Numerical comparison on Shell side performance of Helixchanger with center tube with different helix angles

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***Abstract*-** Computational Fluid Dynamic (CFD) is a useful tool in solving and analyzing problems that involve fluid flows, while shell and tube heat exchanger is the most common type of heat exchanger and widely use in oil refinery and other large chemical processes because it suite for high pressure application. The numerical simulation of Shell & Tube Heat Exchanger with center tube called Helixchanger with center tube with different baffle inclination is to be done. The processes in solving the simulation consist of modeling and meshing the basic geometry of Helixchanger using the CFD package ICEM CFD. Then, the boundary condition will be set before been simulate in Fluent based on the research papers experimental data. Finally results has been examined in CFD-POST. Parameter that had been used was the same parameter of experimental at constant mass flow rate of hot water and varies with mass flow rate at 50,60,70 & 80 LPM of cold water. Thus, this report presents the simulation of heat transfer & pressure drop in Helixchanger model with different baffle inclination as 20, 25, 30 & 40 degree, which gives insight of all parameters affect on Helixchanger design & it also suggests the optimized helix angle which gives better heat transfer with minimum pressure drop.

***Index Terms*-** CFD, Helixchanger, Center tube, Heat transfer coefficient, Pressure drop.

I. INTRODUCTION

1.1 Background of study

Heat exchangers are devices in which heat is transferred from one fluid to another. Heat exchangers are widely used equipment in various industries such as process, power generation, and transportation and refrigeration industry.

In addition to the basic need for transferring heat there are certain additional requirements which tend to be specific to the industry in which they are employed, Mukherji R. et al., 1988. For example, the exchanger used in automotive and aviation industry need to be lightweight. These exchangers as well as those used in commercial and domestic refrigeration tend to use the same types of fluid in many applications. The exchangers used in chemical process industry tend to be used for a wide variety of fluid types with different degree of cleanliness. In contrast, the exchangers used in cryogenic applications invariable handle relatively clean fluids. These and other similar industry specific requirements have resulted in development of different types of exchanger ranging from the conventional shell and tube heat exchanger to other tubular and non tubular exchangers of varying degree of compactness.

Shell and tube heat exchangers (STHXs) are widely used in many industrial areas, such as power plant, chemical engineering, petroleum refining, food processing, and etc. A large percentage of world market for heat exchangers is served by the industry workhorse, the shell-and-tube heat exchanger. According to Master B.I. et al., 2006. more than 35-40 % of heat exchangers are of the shell and tube type due to their robust geometry construction, easy maintenance and possible upgrades. Rugged safe construction, availability in a wide range of materials, mechanical reliability in service, availability of standards for specifications and designs, and long collective operating experience and familiarity with the designs are some of the reasons for its wide usage in industry. Recent developments in other exchanger geometries have penetrated in various industry applications; however, the shell and tube exchanger by far remains the industry choice where reliability and maintainability are vital. Over the years, significant research and development efforts are devoted to better understand the shell-side geometry. A variety of different strategies are available to process and equipment designers to improve industrial heat transfer.

1.1.1 Shell and tube heat exchanger

The basic principle of operation is very simple as flows of two fluids with different temperature brought into close contact but prevented from mixing by a physical barrier. Then the temperature between two fluids tends to equalize by transfer of heat through the tube wall. The fluids can be either liquids or gases on either the shell or the tube side. In order to transfer heat efficiently, a large heat transfer area should be used, leading to the use of many tubes. In this way, waste heat can be put to use. This is an efficient way to conserve energy.

1.1.2 Helical Baffle Shell & Tube Heat Exchanger with center tube (Helixchanger)

The concept of helical baffle heat exchangers was developed for the first time in Czechoslovakia. The Helical baffle heat exchanger, also known as Helixchanger, is a superior shell-and-tube exchanger solution that removes many of the inherent deficiencies of conventional segmental-baffle exchangers. Helical baffle heat exchangers have shown very effective performance especially for the cases in which the heat transfer coefficient in shell side is controlled; or less pressure drop and less fouling are expected Kral D et al., 1993. It can also be very effective, where heat exchangers are predicted to be faced with vibration condition. Quadrant shaped baffle segments are arranged at an angle to the tube axis in a sequential pattern that guide the shell side fluid to flow in a helical path over the tube bundle. Helical flow path of the shell-side fluid can also be achieved by a continuous helix shaped baffle running throughout the length of the shell and tube heat exchanger.

