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COMPARISION OF NUMERICAL HEAT TRANSFER IN CONVENTIONAL AND HELICALLY BAFFLED HEAT EXCHANGER

C.Sivarajan[1], B.Rajasekaran[2], Dr.N.Krishnamohan[3],
[1](Associate professor, Department of Mechanical Engineering, Annamalai University, AnnamalaiNagar-608002 India)
[2](Technical Assistant, Department of Mechanical Engineering, Annamalai University, Annamalai Nagar-608002 India)
[3](Professor and Head, Department of Mechanical Engineering Annamalai University AnnamalaiNagar608002 India)

ABSTRACT

This project work describes computational modeling to study a helically baffled heat exchanger, commercially referred to as a helixchanger.

As the helixchanger offers process designers a high performance, it has been considered for study in this project.

Helical baffles are employed increasingly in Shell-and-tube heat exchangers (Helixchanger) for their significant advantages in reducing pressure drop, vibration and fouling while maintaining a higher heat transfer performance. In order to make good use of helical baffles, serial improvements have been made by many researchers.

Helixchanger is cost effective, having lesser shell side fouling. It has higher shell-side heat transfer and lower shell-side pressure drop. Because of homogeneous flow distribution it improves plant reliability and run length, having reduced vibration hazards.

Helixchanger has a complicated model involving tactful maintenance with high initial investment. As the technology is not well known, research works are being carried out worldwide.

In the present study, a 3D numerical simulation of a Shell and tube heat exchanger with continuous helical baffle is carried out by using commercial codes of **GAMBIT 2.3** and **FLUENT 6.3**. A general analysis and comparison is provided of developments and improvements on Conventional Shell and Tube heat exchanger (STHX) and Shell and tube heat exchanger with continuous helical baffle (STHXHB). Extensive analysis results from numerical simulations indicate that these STHXHB have better flow and heat transfer performance than the STHX.

Based on these new improvements, the STHXHB might be replaced by STHX in industrial applications to save energy, reduce cost, and prolong the service life and operation time.

Key words: *Heat transfer rate, helical baffle, helix heat exchanger, pressure drop, shell and tube heat exchanger.*

1. INTRODUCTION

Heat exchangers play an important role in many engineering processes such as oil refining, chemical industry, environmental protection, electric power generation, refrigeration, and so on. Among different types of heat exchangers, the shell-and-tube heat exchangers have been commonly used in industries. It was reported that more than 35–40% of the heat exchangers are of the shell-and-tube type, because of their robust construction geometry as well as easy maintenance and possible upgrades. 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. One useful method is using baffles to change the direction of flow in the shell side to enhance turbulence and mixing.

For many years, various types of baffles have been designed, for example, the conventional segmental baffles with different arrangements, the deflecting baffles, the overlap helical baffles, the rod baffles, and others. The most commonly used segmental baffles make the fluid flow in a tortuous, zigzag manner across the tube bundle in the shell side. This improves the heat transfer by enhancing turbulence and local mixing on the shell side of heat exchangers. However, the traditional STHXs with segmental baffles have many disadvantages: (1) high pressure drop on the shell side due to the sudden contraction and expansion of flow, and fluid impinging on the shell wall caused by segmental 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; (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 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 of the traditional segmental baffles. 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 have a better thermodynamic performance.

The shell-and-tube heat exchanger with helical baffles (STHXHB) is usually called a helixchanger. It was invented in Czech Republic and commercially produced by ABB Lummus Heat Transfer. 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 have been continuously developed and improved and have been widely accepted by engineers [5].

The aim of this study is to present a critical review of the developments and improvements conducted on STHXHB, which is of importance for further improvements research in the future.

2. Computational model for STHX and STHXHB

The computational model of the STHX and STHXHB is as shown in the following figures and the detailed geometry parameters are listed in Table.1, The 3D models of STHX and STHXB are created by using Solid works (drawing software) shown in fig.1and fig.2 respectively. The STHXHB has continuous helical baffles in the shell-side direction with total tube number of 10 and one centre tube. The whole computational domain is bounded by the inner side of the shell and everything in the shell is contained in the domain. The inlet and outlet of the domain are connected with the corresponding tubes.

Fig.1 Shell and tube Heat Exchanger with Conventional Baffles (STHX)

Fig.2 Shell and tube Heat Exchanger with continuous Helical Baffle (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. Numerical analysis

A CFD software, Fluent, was used for the numerical analysis. The first step of CFD simulation was mesh generation, which was the geometrical domain. The suited model, which was shown in Fig.3 & Fig.4, consisted of conventional and continuous helical baffles. The model was created and meshed by using GAMBIT software. As a result, approximately 2.5 lakhs tetrahedral elements were generated for the model. Then, the created model in GAMBIT software was exported to the fluent software in which boundary conditions and material properties were defined.

