Computational analysis of helical coil Heat exchanger for Temperature and Pressure drop

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Abstract – *A helically coil-tube heat exchanger is generally applied in industrial applications due to its compact structure, larger heat transfer area and higher heat transfer capability, etc. The importance of compact heat exchangers (CHEs) has been recognized in aerospace, automobile, gas turbine power plants, and other industries for the last 60 years or more due to several factors as mentioned above. However flow and heat transfer phenomena related to helically 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.

Key Words: Computational fluid dynamics, helical coil heat exchanger, Heat transfer, temperature drop, Pressure drop.

1. INTRODUCTION

Heat transfer in helical coils is higher than as compared to straight coils. Because of its compact size, higher film coefficient, they are widely used in industrial applications like power generation, nuclear industry, process plant, heat recovery system, chemical process industries etc. These heat exchanger are used to control the temperature of the reactors for exothermic reactions. They have less expensive design. Helical geometry allows the effective handling at higher temperatures and extreme temperature differentials without any highly induced stress or expansion of joints. Helical coil heat exchanger consists of series of stacked helical coiled tubes and the tube ends are connected by manifolds, which also acts as fluid entry and exit locations.

S.D. Sancheti & DR.P.R .Suresh [1] have 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. 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. *J. S. Jayakumar[2]* observed that the use of constant values for the transfer and thermal properties of the fluid resulted in inaccurate heat transfer coefficients. Based on the CFD analysis results a correlation was developed in order to evaluate the heat transfer coefficient of the coil. In this study, analysis was done for both the constant wall temperature and constant wall heat flux boundary conditions. The Nusselt numbers that were obtained were found to be highest on the outer coil and lowest in the inner side. Various numerical analyses were done so as to relate the coil parameters to heat transfer. The coil parameters like the diameters of the pipes, the Pitch Circle Diameters have significant effect on the heat transfer and the effect of the pitch is negligible. *Rahul Kharat, Nitin Bhardwaj and R. S Jha[3]* worked on the Development of heat transfer coefficient correlation for concentric helical coil heat exchanger. The existing correlation was found to result in large discrepancies with increase in the gap between the two concentric coils when they were compared with the experimental results. In their work, CFD simulations and with Fluent 6.3.26 was compared with the experimental data, which was used to develop improved correlation for the heat transfer coefficient. Mathematical model was also developed for analyzing the data, which were obtained from experimental results and CFD to accounts for the effects, by different parameters and functional variables like coil gap, coil diameter and tube diameter. Using numerical technique Optimization was done for the heat transfer coefficient by the new correlation, which fits the experimental data within an error band of 3-4%.