Manufacturing of helical baffle is very difficult. In order to avoid manufacturing difficulties of continuous helical baffles in the center region, a center tube has to be installed, Chen G.D. et al., 2011.

The helical flow provides the necessary characteristics to reduce flow dispersion and generate near plug flow conditions. It also ensures a certain amount of cross flow to the tubes to provide high heat transfer coefficient. The shell-side flow configuration offers a very high conversion of pressure drop to heat transfer.

The Helixchanger design provides:-

- Enhanced (Heat transfer performance/ Shell-side pressure drop) ratio.
- Reduced fouling characteristics.
- Effective protection from flow-induced tube vibrations.
- It results in lower capital costs, reduced operating costs, lower maintenance costs and consequently, significant lower total life cycle costs.
- For existing plants, the Helixchanger design helps to increase the capacity while lowering maintenance cost, plot space and energy costs.

It is better to consider the Helixchanger option when investigating the following:-

- Plant upgrade with replacement tube bundles.
- Capacity expansion with limited plot space.
- Reduce fouling problems and frequent downtime

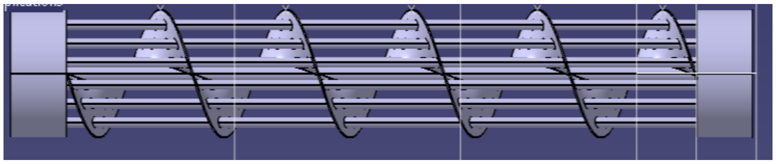


Fig. 1.1: Helical Baffled Shell & Tube Heat Exchanger (Helixchanger)

According to Yong-gang Lei et al. the performance of helixchanger depends on helix angle which determines pressure drop on shell side i.e. pumping power required. The heat transfer per unit pressure drop is a good metric for comparing the performance. As we know heat exchangers are widely used equipments in various mechanical, chemical, power generation and refrigeration industry. The present well established process design trend requiring high degree of heat recovery usually results in installing a larger heat exchanger area. However adding a few more heat exchangers causes an increase in pressure loss together with a greater pumping power requirement.

On the shell side the conventional segmental baffles exhibit rather high-pressure difference to produce sufficiently high heat transfer rate. Therefore fresh look into the baffle arrangement is needed. So, use of helical shaped baffles is proposed.

The fluid flow pattern, particularly within the shell, may significantly influence the heat exchanger efficiency. The development of shell and tube exchanger centre on better conversion of pressure drop into heat transfer by improving the conventional baffle design.

2.Helixchanger & Segmental Heat Exchanger:

Conventional segmental baffles in shell and tube heat exchangers, while having an excellent record of acceptance and functionality, represent some limitations and shortcomings. In particular, shell-side flow path is wasteful which causes excessive pressure loss while recovering less heat transfer. This particular arrangement of baffles also limits maximum thermal effectiveness and encourages dead zones where fouling occurs, Sirous Z. M. et al.,2012.

Time & money spends on heat exchanger cleaning process for better performance. From fig. shown below it is observed that the running time for helical baffle is 3 times more than segmental baffle . It can be found out from mentioned pictures that the fouling for helical baffles is significantly lower and also distribution of fouling is more scattered all over the surface of tubes. On the other hand, fouling for segmental baffles is higher and is more accumulated on local areas. Accumulation of fouling on local areas causes corrosion on the surfaces of tubes and baffles and lowers the operation period of heat exchangers.

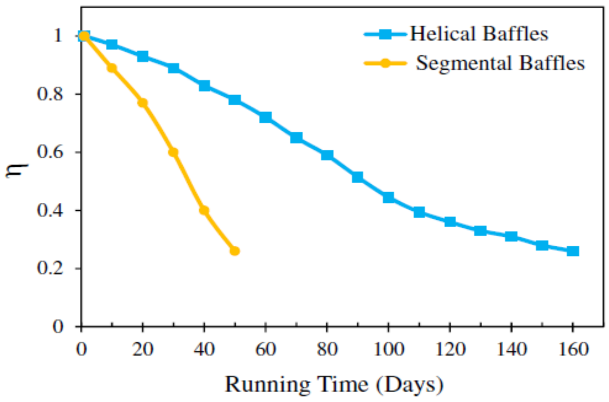


Fig.1.2 Running times of segmental and helical baffles.

