitudinal velocity contour for water with rectangle baffle

5 Conclusion

From the results, which shows the effect of the shape of baffles and mass flow rate, we conclude this:

1. Adding baffles increases heat transfer rate because of increasing residence time of the fluid at heat exchanger that allow more heat exchange. The enhancement reachesto 19% in half circle baffles.
2. The half circle shape baffle is the best one since it has the maximum performance thermal then rectangle and finally triangle baffles.
3. Increase velocity and action eddies subsequently enhance heat exchange. The guides the jacket side backflow and forwards over the pipe field, increase the velocity of and the heat transfer coefficient.

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