ISSN: 0974-5823 Vol. 6 No. 3 December, 2021

International Journal of Mechanical Engineering

Analysis of Performance for Shell and tube heat exchangers using Baffles

Shailandra Kumar Prasad[1*], **Dr. Mrityunjay Kumar Sinha**[2]

[1] Research Scholar, Department of Mechanical Engineering, National Institute of Technology, Jamshedpur, Jharkhand, India

[2] Professor, Department of Mechanical Engineering, National Institute of Technology, Jamshedpur, Jharkhand, India

* **Corresponding author:** Shailandra Kumar Prasad

Abstract

The present article is based on the performance analysis of shell and tube heat exchanger that utilizes baffle. The efficiency of the exchanger is enhanced by using baffles of different geometry to improve heat capacity. In modern heat exchangers clamping baffles with anti-vibration is proposed to avoid the recirculation zone in the elemental segment and vibration flow. The comparative analysis of the heat transfer co-efficient and pressure drop is required for heat exchanger simulation for 3-D CFD implementation. The modeling of heat exchangers through statistical presentation demonstrates the higher accuracy and performance of the exchanger. A comparison of thermo-hydraulic heat exchangers are carried out with two different methods called-Esso and Kern. The study shows that heat exchanger performance plays an important role in identifying various characteristics including reflective angle, diameter ratio, and other factors for corrugated tubes.

Keywords: Performance analysis, Shell and tube heat exchanger, Segmental baffle, Statistical presentation, Coefficient of heat transfer

1. Introduction

A device that is used for transferring the thermal energy among two or more fluids between fluid and solid surfaces is recognized as a heat transfer device [1]. These devices avoid the mixing of fluids and maintain the separation through the transfer of heat. Tube present in the temperature exchange devices are known as U-tubes as it is in the shape of U. Heat exchangers are widely used in industries for different types of heat exchangers including plate-fin, shell-and-tube, fin-and-tube, and so on. The focus of the present paper is to analyze the performance quality of STHX (shell-and-tube heat exchangers) due to its simple design and multiple appliances. STHX is effectively working for a high range of pressure and temperature and that is the reason it is used in industrial plants [2]. Different types of baffles are present under STHX which changes the flow direction and provides support to tubes. Segmental baffles are used in the STHX industries due to their numerous advantages.

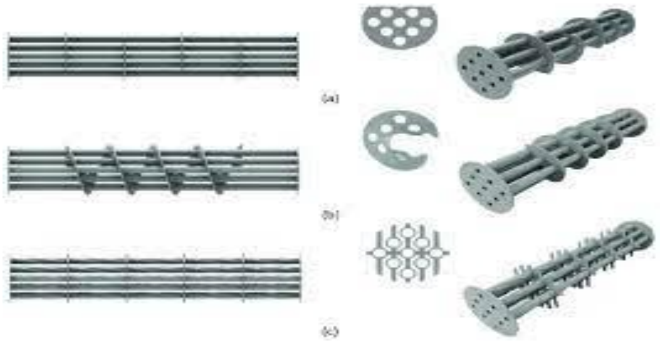

Figure 1: Different types of tube bundles: (a) SGCT-STHX, (b) HBCT-STHX, (c) CBSTT-STHX

(Source: Roy 2019, [3])

Qualities of heat transfer and turbulence improved using segmental baffles for exchanging heat. Multiple cons of the used baffles could also be analyzed while checking the rate of performance. Successive collisions and elaboration increase the pressure drop in the entire shell whenever the flow gets separated at the baffle's edge [4]. Competence of transferring heat decreases due to the segmented flow in a dead zone. The operating time of STHX get affected by induced vibration and result in downing the range of heat. Fouling resistance is created due to the effects that occurred on the large side of shells. All the fault of the STHX would be avoided or the performance could be increased with the application of baffles. Different baffles including helical, segmental, and square-twist are used for the specific role whose models are shown in figure 1. Helical baffles replace segmental baffles to boost the performance quality as it has an optimal angle of 40 degrees [5]. The angle at the vertical position to the axis is in the range between 10 to 45 degrees while adding tube bundles.

