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Numerical And Experimental Study Of Helix Heat Exchanger

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Abstract

Shell and tube heat exchangers with helical baffles are used for improved performance by reducing pressure drop, vibration, and fouling while maintaining a higher heat transfer capability. In the present study, a 3D numerical simulation of a Shell and tube heat exchanger with a continuous helical baffle is carried out by using commercial codes of GAMBIT 2.3 and FLUENT 6.3. An experimental analysis and numerical comparison is provided that examines developments and improvements on a conventional Shell and Tube heat exchanger (STHX) and a Shell and tube heat exchanger with a continuous helical baffle (STHXHB).The analysis has been made for both cold and hot fluid. It was found that the increase in total heat transfer rate is 09% to 23% for the STHXHB compared with STHX for different hot fluid velocities. It is also concluded that STHXHB have a higher total heat transfer rate and a lower pressure drop when compared to the STHX for the same mass flow rate and inlet condition. There is good agreement between numerical and experimental results.

Key words: *Heat transfer rate, pressure drop, helical baffle, helix heat exchanger*

1. Introduction

Heat exchangers play an important role in many engineering processes such as oil refining, the chemical industry, environmental protection, electric power generation, refrigeration, and so on. Among different types of heat exchangers, shell-and-tube heat exchangers have been commonly used in industries. It has reported that more than 35–40% of heat exchangers are of the shell-and-tube type, because of their robust construction geometry as well as easy maintenance and possibility of upgrades [9]. In order to meet the special requirements of modern industries, various ways are adopted to enhance the heat transfer performance while maintaining a reasonable pressure drop for the STHXs [1]. One useful method is by using baffles to change the direction of the flow in the shell side to enhance turbulence and mixing.

For many years, various types of baffles have been designed, examples being, conventional segmental baffles with different arrangements, deflecting baffles, overlapping helical baffles, the rod baffles, and others. The most commonly used segmented baffles make the fluid flow in a tortuous, zigzag manner across the tube bundle in the shell side where they improve the heat transfer by enhancing turbulence and local mixing[6]. However, the traditional STHXs with segmental baffles have many disadvantages[7],these being (1) high pressure drop on the shell side due to the sudden contraction and expansion of the flow; and fluid impinging on the shell wall caused by these baffles; (2) low heat transfer efficiency due to the flow stagnation in the so-called “stagnation regions,” which are located at the corners between baffles and shell wall[8]; (3) low shell-side mass velocity across the tube bundle due to the leakage between baffles and shell wall caused by inaccuracy in manufacturing tolerance and installation; and (4) short operation time due to the vibration caused by shell-side flow normal to tube bundle. When the traditional segmental baffles are used in STHXs, higher pumping power is often needed to offset the higher pressure drop for the same heat load. During the past decades, deflecting baffles, rod baffles, and disk-and-doughnut baffles have been developed to solve these shortcomings [9]. However, none of these baffle arrangements can solve all the principal problems mentioned earlier. New designs are still needed to direct the flow in plug flow manner, to provide adequate support to the tubes, and to provide a better thermodynamic performance.

The shell-and-tube heat exchanger with helical baffles (STHXHB) is usually called a helix changer. It was invented in the Czech Republic and is commercially produced by ABB Lummus Heat Transfer [2]. Helical baffles offer a possible alternative to segmental baffles by circumventing the aforementioned problems of conventional segmental baffles. They are accepted for their outstanding advantages, including: (1) improved shell side heat transfer rates and pressure drop ratio; (2) reduced bypass effects; (3) reduced shell-side fouling; (4)

prevention of flow induced vibration; and (5) reduced maintenance. In the past decades, the STHXHB types have been continuously developed and improved and have been widely accepted by engineers. Therefore, the objectives of this study are to develop STHX with continuous helical baffles and to investigate their performance.

In this work, (1) STHX with continuous helical baffles were designed and tested, (2) a simple and feasible method was developed to fabricate the continuous helical baffles used for STHX, (3) the heat transfer rate and pressure drop of the STHX with continuous helical baffles were compared with those of the STHX with segmental baffles numerically and with STHXHB experimentally.

2. Numerical analysis

The CFD software, Fluent, was used for the numerical analysis. The first step for CFD simulation was mesh generation, this being the geometrical domain. The detailed geometrical dimensions of heat exchangers are summarized in Table 1. The 3D models of STHX and STHXB were created by using Solid works (drawing software) shown in fig.1 and fig.2 respectively. The 3D drawings were then imported into the GAMBIT software. As a result, approximately 2.5 lakhs tetrahedral elements were generated for the models. Then, the model created in GAMBIT software was exported to the Fluent software in which boundary conditions and material properties were defined [3].

