A CFD INVESTIGATION AND HEAT TRANSFER AUGMENTATION OF DOUBLE PIPE HEAT EXCHANGER BY EMPLOYING HELICAL BAFFLES ON SHELL AND TUBE SIDE

by

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The inclusion of baffles in a double pipe heat exchanger is becoming increasingly important as it improves the heat exchanger's performance. The CFD analysis is used in this paper to investigate the performance of double pipe heat exchangers with and without helical baffles on both shell tube sides. The 3-D CFD model was created in Solid Works, and the FloEFD software was used to analyze the conjugate heat transfer between the heat exchanger's tube and shell sides. Heat transfer characteristic like outlet temperature of shell and tube are investigated along with pressure drop on shell and tube side. Based on CFD results of double pipe heat exchanger with helical baffle on both shell side and tube side (Type 4) gives the better results than the other type of heat exchangers with an increased pressure drop than the others, results reveals that Type 4 outlet temperature of shell side is 8% higher and on tube side it is 5.5% higher, also pressure drop on shell side is 12% higher and on tube side it is 42% higher than the other types.

Keywords*: double pipe heat exchanger, CFD, conjugate heat transfer, helical baffles*

Introduction

Double-pipe heat exchangers are more simple and relevant heat exchangers and are frequently used in comparatively lesser flow rates and higher temperatures or pressures. In

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this type of heat exchangers, the working fluids flows moreover in concentric pipes or tubes, but in different configurations, which are parallel and counter flow configurations. Even though this type of heat exchanger has smaller diameter, previous studies show that these types of heat exchangers also find applications in high pressure applications. Also has the integral part in high temperature application where they play significant role in pasteurizing, preheating and reheating applications. Various number of procedures were followed for deriving efficient heat transfer from the double pipe heat exchangers irrespective of its size and dimensions at suitable pumping power. These procedures are classified under two sections as active and passive techniques. In active method, the heat transfer is enhanced by providing energy to the fluid. In passive method, the energy of the fluid is consumed to enhance the output. These two techniques can be collectively synchronized to get efficient performance of the double pipe heat exchanger more than the performance obtained from any of the one type of this technique. This technique is termed as compound enhancement. But these techniques may result in higher pumping power due to rise in pressure drop. Hence the right method has to be chosen to obtain better efficiency. Zhang *et al*. [1] correlated the heat transfer coefficient along the shell side and pressure drop of the heat exchanger with various helix angles. Gorman *et al*. [2] gives a mathematical analysis of the thermal and fluid pattern study of a double-pipe heat exchanger with the pipes having inner walls that are helically corrugated which on comparison with smooth walled double pipe heat exchanger shows better heat transfer rate and comparative pressure drop. Senthilkumar *et al*. [3] stated that there is considerable amount of enhancement in heat transfer can be achieved by piercing oscillatory stripers along its walls, with the help of mathematical study. Chamoli and Thakur [4] mathematically examined the impacts of crosswise pricked baffles enclosed to the hot wall of a rectangular channel on heat dissipation and friction factor. They noted that insertion of pricked baffles increases the heat transfer, while friction loss increases above a flat surface. Hashemian *et al*. [5]. proved to increase the heat transference and effectiveness of the double pipe heat exchanger under optimum conditions by 40% and 55% by using triangular profile of the tube instead of cylindrical one, which is done with the aid of experimental study. A numerical study on the effects of Reynolds number and volume absorption on heat transmission and fall in pressure is done on the helical baffle heat exchanger in combination with three dimensional fined tube working on nanofluids by Gobinath [6] and Targui and Kahalerras [7] had projected the effects of porous baffles on the performance of double pipe heat exchangers along with that they stated that inclusion of turbulators inside the walls of heat exchanger increases the performance of the heat exchanger. Vivekanandan *et al*. [8] and Senthilkumar *et al*. [9] had done an experiment involving a double pipe heat exchanger having a smooth and longitudinal fins over an inlet passage in both laminar and turbulent flow conditions. Depicted the fact in case of low Reynolds conditions, the fins with cut and twist profile gives more advantages than ordinary prolific tubes. Naphon [10] had come up with the finding that, on carrying the hot fluid within the inner tube, along the particular span of Reynolds number the heat transfer rate is higher at the areas of the twisted profile having lower twist ratio and vice versa. A wide range of study is carried out in. The inferences of inner passage with twisted profile were studied by Tang *et al*. [11] and Venkatesh and Christraj [12] by both practical and mathematical way. In the experimental method, the inlet passage had three various cross section profiles which were circular, oval and tri-lobed; surrounded by simple cylindrical outer passage. Among this the tri-lobed profile is concentrated more on performance criterion. This work is done on various cross-sectional profiles in mathematical way. In another study Naphon *et al*. [13] experimentally investigated the pressure drop and the heat exchanger of the double pipe heat exchanger having helical twisted strips, which is made of aluminum and having 1 mm thickness. The result of this experiment shows that the twisted strips insertion in the heat exchanger gives better heat transfer and pressure drop characteristics. By grasping various experiment Yadav [14] and Venkatesh and Vijayan [15] conducted an experiment using half-length twisted strips in double pipe U-bend heat exchanger and got an outcome, that these insertions of this strips in heat exchanger gives increase in efficiency of 40%, comparing to the heat exchangers using smooth tubes. Baffles in a double pipe heat exchanger are becoming increasingly important because they improve the heat exchanger's performance. The performance of double pipe heat exchangers with and without helical baffles on both shell tube sides is investigated using CFD analysis in this paper. Solid Works is used to create the 3-D CFD model, and the FloEFD software is used to analyze the conjugate heat transfer between the heat exchanger's tube and shell sides.

