EXPERIMENTAL AND CFD SIMULATION STUDY OF SHELL AND TUBE HEAT EXCHANGERS WITH DIFFERENT BAFFLE SEGMENT CONFIGURATIONS

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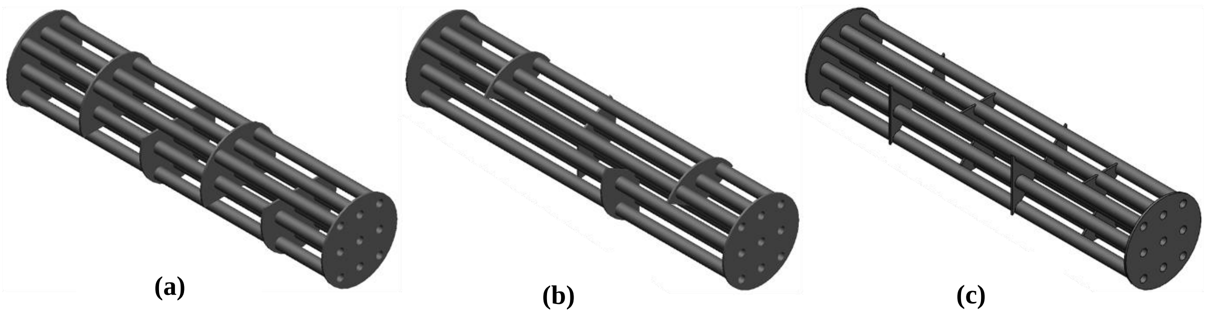
Shell and tube heat exchanger (STHX) is an implement that has tremendous applications in numerous industrial processes and research areas. In this study, the commercial software ANSYS is used for 3-D computational fluid dynamics (CFD) to compare the thermo-hydraulic performance of STHXs with recently developed tri-angular (TRI) baffles, and tri-flower (TF) baffles with conventional segmental (SG) baffles at different flow rates. Simulations have been performed to analyze the heat transfer coefficient, pressure drop, and overall thermo-hydraulic performance among the recently developed TRI-STHX, TF-STHX and conventional SG-STHX. The thermo-hydraulic performance of the numerical model of SG-STHX shows the promising results while validating it with the experimental results, Esso and Kern methods. Then the same study is carried out for comparing the two novel baffles with segmental baffle. The results depict that, novel baffles are much appreciable in increasing heat transfer coefficient. The TF-STHX offers a greater heat transfer coefficient than all others but also offers a higher pressure drop at the same flow rate. Computing the comprehensive performance ($h_s/\Delta p$), the TRI-STHX offers a prominent increment in thermo-hydraulic performance compared to others. Moreover by inserting twisted tapes at the tube side, there is noticeable increase in heat transfer coefficient which tends to increase the thermo-hydraulic performance of STHX. By comparing the flow patterns of TRI-STHX and SG-STHX, the novel TRI-STHX shows the reduction in shell-side induced vibrations and hence helped to increase the overall efficiency of the STHX.

Keywords: Shell and tube heat exchanger, Tri-angular baffles, Tri-flower baffles, Segmental baffles, thermo-hydraulic performance

1. Introduction

Heat transfers from one body to another body via three main ways such as convection, conduction, and radiation. Heat transfer is enhanced by the artificial techniques while it takes place naturally or from the thermodynamic system because of buoyancy forces [1]. Heat transfer is an important phenomena in numerous applications. However, the heat transfer process is found in various useful small devices [2]. The various types of heat exchangers (HXs) are used in countless applications for industries to add or absorb heat, such as refrigeration, vehicle industry, food processing, power plant and so on [3]. The classification of HXs is based on the flow direction (parallel, counter and cross flow) and construction (shell and tube heat exchangers (STHXs), fin and tube HXs and, plate and fin HXs). HXs allow the exchange of heat from two or more mediums (water and air medium, water and oils) [4, 5]. According to market survey, STHX is used in 35-40 % applications of heat transfer. It is easy to assemble and has robust mechanical structure [3]. STHX consists of three major components i.e. shell, tubes and baffles. The shell and tubes contain working fluid in them. The fluid runs in tubes that contains either hot fluid or cool fluid. The fluid at shell side runs over the tubes of either provides the heat or absorb the heat from the tubes [4]. Baffles play vital role as they directed the fluid flow over the tube bundles and provide structural support to them. This support enables an appropriate velocity of fluid flow and reduces the shell-side fluid flow induced vibrations in the tubes [5]. Active and passive methods are commonly used to increase the heat transfer rate. Active methods required a peripheral force such as (fluid surface vibration, mechanical aids) for heat transferring process in STHXs. There are many practical restrictions in this method, as it requires external sources, which causes an impact on the cost factor and reduces the overall efficiency of the system [6]. Passive methods perform work passively (without any involvement of external power source), heat transfer rate is improved by inserting twisted tapes in the tube side, different baffle designs, surface coating and placing zigzag flow generators in tubes [7].