2.1 Helixchanger with center tube:

Continuous helical baffles are manufactured by linking several sets of continuous helical cycles. One continuous helical cycle is lengthened to one screw pitch along the length (axial) direction and rotated at a 2π angle along the circumferential direction, and several continuous helical cycles are linked end to end to form continuous helicoids as shown in Fig.2.2.1(a)

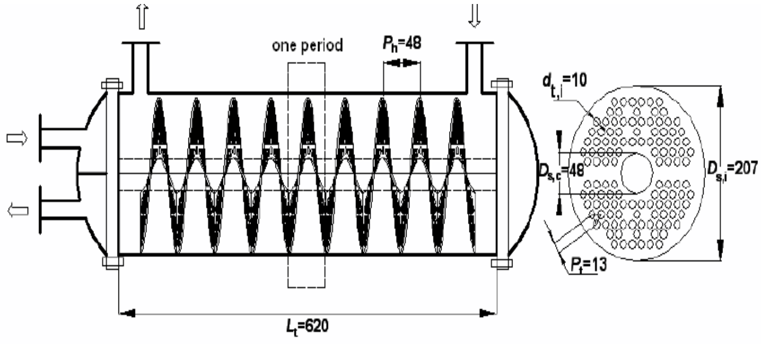
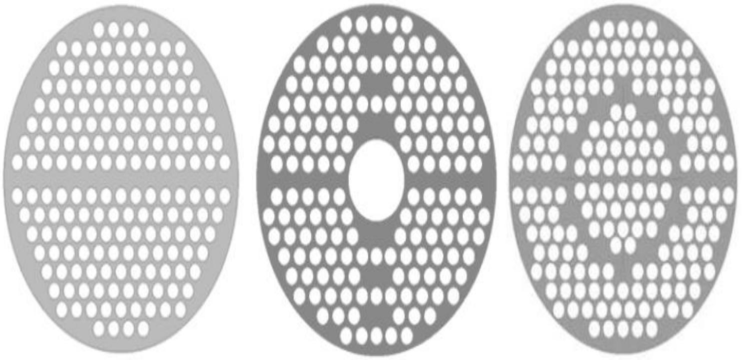
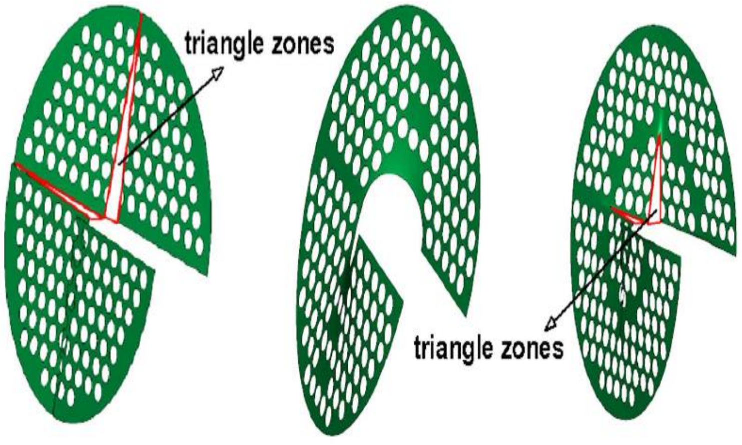


Fig .(a) Structure of simplified model (CH-STHX)



Fig(b) Layout of tubes in different heat exchangers



Fig(c) Structure of helical baffles in different heat exchangers

Fig. 1.3 Computational models of shell-and-tube heat exchangers with three different helical baffles (DCH STHX, CH-STHX and CMH-STHX).

Compared with the DCH-STHX, the “triangle zones” in CMH-STHX, which resulted in leakage, have been decreased greatly. the fluid passes though the tube bundles in an approximately helical pattern and there are serious leakages from the “triangle zones.” The leaking fluid passes through the shell side without rushing across the tube bundle, which can result in lower heat transfer performance and lower pressure drop. the continuous helical baffles (CH-STHX) form a completely helix flow in the shell side, and there is no leakage. These advantages may contribute to its outstanding performance on heat transfer.