Heat transfer devices like CBSTT (Clampng anti-vibration baffles with square twisted tubes) have more strength in comparison to the traditional baffles' performance. The construction style is the basic measure for the categorization of the U-tube heat exchanger (UTHX) [6]. Designing of UTHX has been done through TEMA (Tubular Exchanger Manufacturers Association) maintaining the standard of heat exchanger system. Fluid is either in cold or hot water for the HX and the categorization could be understood with its flow. Fluids enter and come out at the same time while flowing into a double pass UTHX. Motions of fluids are observed UTHX in two-mode simultaneously one flow inside and other flow over the tube. The tube bundle is a vital part of the heat exchanger system which is a set of u-tubes [7]. UTHX is consist of various components such as tie rod, nozzle, baffles, tube bundle, U-tubes, shell, and shell cover as shown in figure 2. Shell and tube heat exchangers are applicable for heating water, gas, and oil cooling for domestic use.

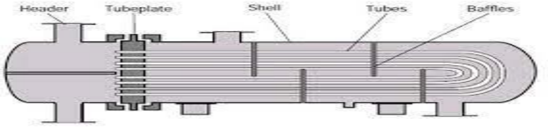

Figure 2: Different parts of U-Tube heat exchanger

(Source: Bart et al. 2018, [8])

STHX is used in power plants in the form of condensers, boilers, and steam generators. The heating of water present in swimming pools is done with the application of UTHX or STHX. Heat is recovered through liquids while applying heat exchangers devices for recovery of wasted heat [9]. Effective use of hew heat exchangers like STHX is used for cooling the glycol in which temperature of the water is boosted using steam. Chemical industries also use heat exchangers for different uses such as refilling petroleum. Previous articles or theories are used for measuring the performance quality of heat exchangers using baffles. Experimentally investigated responses of authors' show a single-phase tube is used in the form of working fluids for the tube and shell side. Examination of flow rate for volumetric and corrugated tubes provides information related to the effect on the pitch [10]. Working fluids for the STHX in the present context are cold and hot water. Mathematical modeling of STHX in multiple sections for example physical, governing, and conditions of boundaries are well-acknowledged in the present paper.

2. Configuration and mathematical modeling

2.1 Configuration of STHX for its geometric model

The geometrical configuration of the STHX with segmental baffles shows the configuration of parameters that is specific for the transferring fluid. Associated elements of the STHX model are recognized through its height, width, and thickness in this configuration. Configuration countering is acknowledged through the geometrical configuration of the system that shows STHX has an external diameter of 50 mm, 200 mm long, and 3mm thick [11]. The shell is the outer portion of heat exchanger while the tube is the internal part that contains fluids. Figure 3 represents the model of the geometric configuration of the STHX model. The below model is effective in presenting the outer and internal structure of the system with its design.

Figure 3: Geometrical configuration of STHX model

(Source: Roy et al. 2020,[12])

2.2 Mathematical modeling of STHX

2.2.1 Physical model

The computed load of the exchanger device could be easily understood with the tiny size of applied STHX [13]. Three different types such as plate-heat exchanger, Shell-and-tube heat, and finned tube heat exchanger models are used for a specific role to fulfill different demands [14]. The physical model of the shell and tube heat exchanger with its baffle is examined to elaborate on the working and structure of the system. The present model of heat exchanging device plays an effective role in decreasing the gap between baffle and tube. The space between the baffle and the design of the internal tube remains constant in STHX.

2.2.2 Identifying equation for calculating performance

Fouling resistance of shell-side is ignored through the equation of energy while assuming the minor shell side of the STHX. The fluid used in the system which is in this context referred to as water is generally known as incompressible fluid or Newtonian fluid. Insignificant seepage is presented among the internal tube, baffle, and shell. Technical measurement of the system could be analyzed through the selection of ANSYS fluent [15]. Unstructured-grid is applicable for the construction of a hydrodynamic model for the continuity maintained in governing equations. Continuity, momentum, and energy for the transferred fluid of STHX could be calculated with the below equations 1, 2, and 3 respectively.