The routinely used segmental baffles, with a cut out segment known as baffle cut as shown in Fig. 1 (a). The baffle cut causes change in the direction of the fluid that flows at the shell side as well as augmenting the fluctuation or variation in the shell-side fluid flow across the tubes [8]. This phenomenon improved the thermal performance by enhancing the turbulence in the fluid of the shell side. However, the STHXs with conventional segmental baffles have many drawbacks such as pressure drop at shell side (large pumping power is required), less heat transfer efficiency due to flow stagnation, fouling factor and the reduced operating period because of strong induced vibrations [9, 10]. To improve the thermal performance of STHXs, helical baffles are the best alternative to commonly used segmental baffles. Numerical simulations have performed to explore the thermal performance of STHXs with helical baffles. The suitable design of helical baffle provides great outcome as it overcome fouling factor at shell side, improve the heat transfer rate, less pressure drop at shell side, preventing flow induced vibrations, and less maintenance cost than the segmental baffles [11, l2]. The commonly used segmental baffles produce unwanted vibrations because of the vertical fluid flow across the tube bundles; however, in the helical baffles fluid flows across the tubes at certain angle relative to the axis and greatly overcome the induced vibrations [13]. Clamping antivibration baffle is recently developed to minimize the shell-side fluid flow induced vibrations in STHX. Firstly, the shape of clamping antivibration baffle is such that it promotes the longitudinal movement of fluid across the tube bundle in the shell side. Secondly, this baffle design provides less pressure drop as compared to conventional segmental and helical baffles. In these two conventional baffles, there is sudden change in the velocity that causes fluid recirculation and higher dead zone produces that lead towards higher pressure drop. While in clamping antivibration baffle, the flow direction does not change much, less dead zones and lower fluid recirculations produce less pressure drop [14]. Heat transfer rate was compensated in clamping antivibration baffle design by inserting porous media [15]. Many investigators have performed numerical simulations on STHXs with twisted tapes. Twisted tape is a swirl flow generator in tubes used as passive heat transfer improvement devices that operate without any external power source. The twisted tapes have gained more attention because of their performance, easy manufacturing and installation. Twisted tapes have shown significant improvement in the heat transfer rate of STHXs. The twisted tapes also improve the gradients of velocity and turbulence of flow intensity near the tube wall, contributing to the heat transfer enhancement [16].



(a) (b) (c)

Figure 1. Model of tube bundles with different baffle types: (a) Segmental baffles; (b) Tri-angular baffles; and (c) Tri-flower baffles

For the present investigation, we would consider two novel baffle designs and one traditional baffle design, i.e. tri-angular, tri-flower and conventional segmental baffles as illustrated in Fig. 1 and compare their effect on the overall performance of STHX. The effect on heat transfer coefficient by inserting twisted tapes at tube is also evaluated using different baffle designs. The STHX complete assembly along with tube bundles, baffles, shell, and nozzles are molded using computer aided design (CAD) software, SolidWorks, for each baffle design. Commercial software ANSYS FLUENT is used for CFD simulations run on the STHXs with different baffle designs. This CFD technique is implemented to conduct the numerical study on different parameters of STHX such as heat transfer rate and pressure drop. The results of heat transfer coefficient and pressure drop are validated by using Kern and Esso methods. Furthermore, the experimental setup is constructed to ensure the validity of trends.

2. Experimental Setup

2.1. Geometric configuration

In experimental setup, a STHX with segmental baffles is used. The experimental system consist of two fluid channels i.e. shell and tubes. The hot water flow in tube side, while the cool water flow in shell side.

Table 1. Geometrical parameters of the STHXs

Description	Numerical Value	Units	Description	Numerical Value	Units
Tube internal diameter	4	mm	Number of baffles	4	-
Tube external diameter	6	mm	Baffle thickness	1	mm
Tube numbers	9	-	Baffle spacing	35.6	mm
Tube effective length	186	mm	Baffle cut	22%	-
Shell internal diameter	44	mm			

A counter flow configuration of fluid is adopted to increase the heat transfer process by increasing the contact time between shell fluid and tube bundles. The non-corrosion material stainless steel is selected for solid construction of STHX. The geometrical details of the shell have an outer diameter: 0.05 m (50mm); shell thickness: 0.003m (3mm); and total length: 0.2m (200mm). The geometrical structural parameters of STHX is list in Tab. 1.