In order to avoid manufacturing difficulties of continuous helical baffles in the center region, a center tube has to be installed.

Table 2.1 Geometrical parameters.

Sr No.	Parameters	Units	DCH	CMH	CH
	Inlet diameter of shell	mm	200	200	200
	Outlet diameter of tube	mm	12	12	12
	Arrangement of tube bundles		Square	Square	Square
	Distance between tubes	mm	20.5	20.5	20.5
	Effective length of tubes	mm	450	450	450
	Helical pitch	mm	32	44	80
	Number of baffles		12	9	5
	Number of tubes		48	48	44
	Diameter of center tube	mm			25
	Minimal flow area	m^2	0.0025	0.00343	0.00546
	Fluid in the shell side		oil	oil	oil
	Mass flow rate	M^3/hr	10.11	10.11	10.11
	Reynolds number		3776.4	2752.5	786.7
	Inlet temperature	K	373	373	373
	Outlet temperature	K	365.7	365.9	367.8
	Tube wall temperature	K	301.7	301.3	301.1
	Log mean temperature difference	K	67.5	68.1	69.3
	Pressure drop	KPa	4.32	2.89	1.70
	Heat transfer rate	KW	39.1	37.8	27.9
	Heat transfer coefficient	W/m^2 K	355.1	340.9	247.2
	Nusselt number		33.8	32.4	23.5

2.2 CFD simulation of Helixchanger:

To model the full heat exchanger is quite difficult task. A 3D numerical simulation of a whole heat exchanger with middle-overlapped helical baffles is carried out by using commercial codes of GAMBIT 2.3 and FLEUNT 6.3. At first, the computational model and numerical method of the whole heat exchanger with middle-overlapped helical baffles is presented in detail, and parallel computation mode is adopted for the simulation of a whole heat exchanger with six cycles of the middle-overlapped helical baffles of 40° helical angle on a grid system of 13.5-million cells, J.F. Zhang et al., 2009.

The temperature of tube walls are set as constant and their values are taken from the average wall temperature determined in the experiments

After validation its found that the cycle average Nusselt number of different cycle in the heat exchanger & pressure drop within the accuracy allowed in engineering computation hence periodic model for one cycle can be used to investigate the heat transfer and pressure drop characteristics for different heat exchanger to save computational source, J.F. Zhang et al., 2009.

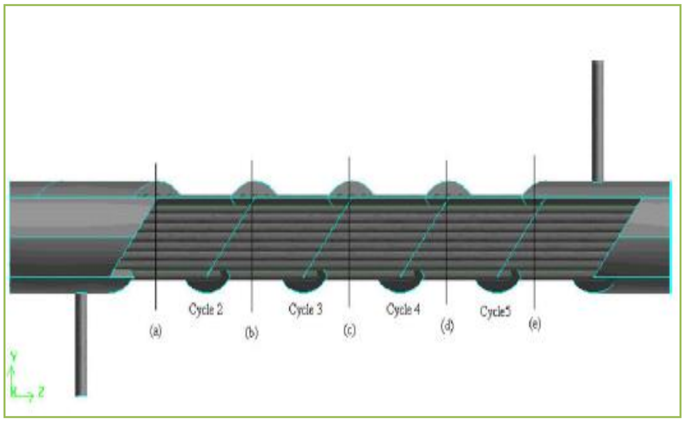


Fig. 1.4 Specifications of specified surfaces and geometric cycle units.

For the case studied the difference between the 2nd cycle and the fifth cycles are both less than 2% for both pressure drop and heat transfer. Thus for the performance simulation of a STHXHB periodic model for one cycle can be used to investigate its performance without inducing large error.

Sr No	Helix angle in degree (α)	Baffle pitch (mm)= π D_i tanα	No. of baffles
1	20	175	6
2	25	224	5
3	30	277.5	4
4	40	403.3	3

Some researches indicated that the larger the helix angle, the better shell-side comprehensive performance of STHXCH when helix angle is less than 45◦. However, a large helix angle, or in other words a large helix pitch, has some adverse effects: first, the shell-side velocity becomes small under the same mass flow rate, which goes against heat transfer; second, the quantity of helical cycle is small, which means the helix flow is possibly not fully developed until it reaches the shell-side outlet; third, the unsupported span on the tube bundles is large, which is not favorable for the prevention of fluid-induced vibration in the shell side, Ji shui et al., 2011.