The second step was the establishment of boundary conditions and material properties. Water is used as the working fluid for both shell side and tube side, inlet boundary conditions were set as velocity inlets, with the corresponding flow rates and the temperatures according to the trial data, and outlets were set as out flow. The materials of the tubes and baffles were assumed to be copper. The physical properties of copper were taken as constant. The exterior wall was modeled as adiabatic. The simulation was solved to predict the heat transfer and fluid flow characteristics by using the $k-\varepsilon$ turbulence model with a pressure based solver. Figures 3 and 4 show Fluent mesh for STHX and STHXB respectively[4]. The following equations were used.

Solver equation: General control volume equation

$$\underbrace{\frac{\partial}{\partial t}\int_{V}\rho\phi\,dV}_{\text{Unsteady}}+\underbrace{\oint_{A}\rho\phi\mathbf{V}\cdot d\mathbf{A}}_{\text{Convection}}=\underbrace{\oint_{A}\Gamma\nabla\phi\cdot d\mathbf{A}}_{\text{Diffusion}}+\underbrace{\int_{V}S_{\phi}\,dV}_{\text{Generation}}$$

Energy transport equation:

$$\frac{\partial(\rho E)}{\partial t}+\nabla\cdot\left[\vec{V}(\rho E+p)\right]=\nabla\cdot\left[\underbrace{k_{\text{eff}}\nabla T}_{\text{Conduction}}-\underbrace{\sum_{j}h_{j}J_{j}}_{\substack{\text{Species}\\\text{Diffusion}}}+\underbrace{\left(\bar{\bar{\tau}}_{\text{eff}}\cdot\vec{V}\right)}_{\substack{\text{Viscous}\\\text{Dissipation}}}\right]+S_{h}$$

Figure 1. 3 D Model of STHX

Figure 2. 3 D Model of STHXHB

Figure 3. Fluent Mesh for STHX

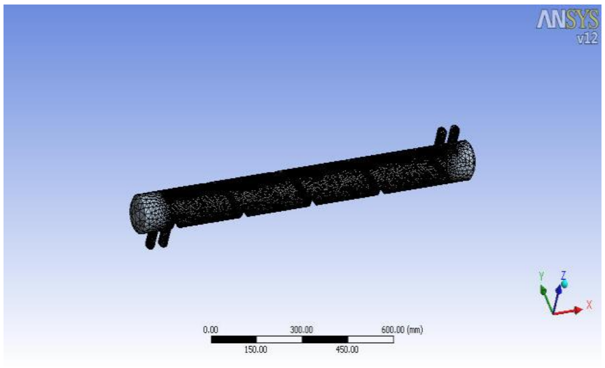


Figure 4. Fluent Mesh for STHXHB

Table 1. Geometric parameters of STHX and STHXHB

Name of the Parts	Material	Size of STHX	Size of STHXHB
Shell	M.S pipe	ID: 101mm OD: 113mm Length: 1m Qty: 1no.	ID: 101mm OD: 113mm Length: 1m Qty: 1no.
Tube	Copper tube	ID: 12mm OD: 13.8mm Length:1020mm Qty:10 nos.	ID: 12mm OD: 13.8mm Length:1020mm Qty:10 nos.
Center Tube	Copper tube	ID: 24mm OD: 25.8mm Length:1020mm Qty:1 no.	ID: 24mm OD: 25.8mm Length:1020mm Qty:1 nos.
Baffle	Copper plate	1mm thick circular plate of 101 mm dia. with 25% baffle cut	1 mm thick helical plate
Stationery Tube Sheet	M.S	5mm thick 100mm diameter plate Qty: 2 nos.	5mm thick 100mm diameter plate Qty: 2 nos.
Shell Cover (Front & Rear)	M.S	Qty: 2 nos.	Qty: 2 nos.

3. Experimental Studies

3.1 Fabrication of STHX with Continuous Helical Baffles

Figure 5 shows the STHXB tube bundle used to provide helical flow on the shell side of the heat exchanger. The continuous helicoids were manufactured by linking several sets of helical cycles. One helical cycle was heightened to one screw pitch along the height (axial) direction and was rotated through a 2 Π angle along the circumferential direction, several helical cycles being linked end to end to form a continuous helicoids, as shown in Fig.5. This method overcame the difficulty in manufacturing whole continuous helicoids at one time and lowered the manufacturing cost significantly [5].

