Journal of Engineering Science and Technology
Vol. 16, No. 2 (2021) 1761 – 1781

EXPERIMENTAL INVESTIGATION AND ANALYSIS OF HEAT TRANSFER RATE IN CONICAL TUBE HEAT EXCHANGER: A NOVEL ENHANCEMENT APPROACH

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Abstract

Heat exchangers are devices employed in transferring thermal energy from one fluid to another at varying temperature rates within thermal contact. Recent uses of such devices are found in oil refineries and (petro-) chemistry, as well as power generating projects, as all of these accommodate shell and tube type heat exchangers (STHEs). The present paper describes the major component of STHE and the modification of heat exchangers that are used in thermal power plants. The STHE is used as a heat exchanger based on its simple design and performance aspects. Even though these shell and tube heat exchangers operate at their designed point, they can be even effectively designed to achieve a better heat transfer rate by using different changes in parameters. In terms of engineering, an optimal design would involve maximal heat transferring and minimal costs. This paper also reviewed different types of STHE enhancements, including modifications in the arrangement and number of tubes, as well as their diameters, length, pitches, and types. Other aspects considered are the height of fins, and baffle types, and their spacing ratios. The outer cylindrical tube of an ordinary heat exchanger-type concentrate tube was replaced by a conical tube during the present experimental analysis. The use of epoxy resin and fibre has been developed to create new conic tubes with different diameter values. Conical tubes had a diameter of 0.882, 0.741, and 0.612. For a conical tube heat exchanger with a length of 1 meter, experiments were performed. For the inner tube, 1 LPM and the outside conical tube 1 LPM to 7 LPM were considered. The conical tube thermal transmission results were analysed and compared with cylindrical tube results. Results show that the heat transfer rate is inversely proportionate to the ratio of diameter. For HTR water flowing through conical external tubes, a correlation was developed. There were results that showed up to 22 present higher heat transfer rates.

Keywords: Baffle type, Conical tube, Heat transfer, Regression analysis, Tube arrangement.

1. Introduction

1.1. Defining heat exchangers

Among the commonly applied uses of heat transferring is the design of heat transferring equipment to exchange heat between two fluids., also known as heat exchangers (HE) [1]. These devices used in transferring thermal energy (enthalpy) among several for differing temperature rates, as one medium has a low temperature whereas the other has a higher one [2]. The heat exchangers can be of two kinds: direct and indirect contact HEs with the former type, a direct contact exists between the two functions involved in the heat exchanging process, whereas no such direct contact exists in the latter, as a wall separates the two media and prevents them from mixing. The shell-and-tube type heat exchanger (STHE) is an example of the latter type of HE device, consisting of sets of tubes through which one of the media runs. The separation between tube and shell side fluids is realized by means of a tube sheet [3].

1.2. Classifying heat exchangers

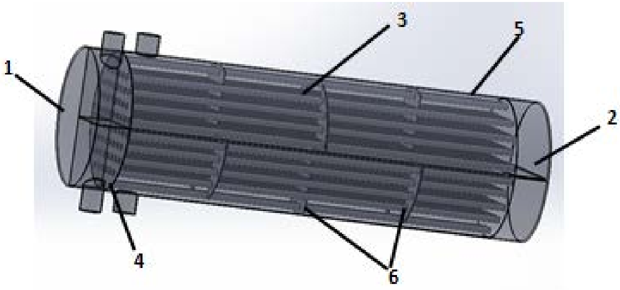
In general, the classification of HEs is done depending on a number of factors. The main factors taken into consideration are: Construction properties, Heat transferring mechanisms, Arrangement of flow, Transferring process, Surface compactness, Number of fluids. The measurement of how efficient the HEs perform is done by means of the amount of heat transferred with the use of the least transferring area and lowest pressure drop rate. This efficiency could be presented in a more sufficient manner, namely by means of calculating the total heat transferring coefficient. The pressure drops and area needed for transferring a particular amount of heat present an indication of the capital costs as well as power demands (running cost) of HEs. Several theories and much literature are devoted to the designing of HEs based on these criteria [2].

1.3. Construction of shell-and-tube heat exchanger

An STHE is formed by a bundle of tubes that are enclosed within a cylindrical shell, having one of the fluids passing through the tubes whereas the other runs between tubes and shell. Basically, the STHE is formed by means of a number of components, including tubes and their sheets and side channels and nozzles, shell and shell-side nozzles, channel covers, pass divider, baffles. The type of STHEs that are more widely used tends to have wider heat transferring surface-area-to-volume ratios for providing relatively higher heat transfer efficiency than others. These could be cleaned with ease, and any failure parts such as gaskets and tubes are replaceable without difficulty [4]. The STHEs represent about 80% of any current exchangers found in refineries, and petrochemical and power plants. Such devices can be applied to a wider range of pressures and temperatures, which in turn could be further extended through novel designs [5].

1.4. Major parts of an STHE

Figure 1 illustrates the main parts that compose an STHE [6], including:



1. Front Header, 2. Rear Header, 3. Tubes (tube bundles),
4.Tube sheets, 5. Shell, 6. Baffles, 7. Impingement plates.

Fig. 1. Shell and tube exchanger.

1. Front Header: It is the part where fluids can enter the tube side of the HE, also known as the Stationary.
2. Rear Header: It is the section from which the tube side fluid exits the HE, or otherwise returns to the front header in HEs of more than one tube side passes.
3. Tubes: These are the basic component of the STHEs which provide the surface for heat transferring between the two fluids that flow parallel to each other, one running within the tube whereas the other flows along the outer side of the tube. Therefore, a major recommendation made includes that the tube material needs to be highly thermally conductive, to ensure proper heat transfer.
4. Tube sheets: The main function of tube sheets is holding the tubes in place, as these are inserted into the holes of the sheet, as the latter could be either expanded into grooves cut in the holes or welded on the tube sheet itself. Sheets are often one round metal plate, drilled and grooved in a suitable manner so as to hold the tubes. A double sheet may help prevent the fluids from mixing.
5. Shell: The shell represents the container that holds the shell side fluids, with its nozzles functioning as inlet and exit ports. The shell has a circular cross-section, often formed by rolling the metal plate of suitable dimensions into a cylinder, after which the longitudinal joint is welded.
6. Baffles: Baffles have two main functions, namely keeping tubes in position during operation, preventing the tubes from vibrating due to flow-induced eddies, and guiding the shell side in flowing back and forth across the tube field, to increase the velocity and heat transferring coefficients. Baffle types include segmental, disc and doughnut, and orifice baffles.
7. Impingement plates: Whenever fluids get into the shell under high pressure, it is very likely that breakage or deformation can take place, as the fluid impinges over them directly. Such a situation can be avoided by means of installing similar impingement plates for wasting the kinetic energy of the fluid up [7].