The presented equation in the below section contains a few symbols which have a specific meaning. For example pressure, velocity, and temperature of fluid are represented through P, u, and T respectively. The density of the fluid is vital to alter the transferred heat coefficient which is represented as p. Pr and v symbolizes Prandtl number and kinematic viscosity of the available liquid [16]. Supplier performance could be achieved with the use of these equations as it provides exact value for the obtained data. The turbulence model for the STHX shows a constant value for empirical in the form of C1 that has value 1.2 whereas Cu is not a constant term. The flows of fluid in the shell are determined for the different system as turbulent.

1. Equation of continuity for the STHX model [17]:

$(dui) / (dxi) = 0$

2. Equation for measuring momentum:

$[(duiuj) = -1/P*dp\backslash dxi+d/dxj\{(a=vturb)(dui/dxi + duj/dxi)\}]$

3. The equation for measuring the energy of STHX [18]:

$duiT/dxi = P\ d/dxi\ \{(v/Pr + vt/\ Prturb)\ dT/dxi\}$

2.2.3 Condition for boundary measure

A set of boundaries are designed for the STHX for improving its performance. Each boundary has its specific conditions for example momentum boundaries show no penetration or slip from the side of tube walls [19]. Inlet and outlet of solid walls required zero flow in the thermal boundary that couple the transfer of heat inside the walls of the tube, baffle, and a bundle of the tube. The boundary condition for the heat exchange system could be recognized as velocity-inlet for outlet and inlet coverage of tube. Pressure drop for the contained fluid could be identified to have zero pressure under the domain of solid and fluid. The range of temperature for the tested system is observed to be between 298K and 374K for the inlet of shells and tube [20]. Simple algorithm and ANSYS FLUENT are majorly used for measuring domains of computation and formulation of finite volume respectively. Second-order is used to upwind scheme for measuring different elements like rate of dissipation, momentum, energy, and turbulence. Governing equations which are presented in the above section (2.2.2) have the strength to measure the system performance [21].

3. Experimental setup or applied methodology

3.1 Setup for the investigation

The UTHX model is set up in the experimental form to obtained different elements that measure the system performance. Multiple elements are present in the experimental organization of the UTHX as shown in figure 4. These elements are temperature indicators, pipes, stopwatch, pails, and flask. More than 11 identical copper pipes are connected from the shell to the tube and work as heat exchangers. The tube is bent in the U shape as per its name and has a thickness of 1.25 mm [22]. The amount of heat transferred through the tube is required to be maintained as 0.26 square meters for the plain tube and for U-tube it should be 1.04 square meters. The length of the shell and tube of the exchanger system should be 300 mm and 700 mm in order. Fluids of the tested device that are hot and cold water are carried through external pipes. Room temperature is favorable for the flow or transferring of cold water. Inlet and outlet temperatures of cold and hot water are measured with the temperature indicator along with thermocouples [23].

Figure 4: Experimental set up of the UTHX

(Source: Kareemullah et al. 2019, [24])

3.2 Procedure of testing

Figure 5 presents the systematic diagram for the investigated layout that test the performance of STHX. The mid section of the below figure represents the tube which is connected with different elements [25]. These elements are hot water elevated tank, cold water elevated tank, bucket for hot besides cold water, separate outlet and inlet for hot along with cold water. Arrangement of fluids is countered for area of high temperature for the transferred fluids.

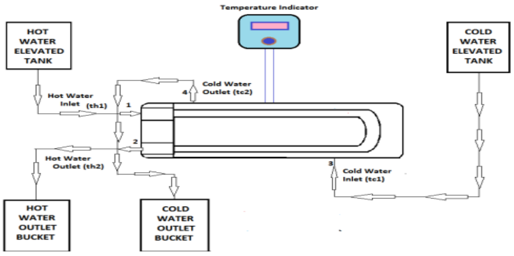

Figure 5: Experimental layout using line diagram

(Source: Colangelo et al. 2021, [26])

3.3 Result obtained through experimental observation

The data presented in the below table shows the experimental result obtained for plain and corrugated tube heat exchanger. Comparative analyses of the data are performed for used fluids such as cold water and hot water. Different parameters are used for observing the rate of performance which is typically type of fluid, inlet temperature, along with outlet temperature of both fluids as shown in table 1.

