Numerical Investigation of Variable Tube Diameter Helical Coil Heat Exchanger

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***Abstract*- A helical coil-tube heat exchanger is widely used in industrial applications due to its compactness. The performance of compact heat exchangers has been recognized in various industries for the last 60 years or more due to several advantages. However, flow rate and heat transfer correlation related to helical coil-tube heat exchanger are very sophisticated. A computational fluid dynamics (CFD) methodology using ANSYS FLUENT 15.0 is used here to investigate effects of tube diameter and mass flow rate on the heat transfer and pressure drop characteristics in a helical coil heat exchanger. Simulation has been done by varying the mass flow rate from 180 Lph to 420 Lph on different configuration of helical coiled tube. The result shows that the temperature drop, and pressure drop are affected by geometry of helical coil heat exchanger.**

Keywords— Computational fluid dynamics, helical coil heat exchanger, Heat transfer, temperature drop

I. INTRODUCTION

Heat transfer rate in helical coils heat exchanger is higher than as compared to straight tube coils heat exchangers, because of its size, higher film heat transfer coefficient, they are widely used in industrial applications. Helical coil heat exchangers have less expensive design. Helical coil heat exchanger are effective in handling higher temperatures and extreme temperature differentials. Helical coils are found to be very effective in enhancing heat transfer compared to straight tube in single phase flow, boiling heat transfer.

Detail study of the performance characteristics of a spiral coil heat exchanger under wet-surface conditions was done by Naphon and Wongwises et al. in year (2005)[1]. The numerical and experimental studies to find out the heat transfer rate and predict the performance of a spiral coil heat exchangers was done by both of them. Cooling and dehumidifying conditions were used for analysis. They found that the rate of mass flow and temperature of air at the inlet affects the temperature of air and water at the outlet. This experiment shows the relation between outlet temperature of air and water with increase in mass flow rate of water.

Kumar et al. (2006) [2] had conducted investigation on hydrodynamic and heat transfer characteristic of tube in tube helical heat exchanger at pilot plant scale. They conducted the experiment in a counter flow heat exchanger. Overall heat transfer coefficients were assessed. Nusselt number and friction factor coefficient for inner and outer tube was found and compared with numerical value got from CFD package (FLUENT). Numerical values received from CFD package (FLUENT) were compared with calculated values of Nusselt number and friction factor coefficient for inner and outer tube. They found that the overall heat transfer coefficient increase with inner coil tube Dean Number for constant flow rate in annulus region.

Jayakumar et al. (2008) [3] had done numerical and experimental work on helical coil heat exchanger considering fluid to fluid heat transfer. They had taken different boundary conditions for example constant heat transfer coefficient, constant heat flux and constant wall temperature. In their study they found that constant value of thermal and transport properties of heat transfer medium results inaccurate heat transfer coefficient. Also the practical applications, the heat transfer in fluid to fluid heat exchangers in arbitrary boundary conditions such as constant wall temperature or constant heat flux conditions are not applicable. Based on the numerical and experimental analysis within certain error limits correlation was developed to calculate the inner heat transfer coefficient of helical coil. Kharat et al. (2009) [4] had done the experiments to study the heat transfer rate on a concentric helical coil heat exchanger and develop the correlation for heat transfer coefficient. Heat transfer coefficient has improved for the tube containing flue gas of the heat exchanger by using CFD simulation and the experimental study. The effect of different operating variables was studied. The variables they had considered are gap between the concentric coils, diameter of tube and coil diameter. The heat transfer coefficients are affected by the coil gap and the tube diameter. They found that the heat transfer coefficient decreases with the increase in coil gap. With increase in tube diameter the heat transfer coefficient increases. Jayakumar et al.(2010) [5] had done the numerical and experimental analysis to find out the variation of local Nusselt number along the length and circumference of a helical tube. They had changed the pitch circle diameter, tube pitch and pipe diameter and their influence on heat transfer rate was found out. They have done the prediction of Nusselt number. The of Nusselt number variation with respect to angular location of the point was also predicted in this literature. In their conclusion they found that the heat transfer coefficient and hence the Nusselt number is not uniform along the periphery of the helical pipe. They had derived an expression to calculate the Nusselt number at various points along the periphery of the tube in the fully developed region. The effect of pipe diameter was studied and it is found that when the pipe diameter is low, the secondary flow is weak and the mixing of the fluid is less. When the diameter of the coil increases the heat transfer at the outer surface is highest. The PCD influence the centrifugal force of fluid flowing inside the tube, which in turn affects the secondary flow. When the PCD is increased, the curvature effect on flow pattern decreases and the centrifugal force plays a lesser role in flow characteristics.