1.5. Limited design

The optimal thermal design of STHE considers several interacting factors of design; these are summed up in the following points [8]:

1.5.1. Process

As for the process itself, five factors should be taken into consideration:

- Assigning process fluids to either shell or tube side.
- Selecting stream temperature criteria.
- Determining the shell side and tube side pressure drop design limitations.
- Determining the shell side and tube side velocity limitations.
- Selecting a heat transferring model and fouling coefficient for each of the shell and tube sides.

1.5.2. Mechanics

In terms of mechanics, the aspects below should be considered:

- Selecting the HE-TEMA design and number of passes.
- Specifying tube variables: size, layout, pitch, materials.
- Setting of maximum and minimum design limitations on tube length.
- Specifying shell side variables: material, baffle cuts, spacing, and clearances.
- Setting of maximum and minimum design limitations on shell diameter, and baffle cuts and spacing.

2. Heat Transfer Enhancement Techniques

Enhancing heat transfer is among the most rapidly developing fields in heat transferring technology. Its techniques are either active or passive, according to the way of improving the heat transferring performance. With the flow turbulent kept low, an increased heat transfer performance can be secured by means of using different tube types and different baffle types.

2.1. Enhancement techniques using different tube types

This case does not require an external form of power, often applying geometrical or surface alterations to the flow tube through extra devices or joining inserts. This type of technique results in a rise in heat transferring rate through the change of flow treatment, which is eventually causing the pressure drop to elevate simultaneously. Bougriou and Baadache [9] considered a novel sort of heat exchanger: shell-and-double concentric-tube HEs. Through the longitudinal optimization of this type of HE, a significant amount of saving is both space and material are provided, in comparison with the STHE having similar diameters for the external tube of the double concentric-tubes and the shell itself. The rise in the primary mass flow rate of fluid (which could be over 70% as relative discrepancies) leads to a corresponding rise in compactness, whereas it decreases the HE in volume or lengthwise. The highest rate indifference maintains some correspondence with a smaller diameter for the internal tube, as a specific diameter is assigned to each mass flow rate.

Rathore and Bergaley [10] attempted the identification of the benefits of Low-Finned Tube HEs as compared to Plain Tube (bare Tube) exchangers. It was shown that the former was more economical than the latter type, of exchangers. The tube side pressure drops, and fluid velocities of the former were higher than the plain tube, thereby preventing any form of foul within the tubes. Although the shell side pressure drop might be somewhat lower, yet the fluid velocity is larger for the plain tube, saving the external tube surface from foul and fluid transfer time. In terms of shell diameters, the Finned Tube exchanger has a smaller diameter than the plain tube, thereby saving sheet materials and reducing the shell in size. This eventually helps with the installation inside the plant. Table 1 compares bare and finned tube heat exchangers [10].

Table 1. Comparing bare and finned tube heat exchangers [10].

Performance Parameter	Bare tube heat Exchanger	Finned tube heat Exchanger
Number of tubes	616	497
Tube bundle weight, kg	2403.197	1450.84
Market price, $	8995.40	7467.11
Tube bundle diameter, mm	656.824	595.94
Shell diameter, mm	800	730
Tube side pressure drop, kPa	7.5	12.7
Shell side pressure drop, N/m^2	2959.81	2743.58
tube-side fluid velocity, m/s	0.722	0.965
Shell side fluid velocity, m/s	0.626	0.704
Overall heat transfer rate, kW	2073.37	2572.34
The heat transfer rate of one tube watt/tube	3365.86	4175.87

Al-Musawi [11] examines the heat transfer augmentation that resulted from the twist factor within a twisted tube having a square cross-sectional area. A rise in heat transferring coefficient has been noted, along with the decrease in the twisting factor. Twisting leads to an increase in the inner mixing procedure, which in turn improves the inner thermal equilibrium. Other factors that increase correspondingly are the heat transferring coefficient, Reynolds number, and componential velocity.

Pimple et al. [12] introduced a heat transfer improvement in STHEs by means of conical tapes. Through the double concentric tube heat exchanger, hot water flows within the internal tube, whereas cold water runs in the annulus. The highest gain rate in heat transfer was 16.5%, achieved through the use of a helical insert, as compared to the bare tubes. The friction parameter rises whenever the conical ratio decreases again as the result of the twisting flow exerted by the conical tape.

Dahare [13] presents a twist-tube technique, which overcame the limits of the common technologies. They additionally provided higher comprehensive heat transferring coefficient values by means of improving the tube sides. This type offered several beneficial factors as compared to the ordinary STHEs having segmental baffles, including increased heat transferring coefficients, low pressure drops, a reduction in fouling, and no vibrating.

Thawkar and Farkade [14] experimentally attempted towards the determination of the overall heat transferring coefficients and friction factors of twisted elliptical tubes in the multi-pass arrangement, using water as a working fluid. The validation of the experimental model has been performed using a computational model. The twisted elliptical tubes have major and minor diameters of (18 mm) and (12 mm) respectively, and a 60 mm twist pitch, using commercially pure copper. The Reynolds numbers differed in the turbulent zone, being within a range of 50000 to 350000. The performance of the twisted tube in this experiment resulted in a higher Reynolds number range. This could be traced back to the fact that the flow in such a case is highly turbulent, and the developed swirls lead to sufficient heat transfer.

Sadeghzadeh et al. [15] examined the optimization design of finned STHEs, which witnessed a successful enhancement by means of a multi-objective genetic algorithm. The objective functions were the maximization of heat transferring, bringing the overall cost to a minimum. The resulting data has been presented in form of a series of solutions on a Pareto front, showing that the heat transferring rates ranged between 3517 and 7075 kW.