Figure 5. Photographic view of Fabricated STHXHB Tube Bundle

3.2 Die for Drilling

One major difficulty related to the manufacturing of continuous helical baffles is the drilling of holes on the baffles. If baffles are drilled with the same size holes as the tubes and then later the pitch is varied by stretching the spiral in or out, the tube does not see a round hole but rather an elliptical hole. It is then impossible to pass a round tube through this elliptical hole. Therefore a die, as shown in Fig. 6, is used to hold the helical cycle at the required pitch, and then drill holes on the baffles. The configuration of the shell of the heat exchanger also plays a major role on the flow pattern of the shell-side flow in the heat exchanger.

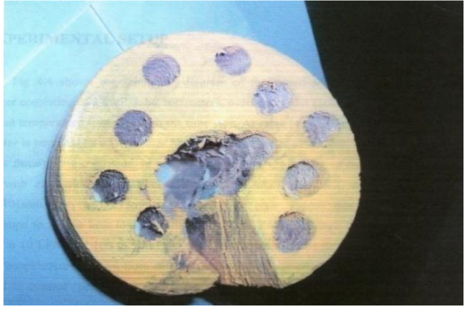
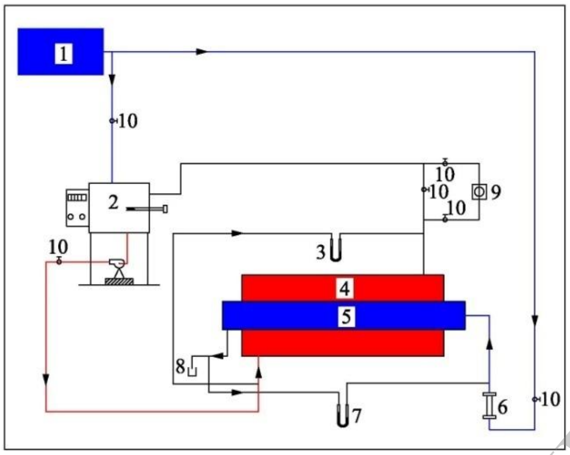


Fig. 6photographic view of Die

An experiment apparatus was designed and built to study the heat transfer and pressure drop of a STHXB. The experiment setup consists of two loops: a hot water loop and a cold water loop, as shown in Fig.7. Tests can therefore be performed for water to water heat exchange.

In the hot water loop in the shell side of STHXB, it contain a water heater (specially designed for maintain constant temperature hot water supply to heat exchanger at different flow rate of water) a Rotameter and a manometer. Similarly in the cold water loop in the tube side of STHXB, it consisting of Rotameter. Four RTDs were installed at the inlet and outlet of shell side and tube side of the heat exchanger to measure the corresponding temperatures through a multipoint digital temperature indicator. Fig.8 shows a photograph of the setup



1. Overhead water tank
2. Water heater storage tank
3. Shell side manometer
4. Shell
5. Tube
6. Rotameter(cold water)
7. Tube side manometer
8. Drain(cold outlet water)
9. Rotameter(hot water)
10. Ball valve

Figure 7. Experimental Setup Layout

Figure 8. Photographic view of Experimental setup

4. Results and Discussion

In the present study, the 3D numerical simulation of a STHX and STHXB is carried out by using commercial codes of GAMBIT 2.3 and FLEUNT 6.3. The computational model and numerical method of shell and tube heat exchanger with conventional baffles (STHX) and shell and tube heat exchanger with continuous helical baffles (STHXHB) is presented in detail. A parallel computation mode is adopted for the simulation of STHX and STHXHB on a grid system. The validation of the computational model is performed by comparing the performance parameters with experimental heat exchanger data. An increase in total heat transfer rate of 09% to 23% for the in STHXHB compared with the STHX was obtained for different hot fluid velocities shown in Fig.9 The pressure drop also considerably reduced in the STHXHB compared with the STHX.