2.2. Experimental System and Procedure

The experimental system as shown in Fig. 2, contains two close cycles; heated and cold water cycles. For the heated water cycle, an electrical heater (2 kW) is used for heating; with a controlled temperature. The submersible pump is used to drive the hot water in tube side and cold water in shell side. The flow rates of the heated water and chilled water are adjusted by solenoid valve. Four PT-100 thermocouples has been used for the measurement of temperature at the inlet and outlet of shell side and tube side having accuracy of 0.015 °C. The pressure in the system was measured from a pressure gauge with accuracy of 0.5 %.

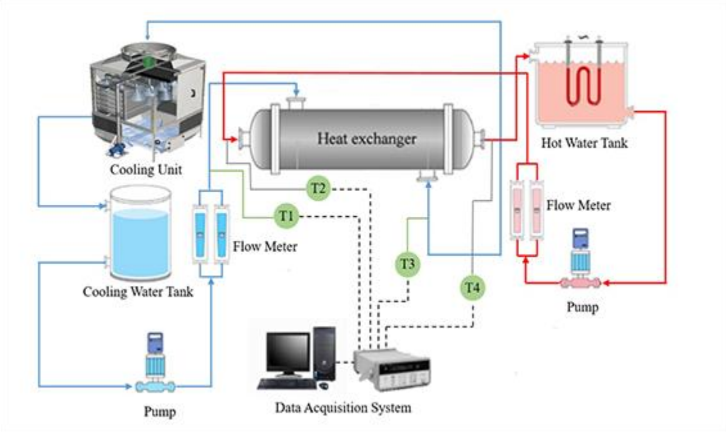


Figure 2. Schematic drawing of the experimental system

Heat transfer rate of the shell-side fluid and tube-side fluid is calculated from Eq. (1) and Eq. (2) respectively:

$$U_s = \dot{m}_s \times c_{p,s} \times (T_{s,out} - T_{s,in}) \quad (1)$$

$$U_t = \dot{m}_t \times c_{p,t} \times (T_{t,in} - T_{t,out}) \quad (2)$$

The uncertainty in results of heat transfer rate at shell and tube side was assessed by Eq. (3) [17].

$$w_U = \sqrt{\left(\frac{\partial U}{\partial T_{s,out}}\right)^2 w_{T_{s,out}}{}^2 + \left(\frac{\partial U}{\partial T_{s,in}}\right)^2 w_{T_{s,in}}{}^2 + \left(\frac{\partial U}{\partial T_{t,in}}\right)^2 w_{T_{t,in}}{}^2 + \left(\frac{\partial U}{\partial T_{t,out}}\right)^2 w_{T_{t,out}}{}^2} \quad (3)$$

3. Mathematical Modeling

3.1. CAD Models

The small size of STHX has chosen to increase the numerical model details and make solid output observations about the fluid inside the shell. Due to the small size, computational load expense for various types of baffles can be tolerated. The geometrical model of STHX with segmental baffles is the same as used in the experimental study. The baffle spacing of the three modeled heat exchangers is kept constant, and all other geometrical parameters are consistent except the baffle type.

The material chosen for the solid domains (shell, baffles and tubes) was stainless steel with thermal conductivity of λ=15.2 W/m K. The working fluid in both the shell and tube sides of STHXs was water; however, the properties of water are already defined in the FLUENT database.

4. Governing Equations

In the present work, water is considered as a Newtonian and incompressible fluid with constant thermal properties. The fluid movement in the shell and tube side is smooth, therefore, in numerical investigation the conditions for fluid is consider to be in steady state. The STHX has supposed to be novel built and consequently has a negligible fouling factor. The STHX hydrodynamic model based on the unstructured-grid finite volume method has been established using ANSYS. The design model of STHX is based on the solution of momentum, continuity, and energy equation [14, 18].

Continuity Equation:

$$\frac{\partial U_i}{\partial X_i} = 0 \tag{4}$$

Momentum Equation:

$$\frac{\partial U_i U_j}{\partial X_i} = -\frac{1}{\rho}\frac{\partial p}{\partial X_i} + \frac{\partial}{\partial X_j}\left(\left(v + v_{turb}\right)\left(\frac{\partial U_i}{\partial X_i} + \frac{\partial U_j}{\partial X_i}\right)\right) \tag{5}$$

Energy Equation:

$$\frac{\partial U_i T}{\partial X_i} = \rho \frac{\partial}{\partial X_i}\left(\left(\frac{v}{pr} + \frac{v_t}{pr_{turb}}\right)\frac{\partial T}{\partial X_i}\right) \tag{6}$$