Marode and Keche [16] examined the extent of thermal analysis validity for differently designed tubes within HEs. Through the comparison of the resulting data of water-water (Case-I) and water-Al2O3 (Case-II) in four different tubes (Circular, Elliptical, Twisted, Coil), the conclusion was drawn that the twisted tubes provide relatively higher heat transferring coefficients than others (+1.14%). In addition to their efficiency, the twisted tubes are (1.17%) higher rate. This research claims that the use of a twisted tube is highly recommended.

Rao and Raju [17] studied experimentally and numerically performed simulations for only one shell and several passes HEs of differing tube designs (i.e., circular to elliptical). The results indicated that the total heat transfer rates for the Reynolds value differ from 4000 to 20,000, rising along with the mirror baffle cut of 45° tube orientation. The elliptical form seemed to be 10 % higher as compared to the current STHE, whereas the pressure drops on the tube side declined to 25 %.

Dizaji et al. [18] performed an experimental exergy analysis for STHEs made from corrugated shells and tubes. The resulting data indicated that such cases of corrugation cause an increase in exergy loss and NTU simultaneously. Whenever the tubes and shells are corrugated together, the exergy loss and NTU rise approximately (17-81%) and (34-60%) respectively.

The highest rate of exergy loss has been observed in STHEs with convex corrugated tubes and concave corrugated shells. Naidu and Kishore [19] introduced and tested a method for passively improving heat transfer. The design of tubes within the STHE has circumferential fins placed longitudinally along the tube, a spiral insert within the tubes. The resulting data showed that HEs having twisted tape inserts performed better than the bare tubs with regards to the heat transferring factors. Nonetheless, the increase in twist radio had no significant adverse effect on the increase in heat transferring (88.88%), as compared to the bare tubes. It was noted that the friction factor reinforces the limits for tubes (both with and without twist tape inserts) remarkably, with a 30% rate.

Pathade and Singh [20] examined the construction, performance, and thermal characteristics of TTSTHE. Figure 2 shows several beneficial features as compared to ordinary STHE, as the former have relatively higher initial costs than conventional exchangers, yet their payback time is shorter. Taking into consideration the process development, this seems to be a sufficient aspect to be invested.

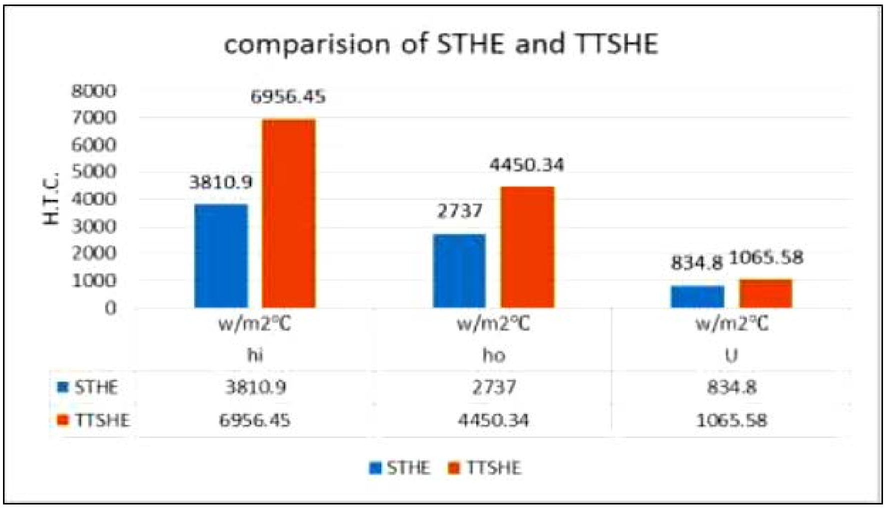


Fig. 2. Thermal performance [20].

Ahmed et al. [21] compared STHEs to plain tube bundle (STHXsPT) and annular-finned tube bundle (STHXsFT) in terms of their performances. The resulting data indicated that STHXsFT had about 14% higher shell-side heat transferring coefficients and enhanced shell-side cross flow features, meanwhile STHXsPT had relatively reduced shell-side pressure drops. Additionally, the heat transferring coefficient per unit pressure drop was found to have a slight increase in STHXsFT over STHXsPT.

Labbadlia et al. [22] investigated the influence of arranging tubes and the way in which they are distributed. They stated that the flow distribution when arranging tubes at 60° is more uniform than the usual form of arranging (90°) by 21%. Besides, the 45° arrangement resulted in a uniformly distributes pressure, as compared to the remaining forms of arranging.

Salmanzadeh and Isvandzibaei [5] investigated the effect of circular and elliptical designed tubes in HEs. Four differing cases have been studied. They stated that the static pressure of fluid within shells seemed to be more suitable in Case 2 (90° square layout pattern) and Case 3 (90° square layout pattern of elliptical tubes), than in alternative designs, which is due to the lower static pressure exertion onto the shells. Case 2 or square layout pattern (90°) turned out to be more efficient than Case 3. The compression of pressure exertion onto the tube shows that lower pressure application occurs onto tubes in Case 3, which prevents damaging them over time. Figure 3 shows that the mean high temperature is clearly favourable in Cases 1 and 2 than in others, and the 90° circular tube design distributed temperature most appropriately.

Shirvan et al. [23] proposed a new tube structuring Design using cosine waves (see Fig. 4) to experimentally examine the influence of wavy surface features on thermal performances in STHE. The thermal performance factor declined whenever the wavy starting length and hot water flow rate rose. The rise in cold water flowing rate increased the thermal performance factor correspondingly. Ayub et al. [24] studied a new STHE having interstitial twisted tapes and an ordinary HE of similar size having singular segmental baffles. The new design of HEs presented a more favourable thermal improvement index throughout all fluid concentrations.