The CFD analysis

The CFD is the visual simulation of the fluid, either a liquid or a gas within the required domain or the object and to study the effects of the fluid, within the domain and also their effects on the past objects within the domain with the aid of math, physics and flow simulation software. The CFD is based on the Navier-Stokes equations which gives the velocity, pressure, temperature, and density of a moving fluid that are associated within the domain. In this paper, the flow simulation is done with the aid of FloEFD which will give the solution of the required Navier-Stokes equations. Figure 1 shows the different types of heat exchanger setup utilized for analysis.

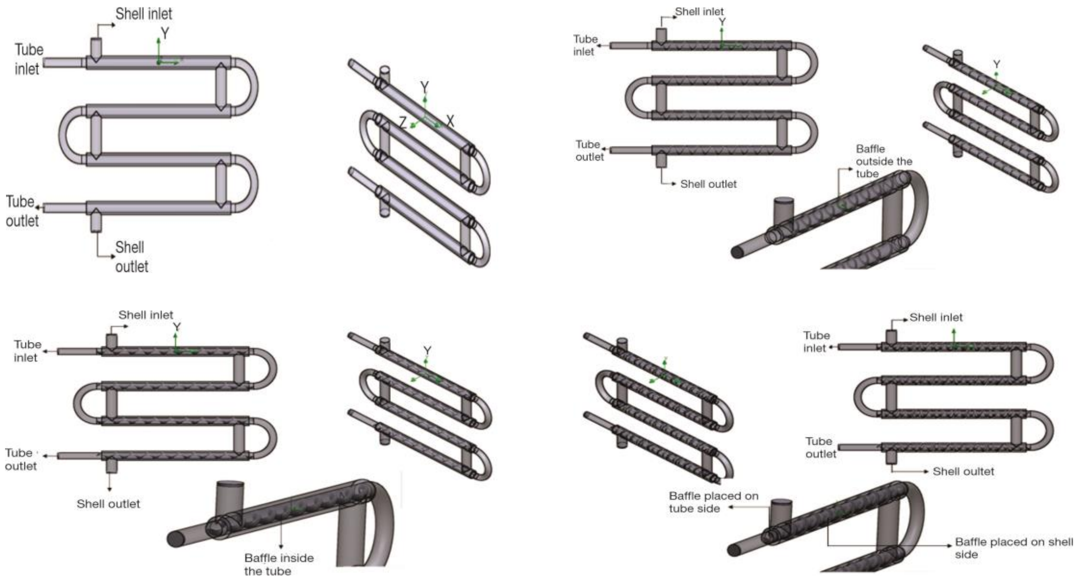

Figure 1. Four types of heat exchangers used for the analysis; (a) Type 1: heat exchanger – without baffles, (b) Type 2: heat exchanger – baffle on shell side, (c) Type 3: heat exchanger – baffle on tube side, and (d) Type 4: heat exchanger – baffle on both shell side and tube side

Mesh independency is done for Type 1 heat exchanger with the following cells, as seen from the table there is not much deviations are noted between the values, hence a 5,51,810 cells (Sl.No. 3) cells mesh size is chosen for the analysis of heat exchanger. Tables 1 and 2 shows the cell count and mesh independency for all four heat exchangers.