The second step was establishment of boundary conditions and material properties. Water is used as working fluid for both shell and tube, 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 tubes and baffles were assumed to be copper. The physical properties of copper are taken as constant. The exterior wall was modeled as adiabatic. The simulation is solved to predict the heat transfer and fluid flow characteristics by using $k-\varepsilon$ turbulence model [3] and [7]. The pressure based solver is used to solve. The following equations are used [9]

Solver equation:

General contol 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:

$$\frac{\partial(\rho E)}{\partial t} + \nabla\cdot\left[\vec{V}(\rho E + p)\right] = \nabla\cdot\left[\underbrace{k_{\text{eff}}\nabla T}_{\text{Conduction}} - \underbrace{\sum_j h_j J_j}_{\text{Species Diffusion}} + \underbrace{\left(\bar{\bar{\tau}}_{\text{eff}}\cdot\vec{V}\right)}_{\text{Viscous Dissipation}}\right] + S_h$$

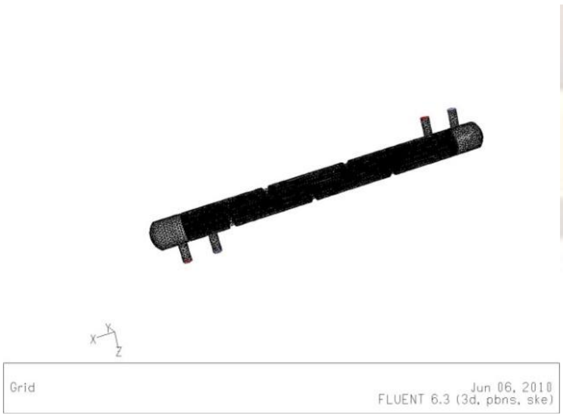

Fig.3 FLUENT Mesh for STHX

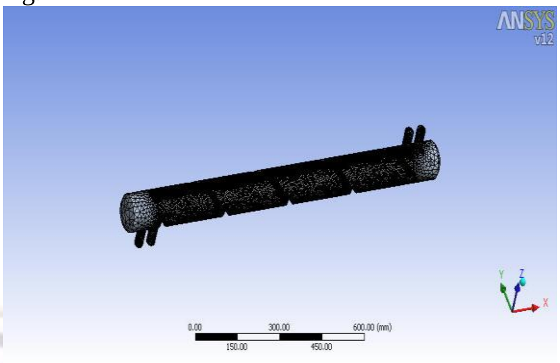

Fig.4 FLUENT Mesh for STHXHB

4. Principle of Heat transfer enhancement in STHXHB:

One useful method to enhance heat transfer performance of heat exchanger is using baffles to change the flow direction to enhance turbulence and mixing, as do the helixchanger. In the shell side of the helical baffled STHXs, the helical baffles are located at a certain angle to the tube bundle, creating a helix flow path for the working fluid. The helix flow provides some characteristics to enhance heat transfer and low pressure drop [1] and [10].

The fluid flow in the shell side of STHXHB (due to continuous helical baffles) is a complete helix in nature. This flow pattern can avoid abrupt turns of flow direction and maintain a constant rush on the heat exchange tubes. It can have superior advantages in preventing leakage, mitigating fouling, and increasing heat transfer coefficient [1] and [10].

5. RESULTS AND DISCUSSIONS

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, and 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 of heat exchangers. For this analysis both cold and hot fluid is taken as water. Increase in total heat transfer rate is 7% to 17% in STHXHB with STHX is obtained for different hot fluid velocity shown in Fig.5 and 6 and pressure drop also considerably reduced in STHXHB compared with STHX.

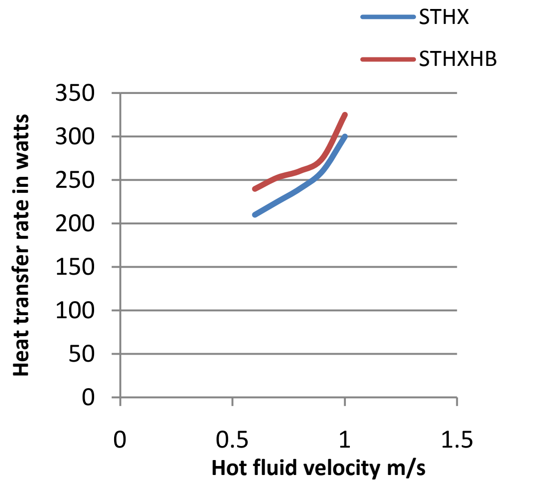

Fig. 5 Hot fluid velocity Vs Heat transfer rate (Cold fuid velocity kept constant as 0.5m/s)