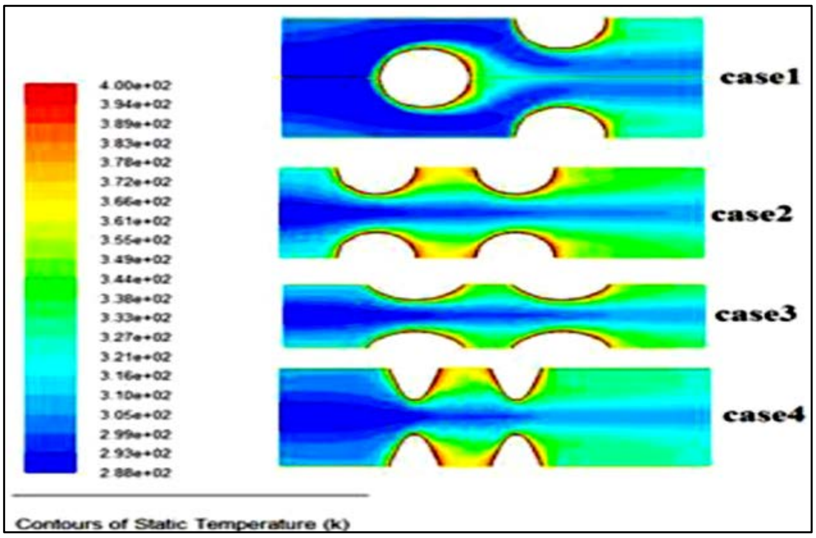


Fig. 3. Fluid temperature distribution inside the shell in Cases 1, 2, 3, and 4. [5].

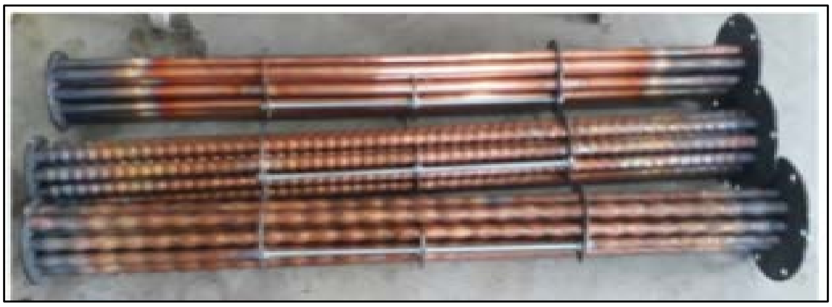


Fig. 4. A schematic presentation of studied corrugated tubes no initial length [23].

Saffarian et al. [25] numerically studied various cross-sectioned and combined tubes, as shown in Fig. 5, 10 including circular and elliptical forms (the latter having an attack angle of 90° once and in another case of 0°). They stated that (STHE-CT&ET 90°) and (STHE-ET90°&CT) combinations increased the heat transferring by 10% and 3%, respectively. In comparison with STHE-CT, these lead to a rise in pressure drop on the shell side by 80% and 67%, respectively, causing 55% and 40% increments on the tube sides.

The twisted tube was found to be having a baffle-free layout (see Fig. 6). It is assumed that such a design leads to a fragilely constructed bundle of tubes, exposing the HE to vibrations through fluid induction. However, the twisted tube layout provides a more definite and stricter bundle of tubes, in comparison with ordinary STHEs. Beneficial aspects of using twisted tubes include increased heat transferring coefficients, low pressure drops, a reduction in fouling, and no vibrating [13].

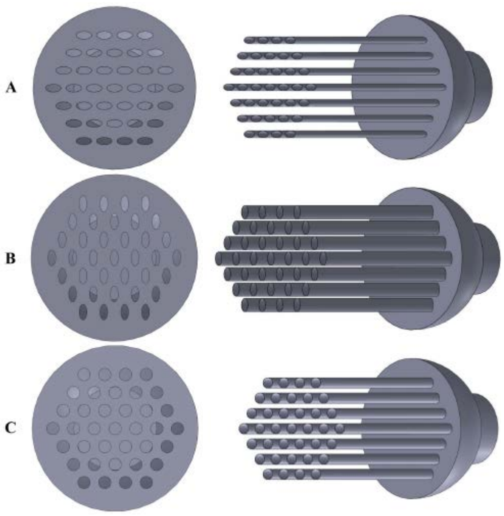


Fig. 5. circular and elliptical tube [25].

Fig. 6. Shell and twisted tube [13].

2.2. Enhancement techniques using different baffle types

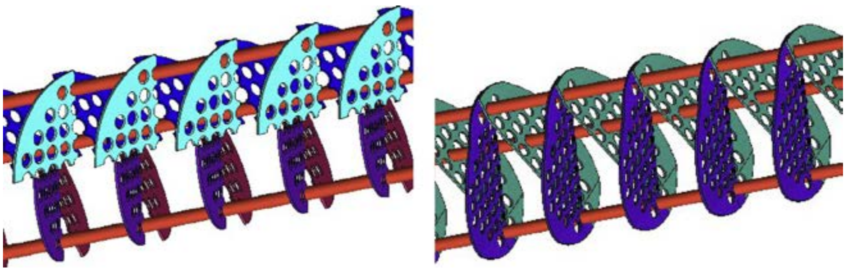
A baffle is an essential element of design that may influence heat exchanging performances. The heat exchanging performances can be improved by changing baffle configurations, spacing, and cuts (which represent the most influential geometric factors upon shell side pressure drops and heat transferring), as well as different baffle angles on STHEs. Radojković et al. [26] examined the effect of baffle cut on heat exchange. Through analysing the result of the experiment, several conclusions can be drawn:

- The presence of segmental baffles within the heat exchanger shells increases the value of heat properties. To exemplify, for a single segmental baffle having a cut of 22%, the HE efficiency increases by 13.6%, as compared to shells with no such baffles.
- The HE heats efficiency drops whenever the baffle cut increases from 22% to 32%. The apparatus heat efficiency increases by 6.9% and 5.6% for baffles with a cut of 26% and 32% respectively, as compared to those without baffles.