Study on the flow and heat transfer characteristics in a spiral-coil tube had done by Naphon (2011) [6]. He did both the numerical and experimental study on a horizontal spiral-coil tube to predict the flow characteristic. The standard k–ε two-equation turbulence model was used to simulate the turbulent flow and heat transfer characteristics of the fluid. The heat transfer rate or heat transfer coefficient had affected by the centrifugal force. However, the pressure drop also increases. He found that the Nusselt number and pressure drop obtained from the spiral-coil tube are almost one and half times higher than that of the straight tube due to the centrifugal force.

Pawar and Sunnapwar et al. (2014) [7] have done the Experimental analysis on isothermal steady state and non-isothermal unsteady state conditions in helical coils. They had considered both the Newtonian as well as non-Newtonian fluids for working fluid. For Newtonian fluid they considered water and glycerol–water mixture (10 and 20% glycerol). For non Newtonian fluid they considered 0.5–1% (w/w) dilute aqueous polymer solutions of Sodium Carboxy Methyl Cellulose and Sodium Alginate. The correlation was found out between the Nusselt number and nondimensional number, 'M', Prandtl number and coil curvature ratio. They found the heat transfer rate under isothermal steady state and non-isothermal unsteady state conditions in laminar and turbulent flow conditions. Lu et al. (2014) [8] had done the experimental and numerical study on the shell-side thermal-hydraulic performances of multilayer spiral wound heat exchangers under different thermal boundary wall conditions.

S. D. Sancheti & Dr. P. R. Suresh [9] has worked on the Experimental and CFD estimation of the heat transfer in helically coiled heat exchanger. His work focused on the fluid –to – fluid heat transfer. He validated the basic methodology of CFD analysis in a heat exchanger, without considering actual properties of fluid, a constant value was established instead. For various boundary conditions, the heat transfer characteristics were compared for a helical coil. He found that specification for constant heat flux and constant temperature boundary condition doesn't yield desired modeling for an actual possible heat exchanger. So, heat exchanger was analyzed considering conjugate temperature dependent and heat transfer properties. The fabrication of an experimental set up for the heat transfer characteristics was developed. Experimental results were compared with the results of CFD calculation using CFD package i.e. FLUENT 15. Use of constant values for the basic thermal and transport properties in the heat exchanger resulted in prediction of inaccurate heat transfer coefficients. From the results obtained from experiment a correlation was developed for the calculation of inner heat transfer coefficient in a helical coil heat exchanger

GOVERNING EQUATIONS

The governing differential equation for the fluid flow is given by Continuity equation or mass conservation equation, Navier Stokes equation or momentum conservation equation and energy conservation equation.

A. *Continuity equation*

$$\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0 \qquad (1)$$

B. *Navier Stokes equation*

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial w}{\partial z}\right)=\rho x-\frac{\partial p}{\partial x}+\frac{1}{3}\mu\frac{\partial}{\partial x}\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)+\mu\nabla^2 u$$

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial w}{\partial z}\right)=\rho y-\frac{\partial p}{\partial y}+\frac{1}{3}\mu\frac{\partial}{\partial y}\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)+\mu\nabla^2 v$$

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial w}{\partial z}\right)=\rho z-\frac{\partial p}{\partial z}+\frac{1}{3}\mu\frac{\partial}{\partial z}\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)+\mu\nabla^2 w$$

C. *Energy equation*

$$\rho c_p\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}\right)=\left(u\frac{\partial p}{\partial x}+v\frac{\partial p}{\partial y}+w\frac{\partial p}{\partial z}\right)+k\nabla^2 T+\mu\varphi$$

II. CFD ANALYSIS

Various tube dimension which are selected for CFD analysis is shown in table 1. Tube dimension were selected from standard copper handbook. Table 2 shows the various helical coil dimensions.