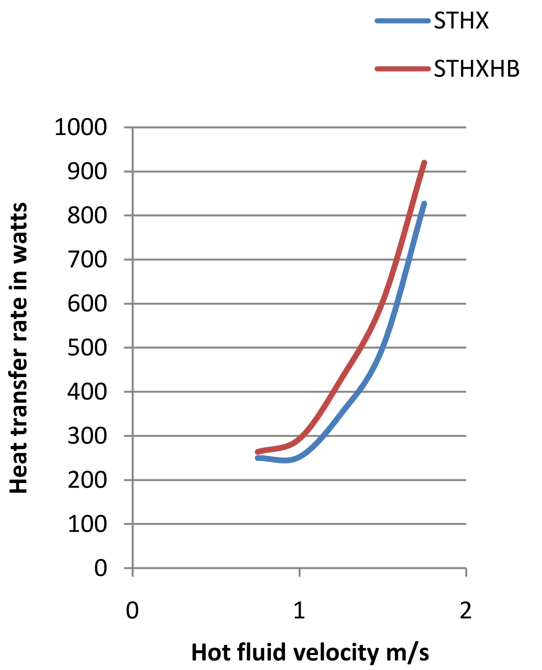

Fig. 6 Hot fluid Velocity Vs Heat transfer rat (cold fluid velocity kept constant as 1.0 m/s)

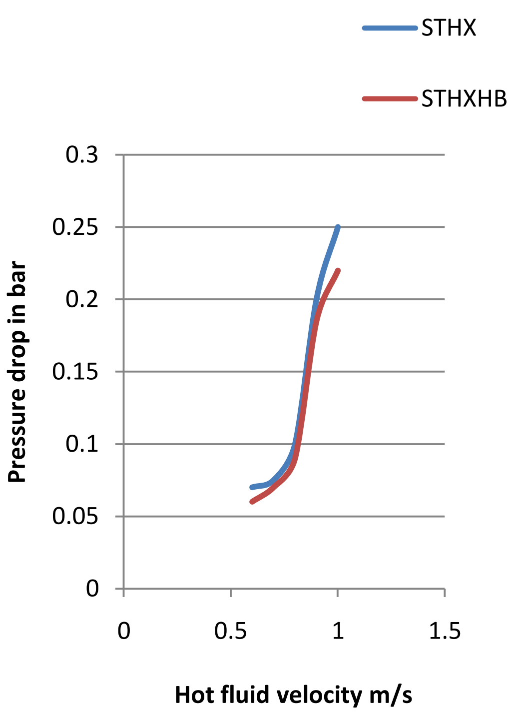

Fig. 7 Hot fluid velocity Vs Pressuredrop in shell side (Cold fluid velocity kept constant as 0.5 m/s)

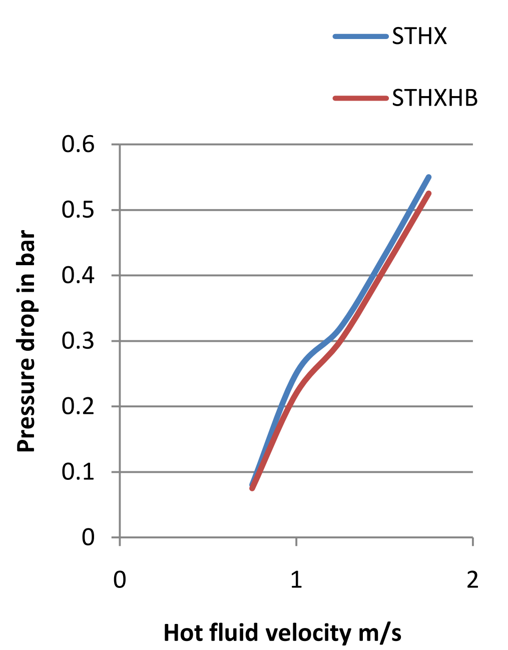

Fig.8 Hot fluid velocity Vs Pressure drop in Shell side (Cold fluid velocity kept constant as 1.0 m/s)

6. CONCLUSION

In this study, a comprehensive simulation model for a whole STHX and STHXHB is developed by using commercial code FLUENT and the grid generation program GAMBIT.

A general computational analysis of STHX and STHXHB has been made and it has been concluded that STHXHB have higher total heat transfer rate and lower pressure drop when compared to STHX for the same mass flow rate and inlet condition.

Based on this study and the presented results, the STHXHB is proper replacement for STHX. They could overcome or eliminate many of the drawbacks of conventional shell-and-tube heat exchanger.

6.1 Recommendations for Future Work

Shell-and-tube heat exchangers play an important role in traditional energy process as well as the new energy techniques and applications. Much more work is required for Helixchanger.

In order to popularize these new helixchanger and improvements, experimental tests and industry application feedback are needed to confirm the heat transfer and flow advantages compared with the traditional shell-and-tube heat exchangers. In addition, accurate heat transfer and pressure drop correlations based on experimental test results and industry application feedbacks are required for the heat exchanger design process. The design software also needs to be developed for the helixchanger to make the design process more accurate and convenient for engineers.

In order to optimize the analysis, various geometries of helical baffle (helix angle, pitch length, discontinuous helical baffle, and segmental helical baffle) to be analyzed.

In the present work, working fluids used is water to water, in future, the working fluid can be changed as water to high viscous fluid (Shell side). Also a model may be fabricated and the experimental results can be compared with present analytical results.

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