Akpabio et al. [27] examined the influence of baffle in STHEs, through the Microsoft Excel 2003 package. The resulting data illustrates that obtaining optimal values of total heat transferring coefficients in STHEs is commonly realized by means of using baffle cuts of 20-25% of its diameter. The maximal spacing is determined by the amount of support the tubes require. It has been concluded that baffle spacing increased the heat transferring coefficients within tubes; meanwhile it decreased their Reynold values. Singh and Sehgal [28] experimented with STHEs containing segmental baffles at various orientations. It has been noted that the increase in inclining angle from 0° to 60° leads to a subsequent increase in heat transferring coefficients, because of the rise in the swirl.

Bhatt and Javhar [1] reported on a STHE performing analysis. They stated that the spacing of baffles drops with the rise in the number of baffles, thereby increasing the shell side Reynold's value. This results in the increase of total heat transferring coefficients. Kirubadurai et al. [29] examined the orifice baffle and convergent-divergent tubes in SHTEs experimentally. The proposed HE provided maximal heat transferring coefficients and low-pressure drops. The numerical results of the experiment indicate that the HE performance increased with the change in baffles and tubes, rather than with the segmental baffles and tube arrangements.

Wen et al. [30] suggested an enhanced design in ladder-type fold baffles, as presented in Fig. 7, for blocking triangular leakage zones in conventional HEs having a helical baffle. The numerically obtained results indicated enhancement of thermal performance factor by 28.4% to 30.7%. This implies that the proposed baffles result in the effective improvement of heat transferring HEs of the helical baffles.



(a) The sector-shaped baffle **(b) The ladder-type fold baffle**

Fig. 7. Schematic diagram of the heat exchanger tube bundle [30].

Leoni et al. [31] examined how the clearance of baffles affects the shell side flow in STHX, using computational fluid dynamics. The resulting data demonstrates that the assessed baffle clearances have relatively small recirculating zones and low-temperature peaks, in comparison with similar HEs without such clearances. Maakoul et al. [32] have numerically compared the performances of shell-sides in STHEs having a trefoil-hole, helical or segmental baffle, as shown in Fig. 8. The resulting data indicates that using a helical baffle leads to better thermo-hydraulic performance, whereas a trefoil-hole baffle has a more advanced heat transferring with a larger pressure drop than segmental ones.

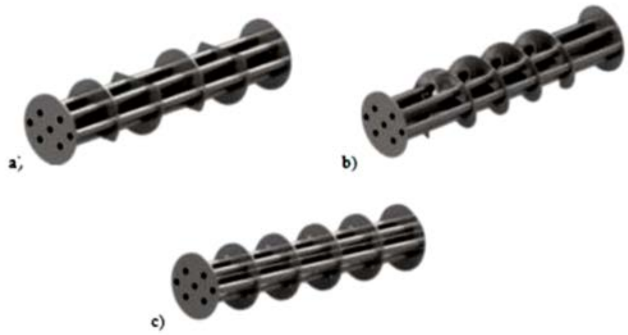


Fig. 8. Model of tubes bundles with different baffles type:
(a) Segmental baffles (b) Helical baffles (c) Trefoil-hole baffles. [32].

Lei et al. [33] made use of a novel structure and performing analysis of the new STHEs having louver baffles, see Fig. 9. They stated that the overall performances of the new STHEs were better than conventional STHEs having segmental baffles. The heat transfer coefficients for each pressure drop of louver-baffle HEs turned out to be higher than that of conventional STHEs. Zebua and Ambarita [34] studied how baffle spacing affects the sufficiency of HEs. The spacing of baffles ranged between 40 mm, 50 mm, and 60 mm. It was stated that the small spacing between baffles (40 mm) resulted in increased thermal efficiency (65.18%). Wang et al. [35] suggested a STHE with staggered baffles (STHX-ST), based on the properties of fabricating STHEs with segmental baffles (STHX-SG), as well as the helical flow of the STHEs with continuous helical baffles (STHX-CH). The resulting data indicates that the overall performances of STHX-STs are better than that of both STHX-SG and STHX-CH.

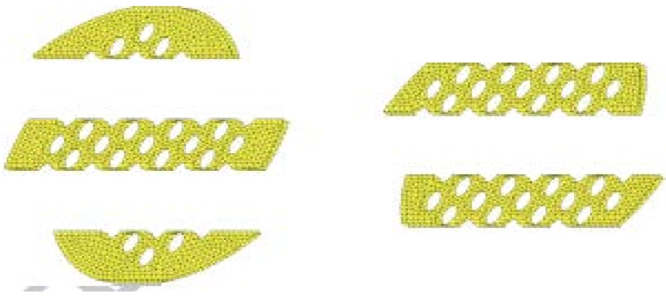


Fig. 9. Local mesh of louver baffles [33].

Yu et al. [36] suggested a novel sort of hexagon clamping anti-vibrating baffles called HCB. The resulting data indicated that the HCB seems to be more favourable in larger and heavier bundles of tubes, as it is provided an improved rigidity. HCB was found to have an improved heat transferring yet weaker comprehensive performance, as compared to curve-rod baffles in STHEs (CRB).

Gu et al. [37] numerically and experimentally investigated the HE with trapezoidal baffles, presented in Fig. 10. In comparison to the shutter baffles in HEs, the resulting data implies that the heat transfer coefficients of twisty flow HE increased by 7.3-10.2%, pressure drops declined by 18.5-21%, and the thermal performance factor TEF was improved by 14.9-19.2%.

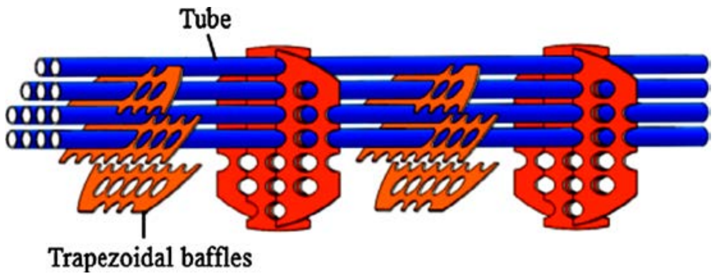


Fig. 10. Trapezoidal baffle of twisty flow heat exchanger [37].