Table 1 Model dimension with different tube diameter

Sr. No.	Nominal or Standard Size	Nominal Dimensions		
		Outside Diameter	Inside Diameter	Wall Thickness
Units	Inches	mm	mm	mm
1	3/8	9.525	7.8994	0.8128
2	5/16	7.9248	6.2992	0.8128
3	3/16	4.7498	3.2512	0.762

Table 2 Model dimension for various helical coils

Coils	Outside Diameter	Inside Diameter	Wall Thickness	Pitch	Coil Diameter
	mm	mm	mm	mm	mm
1	9.525	7.8994	0.8128	10	210
2				20	
3				30	
4	7.9248	6.2992	0.8128	10	210
5				20	
6				30	
7	4.7498	3.2512	0.762	10	210
8				20	
9				30	

Table 3 CFD results for Pressure drop with different pitch

CFD results for pressure Drop									
Flow rate (Lph)	30 mm pitch			20 mm pitch			10 mm pitch		
	Pressure Drop			Pressure Drop			Pressure Drop		
	3_8	5_16	3_16	3_8	5_16	3_16	3_8	5_16	3_16
180	2040	2238	2962	2336	2239	2997	2338	2239	3031
200	6549	6943	8338	6525	6946	8418	6531	6949	8497
260	6424	7182	9981	6412	7185	10107	6416	7184	10233
305	8713	9937	14483	8703	9941	14679	8709	9938	14875
340	8451	9946	15539	8440	9950	15769	8445	9944	15998

400	15534	17428	24423	15516	17434	24736	15527	17432	25048
420	21901	24008	31708	21797	24018	32077	21814	24021	32444
460	22212	25851	31642	23111	25859	32067	22124	25853	32492

Table 3 shows CFD results for the pressure drop for different pitch of 30 mm, 20 mm and 10 mm with different flow rates.

Fig. 1 ANSYS results for heat exchanger showing the temperature profile from inlet to outlet. From ansys results it shows that temperature goes on reducing

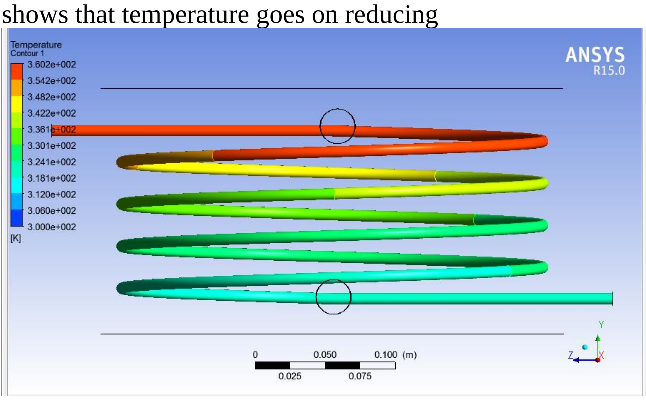

Fig. 1 shows the results for von mises stress produced during ANSYS simulations done. Regions of high localized stress found.

III. Experimental Setup.

Fig. 2 shows the experimental setup used in the conduction of experiment for helical coil heat exchanger.

Fig. 2 Experimental setup

IV. Results

Fig. 3 shows experimental Vs CFD results for the temperature drop Vs flow rate for 30 mm pitch. Fig. 4 shows experimental Vs CFD results for the temperature drop Vs flow rate for 20 mm pitch. Fig. 5 shows experimental Vs CFD results for the temperature drop Vs flow rate for 10 mm pitch.

In table 4. Shows experimental results which are tabulated for temperature drop for various pitch dimensions it shows that pitch length effect is negligible.