Table 1: Result obtained through experimental setup of the heat exchanger device

Serial Number	Tested parameters	Result obtained through plain tube heat exchanger	Result obtained through corrugated tube heat exchanger
1.	Hot Fluid	Warm water	Warm water
2.	Inlet temperature for hot water	326.6 K	326.6 K
3.	Outlet temperature for hot water	324.2 K	322.9 K
4.	Net flow rate of hot fluid	0.124 Kg/s	0.128 Kg/s
5.	Cold fluid	Cold water	Cold water
6.	Inlet temperature for cold water	307.8 K	305.7 K
7.	Outlet temperature for cold water	305.4 K	310.2 K
8.	Net flow rate of cold fluid	0.114 Kg/s	0.118 Kg/s

4. Result and Analysis

4.1 Result

4.1.1 Validation of the tested model

In the current analysis validation of the numerical model has been done by using the Kern method. It provides the scope of calculating the co-efficient for overall shell side heat transfer. For the need of calculating the pressure drop of the shell side of STHX application of the Esso method has been done for the current analysis [27]. Comparison evaluation has been made for findings the developed results co-relations. From this analysis, it has been detected that the average deviation for heat transfer coefficient and pressure drop for the used method is less than 10%.

4.1.2 Measuring of the pressure drop

Pressure drop is very essential for linking the pumping cost developing probability for the heat exchange in shell and tube. It has been observed that as much as the pressure will drop the need for additional pumping costs will arise. Comparison observation develops the understanding scope for helical baffles' high-pressure drop in the current analysis. It has also been detected that other heat exchanges pressure drop is more compared to STHX with CBSTT heat exchange. Comparing HBCT-STHX and STHX with SGCT it has been detected that the pressure drop of HBCT-STHX is lower than the other. The reason for these low or high-pressure drops is because of the segmental baffles flow of motion pattern that is zigzag on shell side that creates the situation for momentum change [28]. From the current research, it has been detected that separation of the flow in baffles is because of the pressure drop severity compared it with helical baffles this flow change is not occurring.

4.1.3 Analysis of heat transferring performances

In the present analysis, a comparison has been developed for three types of heat exchanging processes. From this observation, it has been detected that STHX has higher heat transferring co-efficient compared to the other two types of heat exchangers used in the current research. Compare to conventional segmental baffles heat transfer coefficient is higher for anti-vibration baffles with twisted tubes [29]. In the process of developing results for the different heat transferring ratios determine the scope for the effectiveness and other values have been developed. With developing knowledge scope of controlling the fall and barriers for the required heat exchange has been understood. Heat capacity ratio and Reynolds numbers are the other observational criteria for the current heat exchange experiment observation [30]. The reason for highlighting these specific criteria is so that scope of better analysis has been developed for the current research.

The scope of numerical model analysis and understanding has been developed with the capability of monitoring efficiency. Without suitable monitoring the identification of the change is limited and sometimes it put an impact on the gap of the results. It has been removed through expert handling and proper evaluation [31]. Comparing the heat exchanging process makes the sense of knowing the potential, barriers, and probability of heat fall and by which the scope of future experiment planning will be developed for the current research.

4.2 Analysis of the obtained result

Analysis of performance for the heat exchangers are obtained through the testing of a valid model, pressure drop, and heat transfer rate [32]. Following results are obtained through the modeling and performance investigation of STHX:

1. The coefficient of transferred heat for the contained fluids would be increased with the increase in Nusselt and Reynolds numbers.