Arani and Moradi [38] introduced the CFD method to investigate the thermos-hydraulic behaviour of STHEs having novel baffle and ribbed tubes design in a 3D geometry. The new tubes increased the heat transferring rate because of the promoted surface for heat exchange with such ribbed tubes. The thermos-hydraulic behaviour of this baffle-and-tube combination is presented by means of comparing the net heat transferring to pressure drop ratio for the suggested designs, as given in Fig. 11. They stated that the DB-TR had the optimal performances, implying that this combination could be a suitable alternative for the conventional SBSTHE, as it optimizes the energy and increases the device lifespan.

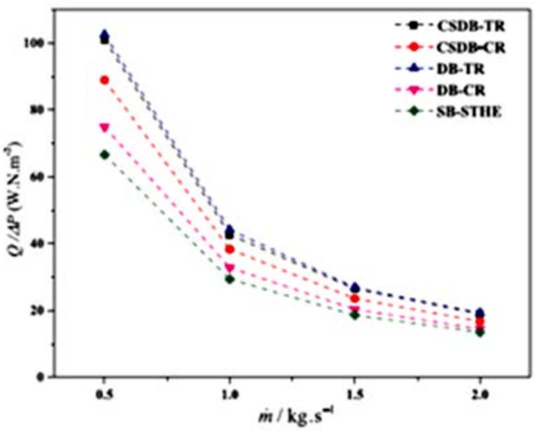


Fig. 11. Variation of performance evaluation factor vs mass flow rate for five studied types of baffles and tubes combination, CSDB-TR, CSDB-CR, DB-TR, DBCR, SB-STHE [38].

Ali [39] experimentally investigated predicting the possible pressure drops of the shell side of STHEs for three sorts of baffle cut equivalents within the flowing areas, given in Fig. 12. The first kind is a segmental baffle with a 25% cut, whereas the other two are concave and convex cuts. The observation was made that baffle cuts lead to higher pressure drops. As for convex ones, on the other hand, the pressure drop was found to decline whenever the baffle spacing was 100mm at all flowing rates that have been tested, meanwhile the other types resulted in its increase.

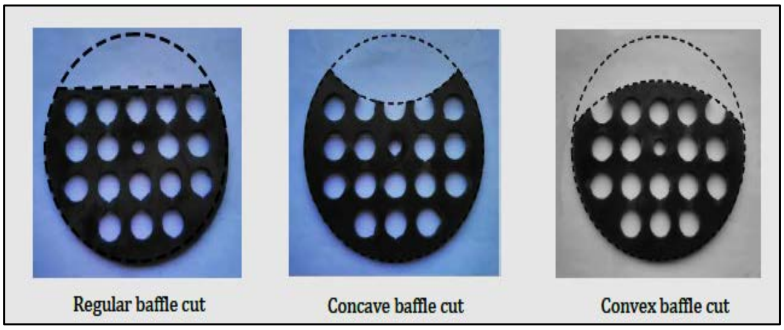


Fig. 12. Shows baffle types used in the heat exchanger [39].

The advantages of STHEs could be summed up in a few points:

- Its configuration provides larger surface areas in smaller volumes.
- Its suitable mechanical design provides an appropriate shape for pressure operations.
- Well-established fabricating methods are used.
- Constructible from different types of material.
- It can be cleaned with ease.
- The designing processes are well-established.

In the concentric tube heat exchanger, inner and outer tubes both are cylindrical. However, in this experimental analysis, the outer cylindrical tube was replaced by a conical tube, and focus was made on the analysis of the HTR in the outer conical tube of a concentric tube heat exchanger.

3. Experimental Setup

The representation diagram of the experimental flow process is shown in Fig. 13. Set-up having two concentric tubes, in which cold fluid (water) flows through the annulus side and hot water flows through the inner tube. The inner tube was cylindrical, made from copper. Copper is used as an inner tube material due to its high thermal conductance, which is even useful for higher the HTR between hot and cold fluid. The inner diameter of the copper tube is 35 mm and the outer diameter is 38 mm. Experiments were conducted for a length of 1 m span. Hot water moves through the inner tube having 0.5 m of settlement zone at the inlet of the pipe to reduce the effect of turbulence. Epoxy-Glass fibre was used as an outer tube having a conical shape. For better thermal resistance at the outer surface and to devise an irregular shape at the outer shell epoxy resin and glass fibre was used. To construct a conical shell, a conical wooden part has been constructed which can be used as a core of the conical shell. After constructing a core, a coating of glass fibre and epoxy resin has been made over a conical core. After the set period, the core was removed to get the conical shell. In the conical shell, cold fluid moves from larger diameter to smaller diameter. The ratio of smaller outlet diameter to larger inlet diameter of conical shell represents a diameter ratio. Three outer conical shells have been constructed considering diameter ratios like 0.882, 0.741, and 0.612.

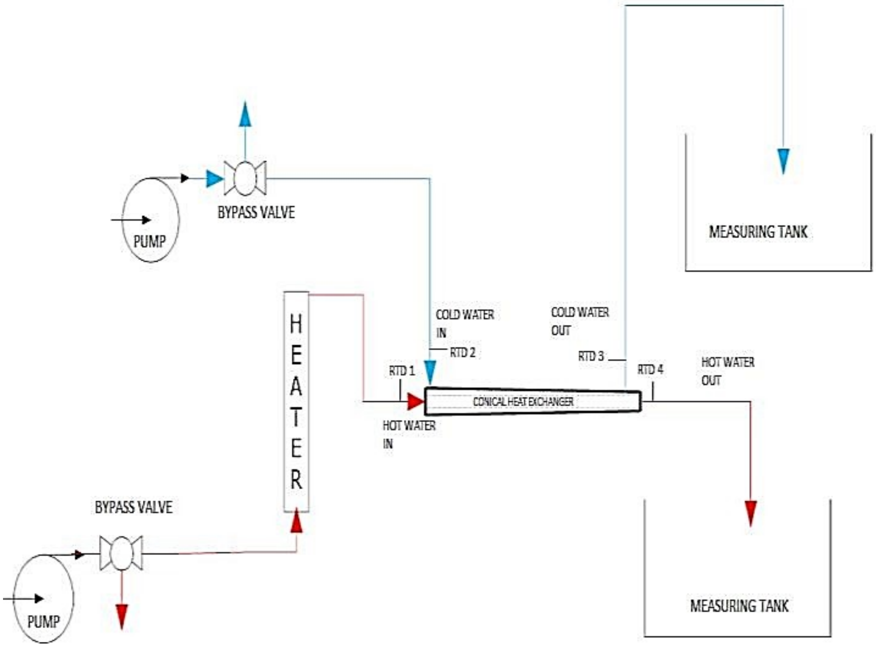


Fig. 13. Schematic line drawing of the experimental setup.