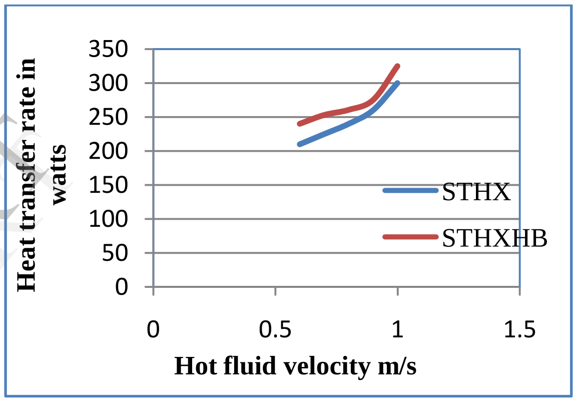


Figure 9. Hot fluid velocity Vs Heat transfer rate (Cold fluid velocity kept constant as 0.5m/s)

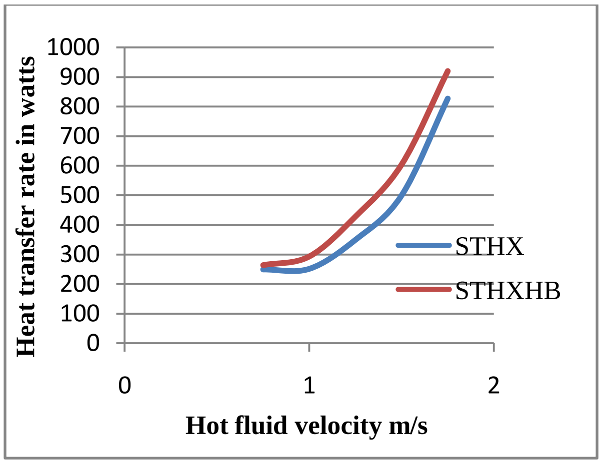


Figure 10. Hot fluid Velocity Vs Heat transfer rate (cold fluid velocity kept constant as 1.0 m/s)

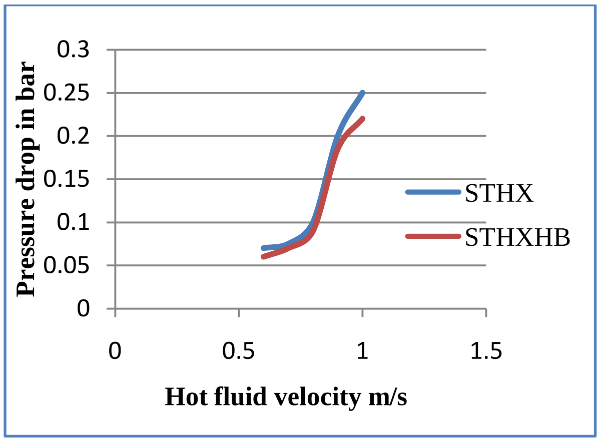


Figure 11. Hot fluid velocity Vs Pressure drop in shell side (Cold fluid velocity kept constant as 0.5 m/s)

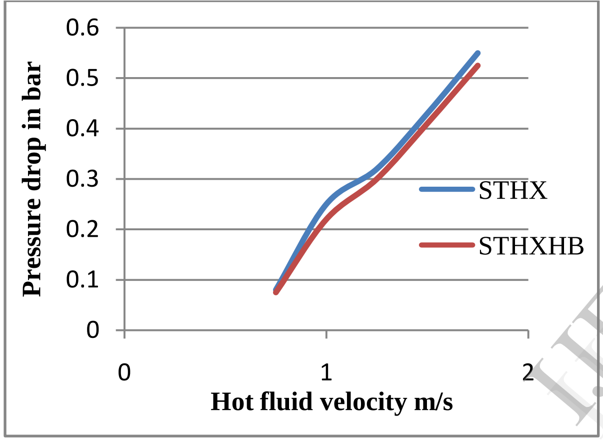


Figure 12. Hot fluid velocity Vs Pressure drop in Shell side (Cold fluid velocity kept constant as 1.0 m/s)

The experiments were conducted for the STHXB described in section3 in which cold water flowed in the tube side and hot water flowed in the shell side of the heat exchanger. Heat was transferred from the hot water to the cold water. In the experimental analysis, the heat transfer and pressure drop characteristics obtained for various hot fluid and cold fluid velocities were compared with the results obtained from numerical analysis of the STHXHB.

From the results, a decrease in the shell side heat transfer rate and increase in the shell side pressure drop for experimental STHXHB was found (figure 12). This heat is loss due to leakages in the shell side (i.e., there is gap between shell and helical baffle) and radiation losses.