3 Governing equations:

Continuity equation

$$\frac{\partial}{\partial x_i}(\rho ui) = 0$$

Momentum equation

$$\frac{\partial}{\partial x_i}\left(\rho u_i u_j - \tau_{ij}\right) = -\frac{\partial p}{\partial x_i}$$

Energy equation

$$\frac{\partial}{\partial x_i}\left(\rho u_i T - k\frac{\partial T}{\partial x_i}\right) = 0$$

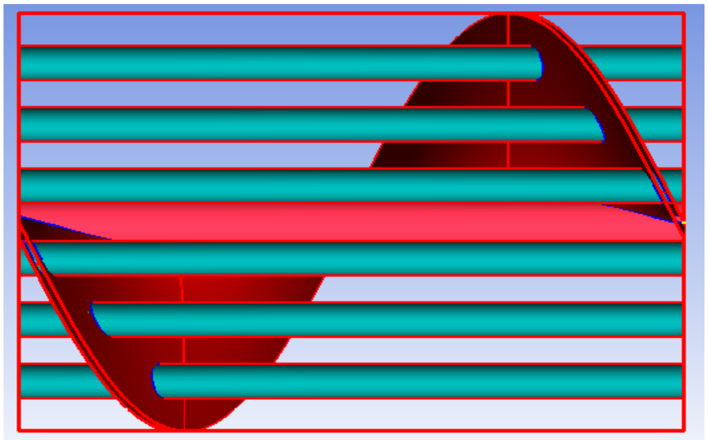


Fig. 1.5 Insight of a one cycle Helixchanger with center tube

Table: Baffle pitch

k-ε realizable turbulence model is applied. The governing equations are iteratively solved by using SIMPLE pressure-velocity coupled algorithm. The convergence criteria for energy variable (T) is < 10^-6. The sum of the normalized absolute residuals in each control volume for other flow variables (such as ui, p) are controlled to be < 10^-3. Each solution takes approximately 4-5 CPU hours to converge on personal computer having 8GB RAM & 2.1 GHZ processor.

Numerical validation:

Computational results were compared with the Periodic model with continuous helix, Zhang J.F. et al., 2009 and it is found that the good agreement in trend of shell side heat transfer coefficient versus mass flow rate.

Computational Results

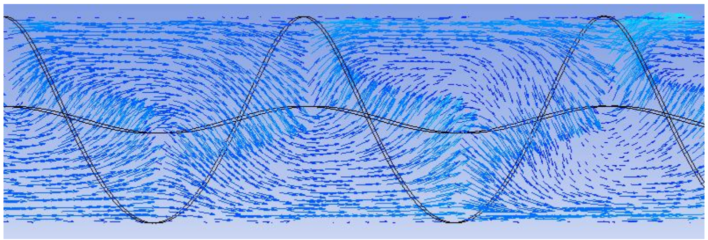


Figure 1.6 Vector plot for Helixchanger with center tube.

The velocity vector distributions & streamlines on the axial sections of shell side fluid are shown in Figure. The shell-side fluids pass through the tube bundles basically in a helical pattern and rush the heat exchange tubes with an inclination angle. On the one hand, helical flow avoids abrupt turns of flow. On the other hand, it changes the cross section shape of tube in flow direction into ellipse. Therefore, it can reduce the pressure drop in shell side and the vibration of tube bundle.

Table: Geometrical parameters

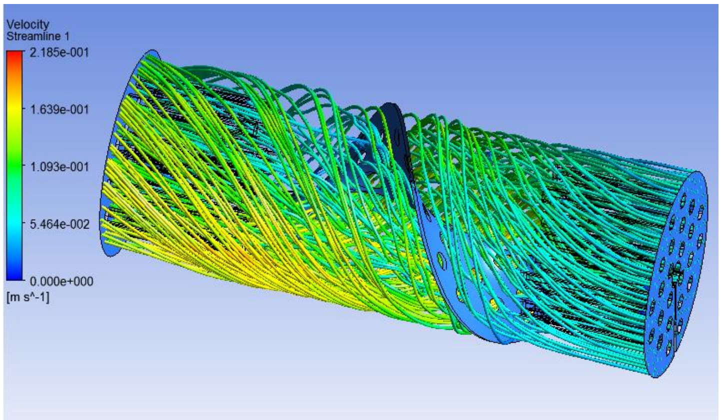


Figure 1.7 Velocity streamlines for Helixchanger with center tube.