Figure 14 shows the circular tube and conical shell heat exchanger. Resistance temperature detectors (RTDs) were used to measure temperature. These RTDs are made with a PT100 sensor for better accuracy. The temperature indicator has to indicate the capacity of 0.1 °C. RTDs, which are attached with the wire of length 1.5 m. Two RTDs were mounted on the copper tube for measurement of the inside water temperature, one at the inlet of the tube and the second at the outlet of the tube. In addition, two RTDs were fitted in the annulus of the test section to keep track of the temperature of the outer water. The flow rate was measured by placing tanks at the outlet end of the tube in the experiment. Two centrifugal pumps attached with the electric motor of the capacity of 0.5 hp were used for the transfer of hot and cold water separately. A heater of rating 1 kW capacity was used for heating water.

Fig. 14. Conical shell heat exchanger.

The conical shape was introduced on the outer shell to increase the turbulence of water in annulus space. The hot water was made to flow constant at 1 LPM through an inner copper tube and cold water was set to flow varying from 1 LPM to 7 LPM through the annulus. Once the steady-state condition achieved, temperatures at the inlet and outlet of hot water and cold water were measured for all configurations of the cylindrical and conical outer tubes.

4. Data Reduction

Heat transfer from the hot fluid:

$$Q = mCp(\Delta Th) = mCp(Th,in - Th,out) \tag{1}$$

Heat transfer to the cold fluid:

$$Q = mCp(\Delta Tc) = mCp(Tc,out - Tc,in) \tag{2}$$

Logarithmic mean temperature difference:

$$\theta 1 = Th1 - Tc2, \theta 2 = Th2 - Tc1 \tag{3}$$

Overall heat transfer coefficient for same configurations and flow rates.

$$\Delta T_{lm} = LMTD = \frac{\theta_1 - \theta_2}{ln\frac{\theta_1}{\theta_2}} \tag{4}$$

The overall heat transfer coefficient of the system

$$U = \frac{Q}{A.\Delta \mathrm{Tlm}} \tag{5}$$

The percentage error of heat loss from hot water and heat gain by cold water was found out to be 1% to 7.8%, ensuring a minimum possible loss of heat to the atmosphere.

5. Exploratory Results

In the present study, heat transfer characteristics are investigated experimentally. Table 2 represents the logarithmic mean temperature difference (LMTD) of all the experiments performed in this research.

Table 2. Logarithmic mean temperature difference.

Flow rate (LPM)	LMTD (°C)			
	1	0.882	0.741	0.612dr
1.00	28.75	27.80	23.35	21.33
1.50	28.93	28.93	24.17	22.87
2.00	29.49	28.04	27.08	23.16
2.50	28.96	27.40	26.59	22.26
3.00	29.94	27.48	24.70	22.78
3.50	29.17	29.13	26.47	23.08
4.00	28.55	27.20	25.00	23.48
4.50	29.54	28.84	24.47	23.79
5.00	29.26	26.95	25.66	23.56
6.00	28.32	27.30	25.86	24.23
7.00	28.49	28.31	26.13	23.79

Figure 15 shows the HTR at different configuration of diameter ratio with change in flow rate of fluid. Figure 16 shows the overall heat transfer coefficient for same configurations and flow rates.

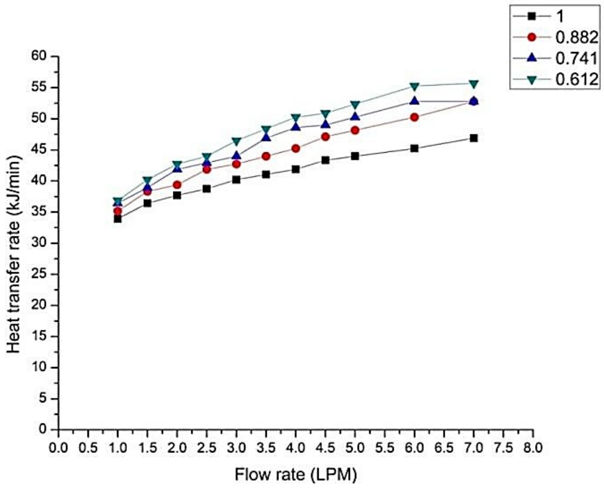


Fig. 15. Rate of heat transfer vs flow rate.

The effects of the flow rate of fluid (water) and diameter ratio of the outer conical tube on heat transfer characteristics were examined. Figure 3 shows the HTR for flow rate ranging from 1 LPM to 7 LPM on outer annulus space. In this experiment, the analysis was done for flow through outer tubes having diameter ratio 1, 0.882, 0.741 and 0.612. The heat transfer rate for cylindrical shell (Diameter ratio 1) heat exchanger varies from 33.91 kJ/min at 1 LPM to 46.89 kJ/min at 7 LPM. Whereas the heat transfer rate in conical shell heat exchanger is: 35.17 kJ/min to 52.75 kJ/min for conical HE with diameter ratio 0.882, 36.42 kJ/min to 52.76 kJ/min for HE with diameter ratio 0.741 and 36.84 kJ/min to 55.68 kJ/min for HE with diameter ratio 0.612. Figure 4 shows the overall heat transfer coefficient. The overall heat transfer coefficient for heat exchanger having diameter ratio 1 varies with flow rate (1 LPM to 7 LPM) from 171.5 W/m^{2}K to 239.34 W/m^{2}K. It is for heat exchanger having diameter ratio 0.882, 0.741 and 0.612 was 183.9 W/m2K to 271 W/m^{2}K, 226.8 W/m^{2}K to 293 W/m^{2}K and 251 W/m^{2}K to 340.3 W/m^{2}K, respectively.