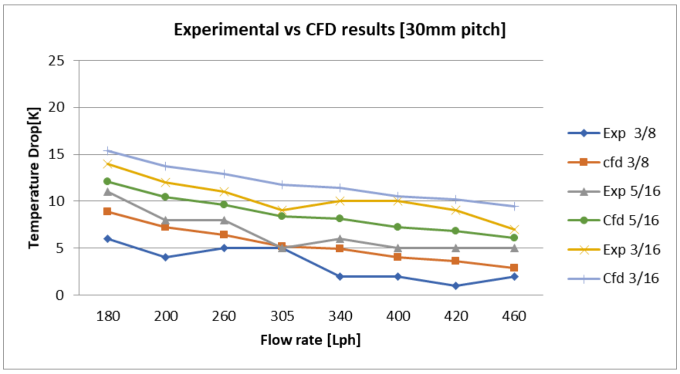

Fig. 3 Temperature drop Vs Flow rate for 30 mm pitch

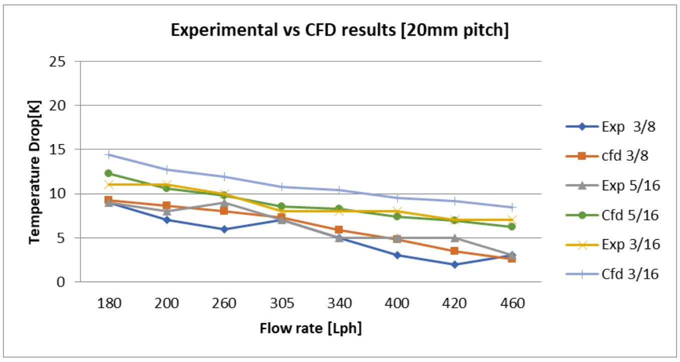

Fig. 4 Temperature drop Vs Flow rate for 20 mm pitch

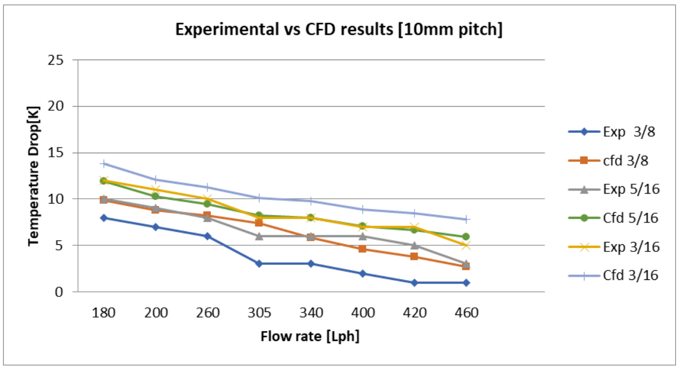

Fig. 5 Temperature drop Vs Flow rate for 10 mm pitch

Table 4 Experimental results for temperature drop

Experimental results for Temperature Drop									
flow rate	30 mm pitch			20 mm pitch			10 mm pitch		
	Temperature drop			Temperature drop			Temperature drop		
	3_8	5_16	3_16	3_8	5_16	3_16	3_8	5_16	3_16
180	6	11	14	9	9	11	8	10	12
200	4	8	12	7	8	11	7	9	11
260	5	8	11	6	9	10	6	8	10
305	5	5	9	7	7	8	3	6	8
340	2	6	10	5	5	8	3	6	8
400	2	5	10	3	5	8	2	6	7
420	1	5	9	2	5	7	1	5	7
460	2	5	7	3	3	7	1	3	5

V. CONCULSION

The CFD results matched with the experimental results within experimental error limits. Analysis has been conducted for both the constant wall temperature and constant wall heat flux boundary conditions. Fluid particles causes fluctuations in heat transfer rates due to oscillatory motion inside the pipe. A number of numerical experiments have been carried out to study influence of coil parameters, viz., pitch circle diameter, coil pitch and pipe diameter on heat transfer and pressure drop. Studies have been carried out by varying coil pitch, pipe diameter with constant pitch circle diameter. Their influence on Performance characteristic heat transfer and pressure drop has been brought out. Unlike the flow through a straight pipe, the centrifugal force caused due to the curvature of the pipe causes heavier fluid (water-phase) to flow along the outer side of the pipe. High velocity and high temperature are also observed along the outer side of curvature of helical coil tube. Temperature drop is inversely proportional to flow rate. As flow rate increases pressure drop goes on increasing. However, the effect of pitch is negligible. Optimum range for flow rate of water through helical coiled tube is 300 -350 lph.

VI. FUTURE SCOPE.

The works which are required to be done in future are:

1.To numerically model a helically coil tube heat exchanger using CFD analysis and optimize the curvature ratio using Dean number and Colburn factor for boundary conditions of constant wall heat flux for laminar flow and turbulent flow.

2.Helical coil with various annular fins.

3.To design an optimized and more efficient helical coil tube heat exchanger.

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