4.1. Turbulence Model

As for the shell side flow, there is turbulence created due to higher flow rates and geometrical factors, therefore, we consider a turbulence model to acquire the accurate results of CFD. The standard K-ε model is a semi-empirical model based on the transport equations model for the K is turbulence kinetic energy and ε is dissipation rate. K and ε are obtained from the transport equation as;

$$\frac{\partial}{\partial X_i}\left(\rho K U_i\right) = \frac{\partial}{\partial X_i}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial X_j}\right] + G_k + G_b - \rho\varepsilon + S_k \tag{7}$$

$$\frac{\partial}{\partial X_i}\left(\rho \varepsilon U_i\right) = \frac{\partial}{\partial X_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial X_j}\right] + C_{1\varepsilon}\frac{\varepsilon}{K} + \left(G_k + C_{3\varepsilon}G_b\right) - C_{2\varepsilon}\rho\frac{\varepsilon^2}{K} + S_\varepsilon \tag{8}$$

The model constants have the following values;

$$C_{1\varepsilon}=1.44 \quad C_{2\varepsilon}=1.92 \quad C_{\mu}=0.09 \quad \sigma_k=1.0 \quad \sigma_\varepsilon=1.3 \tag{9}$$

5. Boundary Condition and Meshing

For investigation of numerical study, three different STHXs along with baffles are modeled. For each of individual, construction of different computational domains are required to study their performances. In each domain the study run under the two fluid domains (shell-side fluid and tube-side fluid) and one solid domain, i.e. tube bundle along with baffles. The geometries are constructed in

SolidWorks and then moved to the ANSYS for meshing by utilizing ANSYS MESHING tool. Built-in unstructured tetrahedral grids are generated at fluid computational domain as illustrated in Fig. 4 (a).

Fine mesh quality and cell sizing are used to ensure good mesh around tubes and baffles overlapping as shown in Fig. 4 (b). Precise and accurate numerical results depend on the quality and selection of mesh. A grid independence test was conducted is detailed in Tab. 2, to ensure the efficient quality mesh for numerical studies. In present work, we ran multiple trials, i.e., at 1.5 million, 2.5 million, and 3.5 million elements in the computation of the SG-STHX. The difference of heat transfer rate at 2.5 million and 3.5 million is less than 2% as illustrated in Fig. 3. Hence, we endorsed 2.5 million elements for getting precise results and less time utilization for solution to converge.

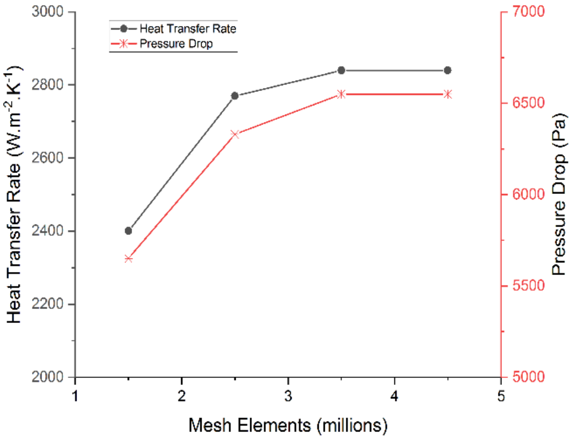


Figure 3. Grid Independence Test: SG-STHX at 0.047 kg/s

Table 2. Mesh details

Baffle Type	Nodes	Elements	Average Skewness	Average Element Quality
Segemntal	546205	2472110	0.22137	0.84187
Tri-angular	550133	2487391	0.22051	0.8425
Tri-flower	576574	2676575	0.22345	0.84055