Table 1. Cell count details for all the heat exchanger types

Type of heat exchanger	Cell count
Type 1	551810
Type 2	561018
Type 3	565950
Type 4	581252

Table 2. Mesh independency

Sl. No	Total number of cells	Shell outlet temperature [°C]	Tube outlet temperature [°C]	Shell pressure drop [Pa]	Tube pressure drop [Pa]
1	100040	34.01	55.02	3573.32	5399.49
2	192292	33.04	55.37	3639.63	5292.14
3	551810	35.08	55.23	3698.28	4201.85
4	1352021	34.34	55.42	3896.07	4941.89

Initial conditions of the working fluid (water) is taken as 30 °C for shell side inlet and tube side inlet temperature is taken as 60 °C, mass-flow rate is taken as 0.8 kg/s for shell side and tube side, conjugate heat transfer analysis is solved by using FloEFD software in a Xeon 32 logical core processor and 64 GB ram computer.

Result and discussion

The CFD simulation is done for four type of double pipe heat exchanger and following are the observations and results (see figs. 2-7 and tab. 3). From the analysis, for shell side of Type 1 heat exchanger the temperature at shell side inlet of 30 °C at the flow rate of 0.8 kg/s, at the first bend the temperature increases to 31.5 °C and at the second and third bend temperature is around 32.8 °C and 33.8 °C. The temperature of shell side outlet is 34.08 °C. Similarly, for tube side the temperature at tube side Inlet of 60 °C at the flow rate of 0.8 kg/s, at the first bend the temperature reduces to 59 and at the second and third bend the temperature is around 57 °C and 56.5 °C. Finally, the temperature of tube side outlet is 55.32 °C.

Tube side inlet pressure is about 102132 Pa, tube side outlet pressure is 107531 Pa. Pressure drop at tube side is 5399 Pa. Shell side inlet pressure 104235.49 Pa, shell side outlet pressure is 107808.81 Pa. Pressure drop at shell side is 3573 Pa. For a conjugate heat transfer preferred velocity is between 0.8 m/s to 1 m/s, whereas which will be around 0.8 m/s to 0.95 m/s across the heat exchanger. Inlet velocity at tube side and shell side is 0.947 m/s and 0.427 m/s, exit velocity at tube side and shell side is 0.935 m/s and 0.721 m/s.

In the case of Type 2 heat exchanger, the temperature at shell side inlet of 30 °C at the flow rate of 0.8 kg/s, at the first bend the temperature increases to 31.8 °C due to the presence of helical baffle in shell side. At the second and third bend temperature is around 33.4 °C and 34.9 °C. The temperature of shell side outlet is 35 °C. Temperature at tube side inlet of 60 °C at the flow rate of 0.8 kg/s, at the first bend the temperature reduces to 59 °C and at the second and third bend the temperature is around 57.5 °C and 56 °C. Finally, the temperature of tube side outlet is 54 °C. Tube side inlet pressure is about 102209 Pa, tube side outlet pressure is 107168 Pa. Pressure drop at tube side is 4959 Pa. Shell side inlet pressure is 116986 Pa, shell side outlet pressure is 107936 Pa. Pressure drop at shell side is 9050 Pa. For a conjugate heat transfer preferred velocity is between 0.8 m/s to 1 m/s, whereas which will be around 0.8 m/s to 0.95 m/s across the heat exchanger. Inlet velocity at tube side and shell side is 0.958 m/s and 0.428 m/s, exit velocity at tube side and shell side is 0.921 m/s and 0.181 m/s.

For Type 3, the temperature at shell side inlet of 30 °C at the flow rate of 1.078 kg/s, at the first bend the temperature increases to 31.2 °C due to the increase of flow rate in shell side. At the second and third bend temperature is around 32.4 °C and 33.4 °C. Finally, the temperature of shell side outlet is 34.3 °C. Also, the temperature at tube side inlet of 60 °C at the flow rate of 0.8 kg/s, at the first bend the temperature reduces to 58 °C due to the presence of helical baffle in the tube side. At the second and third bend the temperature is around 56.5 °C and 55.2 °C. Finally, the temperature of tube side outlet is 54 °C. Tube side inlet pressure is about 115922 Pa, tube side outlet pressure is 107136 Pa. Pressure drop at tube side is 8786 Pa. Shell side inlet pressure 107085 Pa, shell side outlet pressure is 107131 Pa. Pressure drop at shell side is 1170 Pa. For a conjugate heat transfer preferred velocity is between 0.8 m/s to 1 m/s, whereas which will be around 0.7 m/s to 0.96 m/s across the heat exchanger. Inlet velocity at tube side and shell side is 0.954 m/s and 0.565 m/s, exit velocity at tube side and shell side is 0.74 m/s and 0.383 m/s.