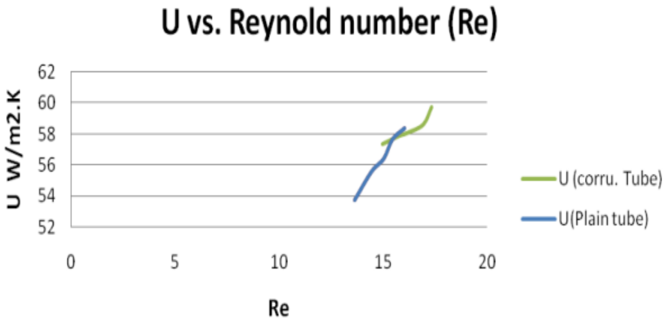

Figure 6: Graphical presentation of Nusselt and Reynolds numbers for plain tube Vs corrugated tube (Source: Abbasi 2020, [32])

2. The obtained result shows the influence of corrugation is comparatively higher for the tube side than the shell side of the heat exchangers.

3. Corrugated tubes show a high-pressure drop in comparison to the straight tube.

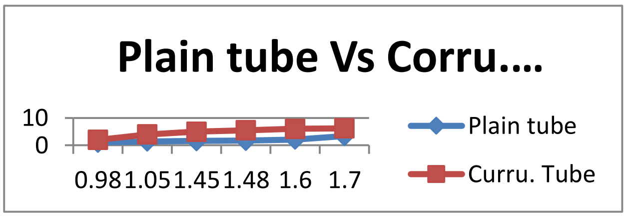

Figure 7: Graphical representation of effectiveness between plain and corrugated tube

4. The efficiency and effectiveness of the tested heat exchanger that is UTHX are high for the corrugated system.

5. Heat transfer could be increased within a special channel which is suitable for the exchange of heat while the Reynolds number is low.

6. Comparing all baffles it has been observed that helical baffle provides best performance in heat exchanger as shown in figure 7.

Table 2: Comparative analysis of pressure drop and mass flow rate for STHXs

Flow rate of shell side	HBCT	SGCT	CBSTT
0.025	1.2	1.0	1.1
0.030	0.9	0.7	0.8
0.035	0.7	0.6	0.65
0.040	0.6	0.5	0.55
0.045	0.4	0.3	0.35
0.050	0.3	0.2	0.3

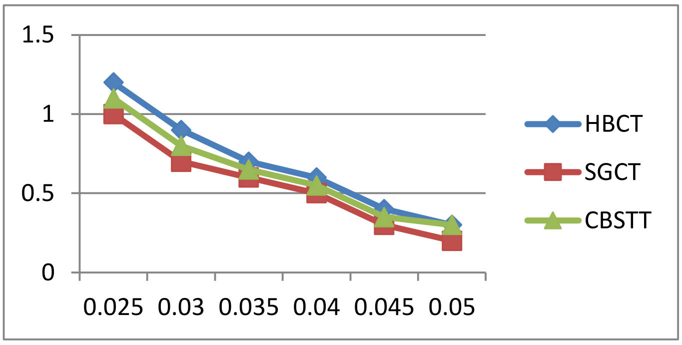

Figure 8: Graphical representation of pressure drop and mass flow rate for STHXs

5. Discussion

Discussion over the presented result beside theory shows the performance rate for the heat exchangers is high for the U-tube. Baffles are used for boosting heat coefficient of the fluid contained in the tube. Fluids used for the heat transfer for the plain and corrugated heat exchanger. Investigation of STHX in systematic way presents the dependence of heat transfer coefficient on the Reynolds number and Nusselt number. Corrugation system for the heat exchange using Esso and Kern method shows pressure drop is less than 10%. Performance of heat transferred for the different heat exchangers such as HBCT, STHX, and SGCT shows lower pressure drop. The performance or the heat coefficient dependent on the temperature maintenance and the rate for the flow of hot water is 0.124 Kg/s while 0.114 Kg/s for cold fluid [33].

6. Conclusion

Numerical model of the heat exchanger are comparatively analyzed for evaluate and relate specific types of tubes and baffles. The concluded result for the present study shows the performance range boosted with the application of baffles. Different types of tubes like CBSTT, HBCT, and SGCT are tested for specific baffles. Performance of heat exchangers improves with the use of helical baffles with 45 degrees. Analysis of liquid flow shows constant distribution of STHX and CBSTT. Helical baffles are best for the improving the performance range while implementing different heat exchangers. Vibration in the flow of liquid could be reduced through recirculation of eliminated segment.

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