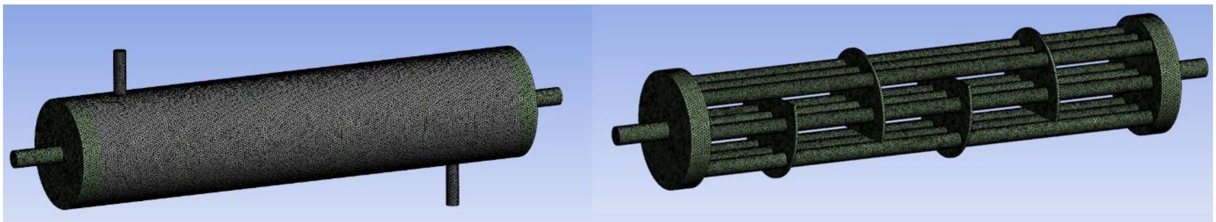


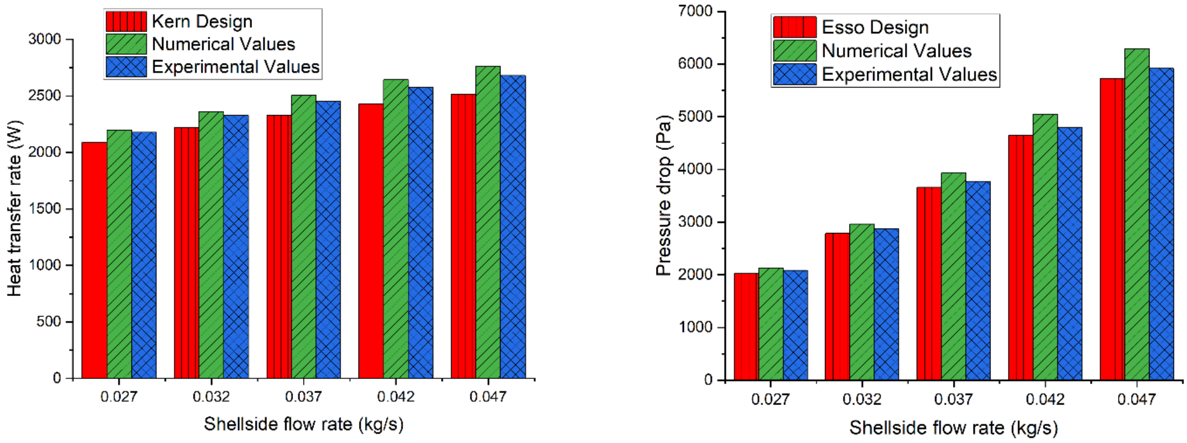
Figure 4. Mesh: (a) Complete geometry; and (b) Baffles and tubes

The inlet boundary conditions for shell and tube side are set as velocity-inlet and outlets are set as pressure-outlet, have zero pressure at outlets. The pressure at the outlet of STHX is same as it requires the fluid to move across the shell side. For inlet boundary conditions, five different flow rates of 0.027 kg/s, 0.032 kg/s, 0.037 kg/s, 0.042 kg/s, and 0.047 kg/s are adopted for each geometrical design. No slip boundary condition is applied on all the solid walls. The shell wall is also considered having zero heat flux while the tube walls, tube bundle and baffles are assumed to have solid-fluid interference as heat transfer boundary condition. The CFD simulation was performed using ANSYS FULENT.

Heat transfer solution is achieved implementing finite volume methods by using the SIMPLE algorithm. The second-order upwind scheme is functional for the turbulence, energy, momentum and dissipation rates. For the convergence criterion, the scaled residuals for continuity and momentum equation are set to10^{-4} and for energy residual is set to 10^{-6}. Default relaxation factors of the solver are used for pressure, momentum, turbulent kinetic energy and turbulent energy dissipation.

6. Model Validation

Kern and Esso methods are used to validate the numerical study. To calculate the heat transfer rate U and overall pressure drop Δp in the shell side of STHX with segmental baffles, Kern method and Esso method are used respectively [19]. Experimental validation is also adopted to ensure the trend of performance of STHX in numerical investigation and a setup base model. A graphical represenattion is shown in Fig. 5. The graphical representation of the present results shows a better agreement with Kern results, deviation found to be within 15% and pressure drop deviation of Esso design from present results is also within 10%. It also illustrates the deviation in experimental results to numerical values of heat transfer coefficient and pressure drop. This deviation is due to mechanical losses and system heat losses.



(a) (b)

Figure 5. Model validation: (a) Heat transfer rate of present work with Kern method and experimental values; and (b) Pressure drop of present work with Esso method and experimental values

7. Heat Transfer Coefficient

Heat Transfer coefficient is evaluated from numerical temperature domain by using Newton's cooling law. The comparison between three described STHX is based on the same initial conditions, i.e., same inlet temperatures and same working fluid velocity. The heat transfer variation across the three STHX is clearly observed in Fig. 6. The Fig. 7 (a) shows the graphical comparison of shell-side heat transfer performance of three STHXs. The figure illustrates that as the mass flow rate of fluid increases the heat transfer coefficient also increases. The tri-flower baffle has greater heat transfer coefficient as compared to segmental and tri-angular baffles. The TRI-STHX offers an impressive enhancement in heat transfer coefficient as compared to SG-STHX. The least heat transfer performance is shown by conventional segmental baffles in set of three.

The heat transfer enhancement in TF-STHX is due to that it covers more solid-fluid interaction area and the edges of the tri-flower baffle helps to generate swirl flow in shell-side fluid flow. These swirls cause higher maximum velocities that ultimately increases the heat transfer rate. The effect of inserting twisted tapes in above three purposed STHX on heat transfer coefficient can be seen in Fig. 7 (b). The graph shows that with insertion of twisted tapes inside the tubes of STHXs, there is an increment in the heat transfer rate between the fluid in tube-side and the shell-side. Thus, using twisted tapes within tubes increases the overall heat transfer coefficient in all three baffle designs.