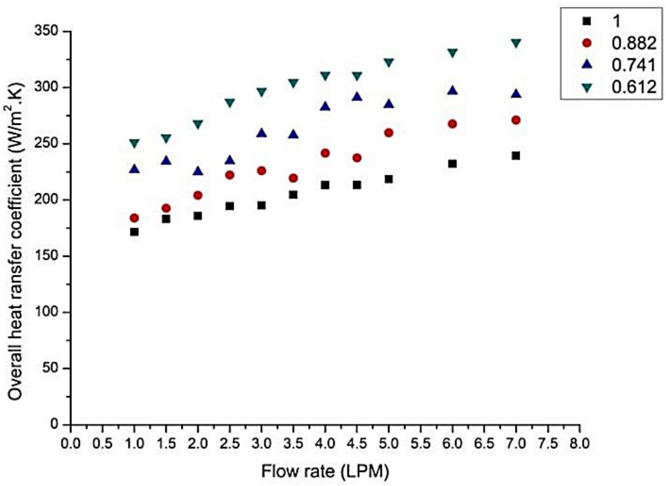


Fig. 16. Overall heat transfer coefficient vs. flow rate.

So, the overall heat transfer coefficient rises up to 12 % in conical shape heat exchanger having diameter ratio of 0.882 compared to cylindrical heat exchanger. Same as overall heat transfer coefficient rises up to 16 % and 22 % in conical shape heat exchanger having diameter ratio 0.741 and 0.612 respectively. From the experimental results, it has been observed that the HTR and the overall heat transfer coefficient improve with the rise in flow rate. It has also been observed that the HTR and the overall heat transfer coefficient increase with the decrease in diameter ratio. Improvement in heat transfer characteristics in conical outer geometry is due to turbulence generated when water passes through the taper section. It happens due to the continuous increase in Re Number along the length. Increases of Re Number along the length ultimately improve the HTR and performance of heat exchanger. In this research, regression analysis was carried out considering R-square value, which shows the closeness with experimental results. The linear regression model was developed using Minitab software for the HTE in the conical shell heat exchanger. R-square value of regression model is 94.02%. Equation of the HTR in the form of flow rate and diameter ratio was developed. The data of the HTR were fitted by following empirical correlation.

$$Q = 48.20 + 2.705(m) - 16.64\,(do/di) \tag{6}$$

Figure 17 represents the comparison between fitted values of the HTR and experimental data. From the figure, it has been concluded that the predicted results are in good agreement with experimental results. The similarity between fitted and experimental values is very well, within a range of ± 7%.

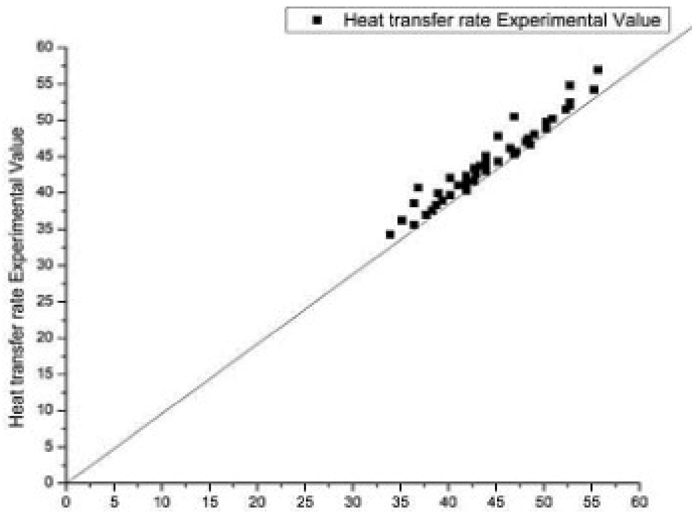


Fig. 17. Predicted vs. experimental results.

6. Conclusions

As compared to ordinary STHEs, HEs having a software-design carry a set of characteristics, including a reduction in shell side fouling; Relatively high shell side heat transferring coefficients; Low vibrating risk; Low shell side pressure drop; Better distributed fluid flow; Economizing on overall lifespan; Eliminated dead zones which existed in common baffles. In the present study, experiments were carried out to analyse the heat transfer rate in the cylindrical and conical outer shell. The flow rate was considered as one of the variable parameters and experiments were conducted for 1 LPM to 7LPM flow rate for both of the outer shell geometry. From the results concluded that for concentric tube heat exchanger with low flow rate operating conditions, an increase in the HTR is achieved with the use of the conical outer shell. Detailed conclusions were drawn:

- It has been concluded from the results that HTR and overall heat transfer coefficient increases with a decrease in diameter ratio.
- The linear correlation was developed relating flow rate and diameter ratio was matching with the experimental data within ± 7 %.
- The experiment can extend for a high flow rate with conical outer shape and further extend with different geometrical shapes.
- The conical shape at outer shell raises the overall heat transfer rate of the heat exchanger in compared to the cylindrical shape.

Nomenclatures

Cp	Specific heat of water, kJ/kg. K
do	Outlet diameter of outer conical tube, mm
di	Inlet diameter of outer conical tube, mm
m	Flow rate of water, L/min
Q	Heat transfer rate of fluid, kW
Th,in	Hot water temperature at entry, °C
Th,out	Hot water temperature at exit, °C
Tc,in	Cold water temperature at entry, °C
Tc,out	Cold water temperature at exit °C
U	Overall heat transfer coefficient, W/m2. K
ΔTlm	Logarithmic mean temperature difference, °C

Abbreviations

CRB	Curve-Rod Baffles
DB-TR	Disk Baffle Shell and Tube Heat Exchanger with Longitudinal Triangular Ribbed Tube
HCB	Hexagon Clamping Anti-Vibration Baffle
HTR	Heat Transfer Rate
NTU	Number of Thermal Units
STHE	Shell and Tube Heat Exchanger
STHXsFT	Shell-and-Tube Heat Exchangers with Annular-Finned Tube Bundle
STHXsPT	Shell-and-Tube Heat Exchangers with Plain Tube Bundle
TEMA	Tubular Exchanger Manufacturers Association HE Heats Exchanger
TTSTHE	Twisted Tube Type Shell and Tube Heat Exchanger

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