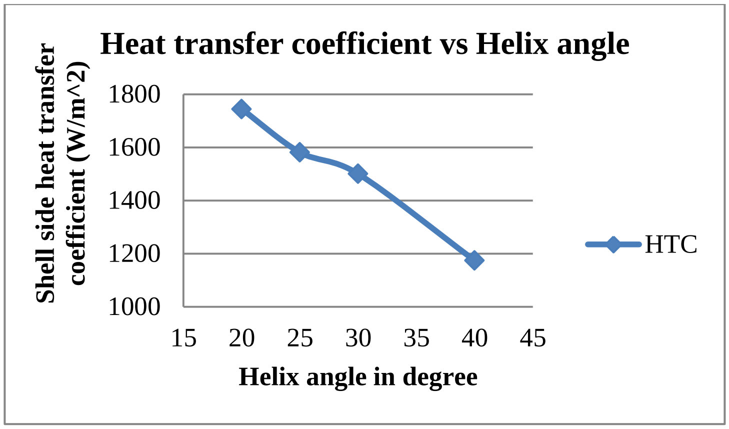


Figure 1.8 Heat transfer coefficient vs Helix angle

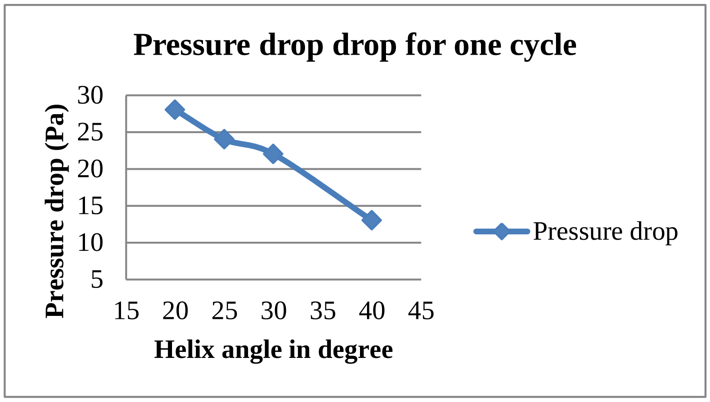


Figure 1.9 Pressure drop for one cycle

Sr.no	Parameter	Shell side
1	Fluid	Water
2	Volume flow rate	50,60,70,80,90 LPM
3	Mass flow rate	0.84, 1, 1.17, 1.34, 1.67 kg/s
4	Shell ID (D_i)	0.153 m
5	Shell length	1.123m
6	Tube pitch	0.0225 m (Square)
7	No of passes	1
8	Tube OD	0.012 m
9	Tube thickness	0.0014 m
10	Number of Tubes	24
11	Helix angle	20, 25, 30, 40 degrees

Conclusion

In this paper, numerical simulations of Helixchanger with center tube with different baffle inclination angles are performed to reveal the effects of baffle inclination angle on the heat transfer and pressure drop characteristics. And based on those characteristics to provide an optimal baffle inclination angle for the required range of heat transfer coefficient and available pumping power. The major findings are summarized as follows:

- As helix angle decreases, the baffle pitch decreases and for the same mass flow shell side velocity increases and hence it leads to increase in heat transfer coefficient.
- Shell side pressure drop decreases with increase in helix angle because baffle pitch increases & flow achieves smooth behavior in shell side.
- Ratio HTC/Pressure drop is higher for helix angle >35º but along with this we should take into account achievable HTC (heat transfer coefficient) range by given helix angle as after certain Pressure drop, HTC values becomes flat. Therefore observing only the ratio of HTC/Pressure drop will not be sufficient, along with that we should take into account plot of HTC versus pressure drop per unit length also. So even HTC/Pressure drop is high for 40^0 helix angle, its HTC is very small compared to other helix angles.

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