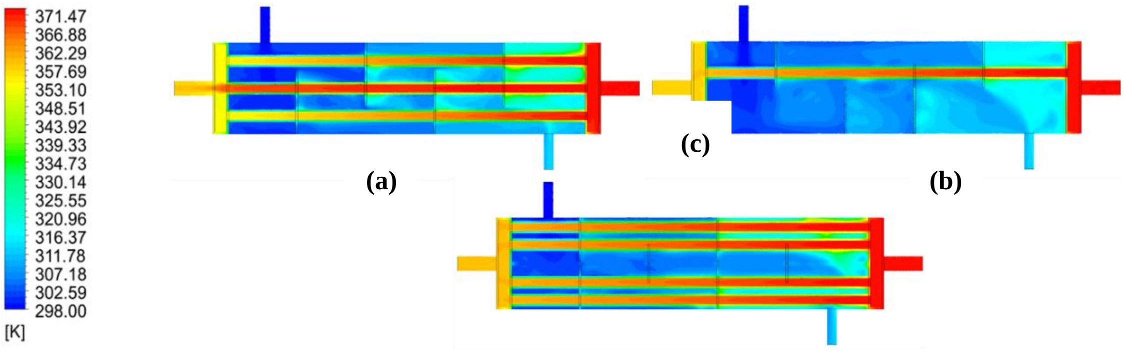


Figure 6. Temperature distribution: (a) SG-STHX; (b) TRI-STHX; and (c) TF-STHX

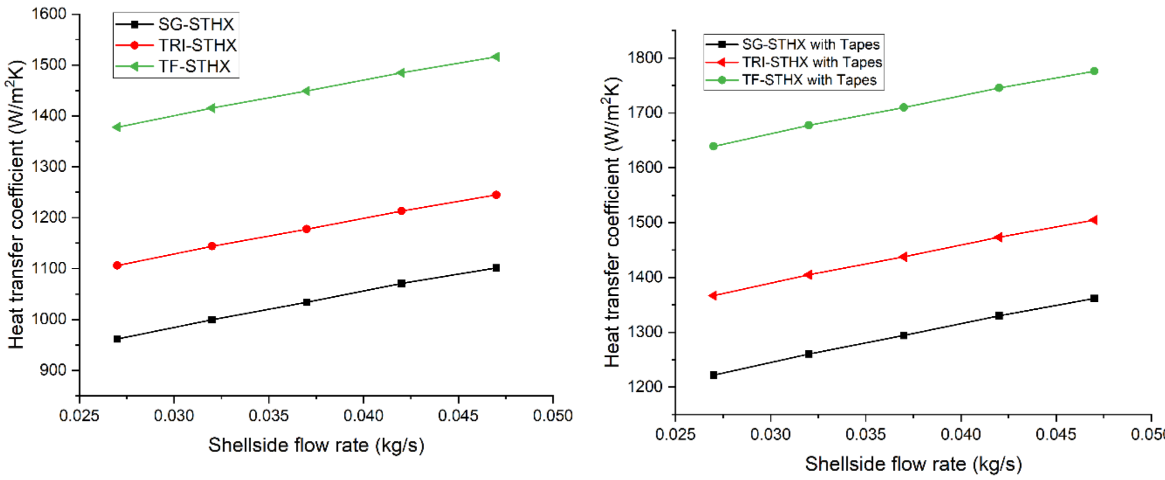


Figure 7. Heat transfer coefficient: (a) Different baffles arrangement at different flow rate; and (b) Different baffles with twisted tapes at different flow rates

8. Pressure Drop

Pressure drop has significance importance in the STHX design. The baffles shape, baffle cut, baffle arrangement and number of baffles, all these causes a hurdle in fluid flow path at shell side that lead towards pressure drop. Pressure drop has direct link with pumping cost, as a small increment in pressure drop value increase the pumping cost.

Distribution of pressure drop of three baffles is shown in the Fig. 8. This illustrates that, the STHX with tri-flower baffles offers higher pressure drop in comparison to the other two baffle designs. The TF-STHX produces maximum velocities that help in the more heat transfer but at the same time result in higher pressure drop. Segmental baffle produces higher maximal velocities and dead zones as compared to tri-angled baffles. On the other hand TRI-STHX has slight variation in pressure curve and shows lowest pressure drop.

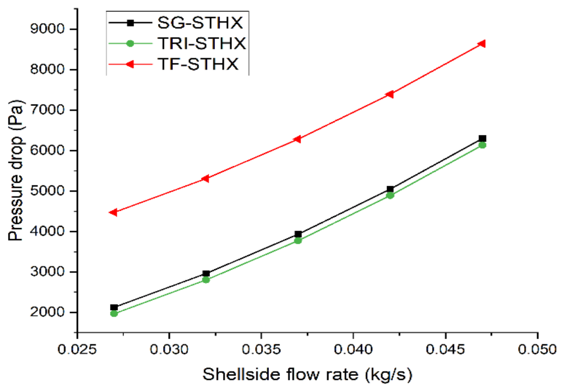


Figure 8. Pressure drop: Different baffles

It is clearly observed that shell-side flow distribution in TRI-STHX offers slight deflection in the direction of fluid flow, causing a smooth flow and better circulation along the shell-side with fewer dead zones. Dead zones, fluid recirculation and higher maximal velocities are the main causes of increment in pressure drop. Pressure drop moves from lowest to highest in the following order; tri-angular, segmental and tri-flower. Note that in case of inserted twisted tapes inside the tubes, there is no effect on the outer shell-side fluid flow. Thus, the pressure variation of different STHXs with twisted tapes is same as without twisted tapes.