The temperature at shell side inlet for Type 4 heat exchanger, at the temperature of 30 °C and flow rate of 1.078 kg/s, at the first bend the temperature increases to 32.2 °C due to the presence of helical baffle in shell side. At the second and third bend temperature is around 34.1 °C and 35.9 °C. Finally, the temperature of shell side outlet is 37.5 °C. Temperature at tube side inlet of 60 °C, at the first bend the temperature reduces to 58 °C due to the presence of helical baffle in the tube side. At the second and third bend the temperature is around 55.8 °C and 54.2 ˚C.

Finally, the temperature of tube side outlet is 52.7 °C. Tube side inlet pressure is about 135887 Pa, tube side outlet pressure is 106887 Pa. Pressure drop at tube side is 29000 Pa. Shell side inlet pressure 116873 Pa, shell side outlet pressure is 106472 Pa. Pressure drop at shell side is 10400 Pa. For a conjugate heat transfer preferred velocity is between 0.8 m/s to 1 m/s, whereas which will be around 0.7 m/s to 0.96 m/s across the heat exchanger. Between the baffle area having higher velocity which is 1.4 m/s. Inlet velocity at tube side and shell side is 0.932 m/s and 0.420 m/s, exit velocity at tube side and shell side is 0.624 m/s and 0.476 m/s. The temperature plot for all four types of heat exchangers are available in fig. 2. For the Type 1 there is more temperature on the center of the tube, as there is no swirl flow for the Type 1, whereas in Type 3 there is swirl flow hence there is high temperature zone is lesser at the center. In Type 4 as fluid swirling on both shell and tube side hence there is less high temperature at the center of the pipe. The contour plot for comparing the temperature is shown in fig. 3.

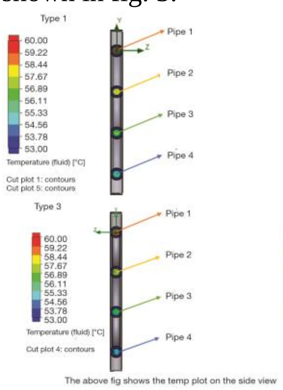

Figure 2. Temperature plot in pipesfor all types of heat exchanger

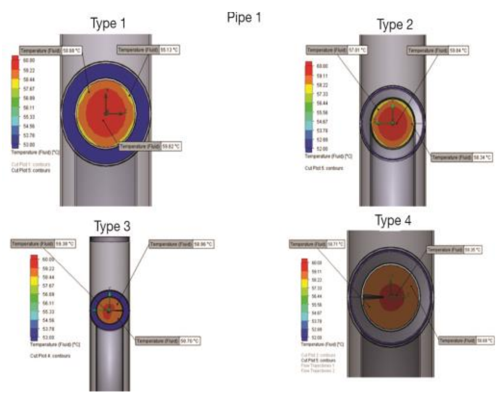

Figure 3. Comparative temperature contour plot of Pipe

Figures 4-7 shows the comparative graphs for the Pipe 1 to Pipe 4 on tube side, from fig. 4 for Type 1 there is a higher temperature near the wall as there is no swirl flow in the tube. From fig. 5 for Pipe 2 Type 4 losses more heat in comparison with the other types, from fig. 6, for Pipe 3 its more evident that Type 4 losses more heat in comparison with the other types. From fig. 7, for Pipe 4 losses more heat in comparison with the other types is explicitly clear from graph.