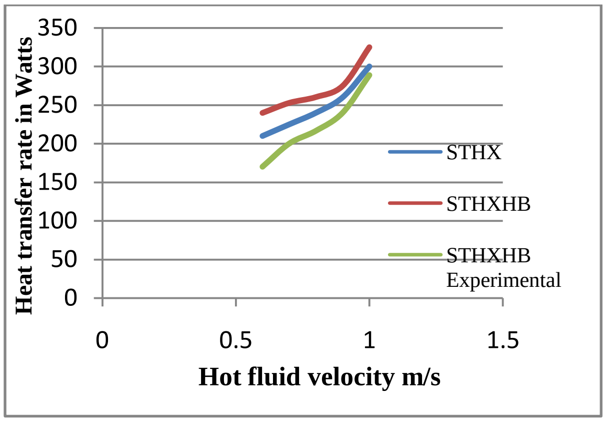


Figure 13. Hot fluid velocity Vs Heat transfer rate (Cold fluid velocity maintained constant as 0.5m/s)

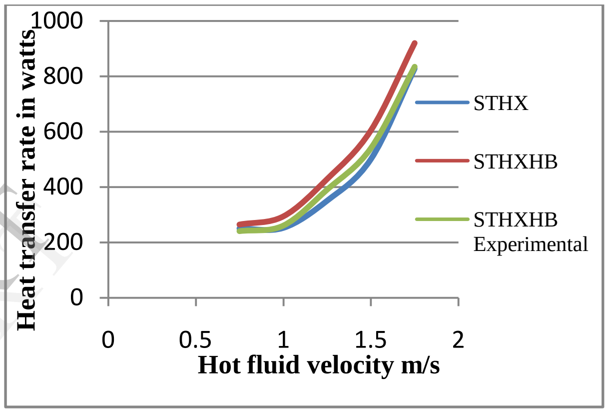


Figure 14. Hot fluid velocity Vs Heat transfer rate (Cold fluid velocity maintained constant as 1.0 m/s)

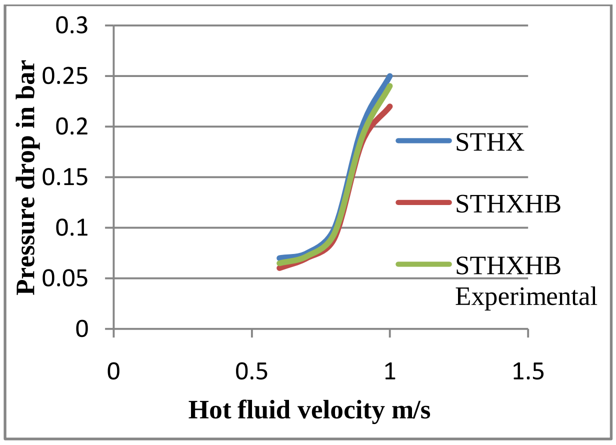


Figure 15. Hot fluid velocity Vs Pressure drop in shell side (Cold fluid velocity maintained constant as 0.5 m/s)

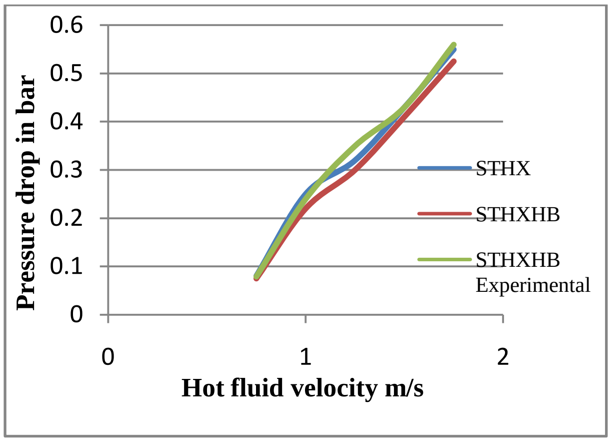


Figure 16. Hot fluid velocity Vs Pressure drop in shell side (Cold fluid velocity maintained constant as 1.0 m/s)

5. Conclusions

The performance of the STHXHB has been experimentally and numerically investigated in terms of its heat transfer coefficient and pressure drop. The conclusions can be summarized as follows.

- A comprehensive simulation model for a whole STHX and STHXHB has been developed by using the commercial code FLUENT and the grid generation program GAMBIT. Initially, a general computational analysis of STHX and STHXHB has been made and it has been concluded that STHXHB have higher total heat transfer rates and lower pressure drops when compared to STHX for the same flow rate and inlet condition.

- The STHXHB was fabricated, as per the design of its comprehensive simulation model and experiment were conducted for same inlet temperature and flow rate conditions.

- Based on this study and the results presented, it is confirmed that the performance of STHX can be improved by helical baffles instead of conventional segmental baffles.

- Use of helical baffles in a heat exchanger reduces the shell side pressure drop, size weight fouling etc., as compared to segmental baffles.

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