9. Comprehensive Performance Analysis (hs / Δps)

To calculate the efficiency of STHX, consideration of both heat transfer coefficient and pressure drop is very important and both of these elements are dependent on each other. Heat transfer rate is increased by increasing the fluid velocity but on the other hand, it also increases the pressure drop. It is essential to increase the heat transfer rate almost at the same pressure drop to achieve the improved comprehensive performance.

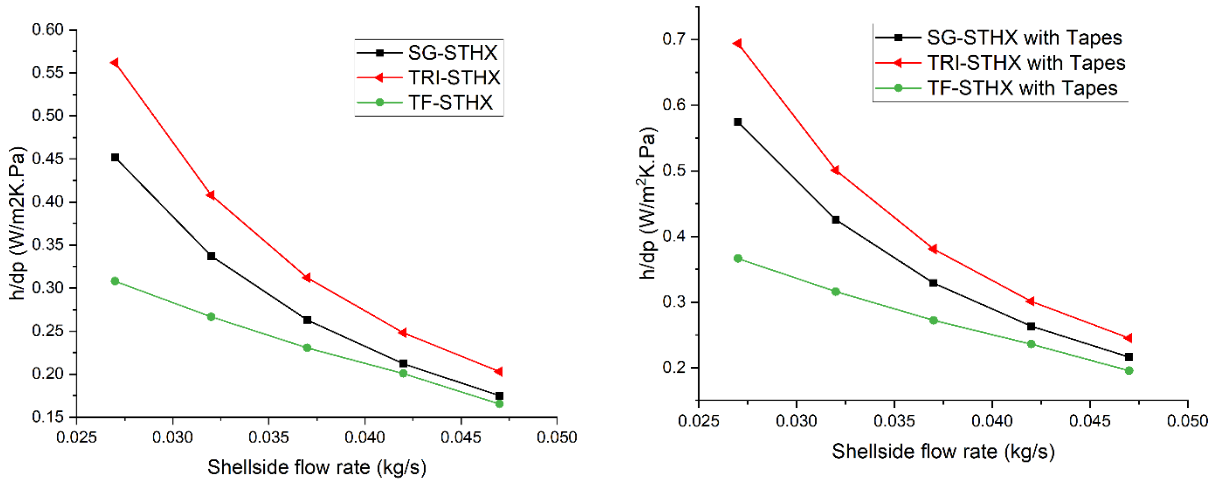


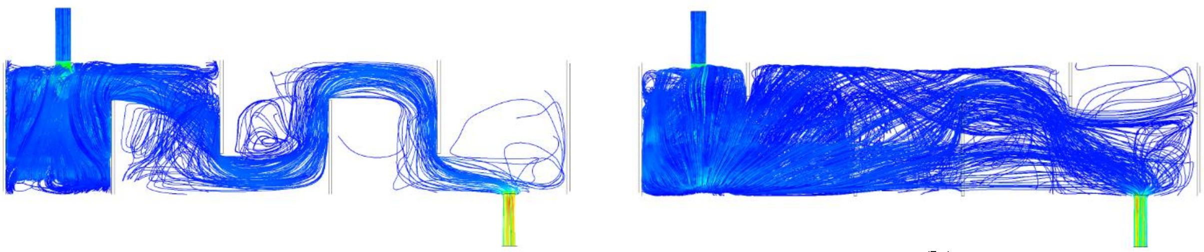
Figure 9. Comprehensive performance: (a) Different baffles arrangement at different flow rates; and (b) Different baffles with twisted tapes at different flow rates

In present study, comprehensive performance of three STHXs is calculated by heat transfer coefficient per pressure drop. Comprehensive performance of different STHXs with segmental and newly designed baffles is displayed in Fig. 9 (a). It can be seen that with increase in shell-side mass flow rate, the heat transfer coefficient per pressure drop decreases for all STHX arrangements. It can be noticed that the comprehensive performance of STHX with tri-angular baffles is greater than STHX with conventional segmental baffles. On the other side, TF-STHX having lower value of comprehensive performance as compared to SG-STHX. Therefore, the STHX with tri-angular baffles has higher heat transfer rate at same pressure drop because of its shape. This baffle design provides suitable swirl flow and acceptable solid fluid interaction to increase the heat transfer. Furthermore, TRI-STHX decreases the dead zones and minimizes the recirculations of fluid that decreases the pressure drop at same heat transfer, thus enhances the comprehensive performance. This tri-angular baffle extends a good mixing effect and consequently less pressure drop and greater heat transfer is conquered compared to the tri-flower and segmental baffles.