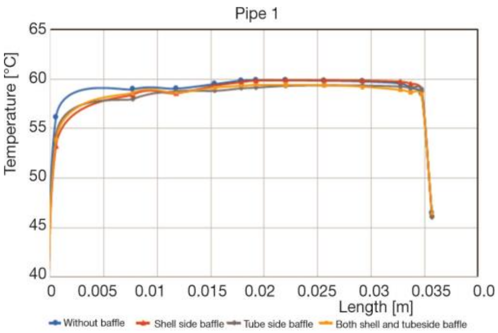

Figure 4. Comparative outlet temperature for Pipe 1

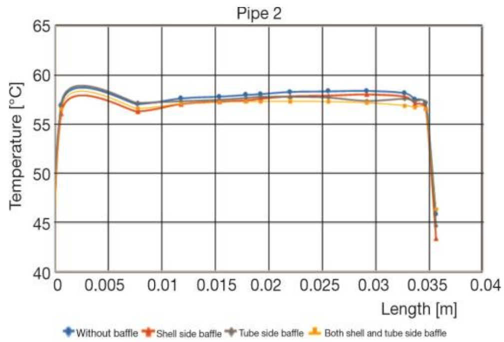

Figure 5. Comparative outlet temperature for Pipe 2

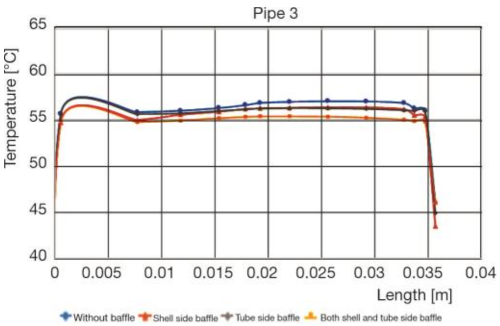

Figure 6. Comparative outlet temperature for Pipe 3

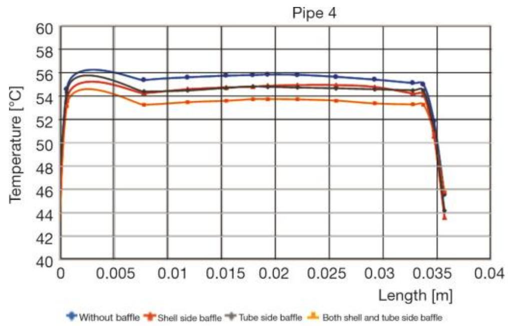

Figure 7. Comparative outlet temperature for Pipe 4

Table 3. Cumulated results for all the heat exchanger types

Type	Description	Tube inlet temperature [°C]	Tube outlet temperature [°C]	Shell inlet temperature [°C]	Shell outlet temperature [°C]	Pressure drop tube side [Pa]	Pressure drop shell side [Pa]
1	Without baffle	60	55	30	34	5399.49	3573.32
2	Shell side baffle	60	54	30	35	4959.55	9050.14
3	Tube side baffle	60	54	30	34	8786.76	1170.41
4	Both tube side and shell side baffle	60	52	30	36.5	29000.09	10400.09

Conclusion

Based on the results, we are having the following conclusions.

- The tube side outlet temperature of Type 2 and Type 3 heat exchangers compared with the Type 1 heat exchanger, there is a 2% increase of tube side outlet temperature for Type 1.

- On comparing the shell side outlet temperature of Type 2 heat exchanger with the Type 1 and Type 3 heat exchangers, there is a 3% increase of shell side outlet temperature for Type 2.
- When the tube side outlet temperature of Type 4 heat exchanger is compared with the Type 1 heat exchanger, there is a 5.5% increase of tube side outlet temperature for Type 4.
- When the tube side outlet temperature of Type 4 heat exchanger is compared with the Type 2 and Type 3 heat exchangers, there is 4% increase of tube side temperature for Type 4.
- On comparing the shell side outlet temperature of Type 4 heat exchanger with the Type 1 and Type 3 heat exchangers, there is 8% increase of shell side temperature for Type 4.
- On comparing the shell side outlet temperature of Type 4 heat exchanger with the Type 2 heat exchanger, there is 5% increase of shell side temperature for Type 4.
- On relating to the shell side pressure drop of Type 4 heat exchanger in comparison with other three types of heat exchanger, the pressure drop increases by 12% for Type 4.
- Similarly, on comparing the tube side pressure of Type 4 heat exchanger with other three types of heat exchangers, the pressure drop raises by 42% for Type 4.

From the previous inferences we get an overview that the Type 4 heat exchanger (having helical baffles on both shell side and tube side), have enhanced heat transfer and higher pressure drop characteristics, on comparison with other three types of heat exchanger.

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