The Fig. 9 (b) illustrates that by inserting twisted tape inside the tubes of STHX increases the temperature difference between tubes-inlet and tubes-outlet. Higher temperature difference results in better heat transfer rate at same shell-side pressure drop as compared to tubes without twisted tapes. Hence, trend of thermohydraulic performance for different baffles is same as for without twisted tapes. Therefore, it is beneficial to use twisted tapes in the tubes to improve the heat transfer coefficient, which obviously increases the comprehensive performance of STHX.

10. Induced Vibrations

Vibration is the main concern in proper working and better efficiency of STHX. The behavior of fluid flow in the shell side determines the amount of induced vibrations in the system. This induced vibration is one of the reasons to increase the pressure drop, reduce the overall efficiency and also leads toward the failure of STHX assembly [14]. The shape of baffles is responsible for the fluid flow behavior in shell-side. The Fig. 10 shows the streamline pattern of fluid flow in shell-side of SG-STHX and TRI-STHX design.



(a) **(b)**

Figure 10. Velocity streamline: (a) Flow pattern of fluid at shell-side with SG-STHX; and (b) Flow pattern of fluid at shell-side with TRI-STHX

The Fig. 10 (a) shows the perpendicular flow pattern in the STHX with standard segmental baffles. The perpendicular flow of fluid in SG-STHX causes direct impulsive force on the tube bundles, which tends to induce vibrations in tube bundle assembly. Due to these induced vibrations, the overall performance of STHX is affected.

It is investigated that the induced vibrations can be reduced if the shell-side fluid strike the tube bundle in the longitudinal manner [14]. Fig. 10 (b) shows the flow behavior of STHX with tri-angular baffle and the flow pattern in TRI-STHX is not perpendicular to the tube bundle, causes the less pressure on the tubes. Due to homogenous and non perpendicular flow of fluid in the shell-side, there are less induced vibrations produced in the TRI-STHX as compared to conventinoal SG-STHX.

11. Conculsion

The present work consists of experimental setup and simulations to evaluate and compare the results of heat transfer rate, pressure drop, and thermo-hydraulic performance of STHXs with different baffles. The study is grounded between two novel baffles; tri-angular, tri-flower and conventional segmental baffle. The outcomes from numerically simulated models showed that TF-STHX has the highest heat transfer rate at the cost of highest pressure drop as compared to that of two other baffle designs. Shell-side flow analysis in the TRI-STHX showed more smooth and homogeneous velocity distribution. It results in reducing the shell-side fluid recirculations and also produces the fewer dead zones. This all out-turned that TRI-STHX offers less pressure drop as compared to the other three designs of baffles. TRI-STHX showed a good balance between pressure drop and heat transfer rate that leads to a thermo-hydraulic performance enhancement. Therefore, the novelty of TRI-STHX design is indicated through comparative results of heat transfer and pressure with conventional design. Moreover insertion of twisted tapes also increases the heat transfer rate in STHX with different baffle designs and does not affect the shell-side pressure drop. Regardless of heat transfer rate and pressure drop, in TRI-STHX design the shell-side fluid moves at certain angle with respect to the tubes and the uniform shell-side fluid flow results in less induced vibrations as compared to the conventional SG-STHX. This factor play vital role to achieve higher efficiency and optimization of the required results. The extensive study on different novel designed baffles as compared to conventional segmental baffle can be summarized as follow;

- The increment in the heat transfer rate for TF-STHX is 25 % and for TRI-STHX is 12 % as compared to SG-STHX. It is notice that by inserting twisted tapes in the tubes, the heat transfer is increased by 12-15 % in each of baffle design.
- The TRI-STHX shows less pressure drop at shell-side as compared to other STHXs and offers less induced vibrations due to better shell-side fluid flow.
- Therefore, the novel TRI-STHX stand out as to provide best thermo-hydraulic performance in comparison of TF-STHX and conventional SG-STHX.

Nomenclature

H - heat transfer coefficient, [$Wm^{-2}K^{-1}$]
$\dot{m}$ - mass flow rate, [kgs^{-1}]
Δp - pressure drop, [Pa]
U - heat transfer rate, [W]
v_t - turbulent eddy viscosity

Abbreviations

HX - heat exchanger
STHX - shell and tube heat exchanger
SG - segmental baffle
TRI - triangular baffle
TF - triflower baffle

Greek Words

λ - thermal conductivity, [Wm-1K-1]
μ - dynamic viscosity, [kgm-1s-1]
ν - kinematic viscosity, [m2s-1]
ρ - density, [kgm-3]

Subscripts

in - inlet
out - outlet

s -shell
t -tube
turb - turbulent

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