J.S. Jayakumar , S.M Mahajani, J.C Mandal, Kannan N. Iyer and P.K. Vijayan[4] worked on the Thermal hydraulic characteristics of air-water two-phase flows in helical pipes. He worked on the Two fluid Eulerian-Eulerian calculation in Fluent 6.3 for the analysis. The parameters which influence the nature of flow are pitch coil diameter, pitch and diameter in helical coils. CFD analysis was carried out and their variation on thermal and hydraulic characteristics by changing the inlet void fraction for a given flow velocity. The correlations forheat transfer and drop in pressure were analyzed. Estimation of inner heat transfer coefficient by changing the void fraction and flow velocity, results in reduction in 'h' is less below 5% and significant above 15% void fraction. *Timothy J. Rennie, Vijaya G.S. Raghavan[5]* worked on the Numerical studies of a double pipe helical heat exchanger. A double-pipe helical heat exchanger was modeled numerically for numerical flow and the heat transfer characteristics were studied for different fluid flow rates and tube sizes. The overall heat transfer coefficient for both counter and parallel flow were calculated. Simulations were validated by comparing the Nusselt numbers. Greatest thermal resistance were found around the annular region. A correlation was found between the annulus Nusselt no. with a modified dean noumber, which gave a strong linear relationship. *Akiyama, M. and Cheng, K.C.[5]* worked on the Boundary vorticity method for laminar forced convection heat transfer in curved pipes. Based on their theoretical work he proposed that the Vortex formation and conversion from laminar to turbulent flow occurs due to the secondary flow by the curvature of the helically coil, which produces a centrifugal force and was analyzed by the CFD using Fluent and various correlations were developed.*R.K Patil, B.W. Shende and P.K Ghosh [7]* worked on designing of helical coil heat exchanger and list simple method to design helical coil heat exchanger. *Promod S. Purandare, Mandar M. Lele, Rajkumar Gupta[8]* has done comparative analysis of the different correlation given by the different researchers for helical coil heat exchanger. ItIndicates that helical coils are efficient in low Re. The analysis also shows that, as tube diameter (d) increases with constant coil diameter (D), the curvature ratio (δ) increases, which increases the intensity of secondaries developed in fluid flow. The increase in the intensity of secondaries developed in fluid flow increases Nu. Hence, it is desirable to have small coil diameter (D) and large tube diameter (d) in helical coil heat exchanger, for large intensities of seconderies in tube. *Shiva Kumar, Kvasudev Karanth[9]* , CFD analysis for a helical coil tubular heat exchanger was carried out and the results of heat transfer parameters have been compared with the straight coil under similar geometrical and operating conditions. CFD results are validated by the correlations used by the different researchers. Pressure drop for helical coil is found to be more when compared with the straight tube for identical conditions. For higher mass flow rates it varies exponentially indicating the necessity of higher pumping power in case of helical coils. *R.Thundil Karuppa Raj, Manoj KumarS, A Mathew C. ,T. Elango[10]*, The analysis on the 30 mm and 60 mm coil pitch for the helical coil heat exchanger The heat removed increases for 60 mm coil pitch compared to that of 30 mm but with an evident increase in the pressure drop. Velocity and the least for 60 mm coil pitch with 3 m/s inlet velocity. As the velocity increases the ratio of pressure drop to heat removed is comparatively less for 60 mm coil compared to the change in 30 mm coil pitch. The Nusselt number to dean number shows that it is same for 60 mm case, but it shows that the ratio is more in 60 mm coil pitch than that for 30 mm coil pitch. Thus the heat transfer characteristics of a 60 mm coil pitch are better compared to a 30 mm coil pitch at higher Dean Number with limitation in space and more loss in pressure drop.

1.1 Governing Equations

Applying boundary conditions, the governing equations for convective heat transfer are as follows:

Continuity equation

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

Navier-stokes field equations (only x-direction equation is given below)

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

Energy equation

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

Heat transfer coefficient

$$h=\frac{-k\frac{\partial T}{\partial x}}{T_w-T_f}$$

Critical Reynolds number as per the correlation given by Schmidt(1967)

$$Re_{cr}=2300\left[1+8.6\left(\frac{d}{D}\right)^{0.45}\right]$$

Friction factor

$$f=\frac{2\nabla pd}{\rho LV^2}$$

2. CFD ANALYSIS

Geometric model is prepared in Ansys-15 design modeler after preparation of model meshing was done using Ansys ICEM CFD software. Sizing of mesh with Relevance centre as Medium with slow transition which will help in getting faster results .Configuration of computer was 2 Gb ram with core i3 processor. Mesh with 368216 nodes and 264053 elements were generated. Various sections were named as inlet, outlet copper, tube and fluid. Fluent with double precision is used for setup. Materials are selected as copper for tube and water as fluid. K epsilon (2eqn) model is selected with energy equation in ON condition.
Boundary condition for inlet as velocity inlet and at outlet as pressure out. The temperature is set at 343K and velocity input is given as per mass flow rate. Heat transfer coefficient is set at 450 w/m2K. The number of iteration is set to 500 and the solution is calculated and various contours, vectors and plots are obtained. Hot water flows inside the tube. Table 2.1 and 2.2 shows the properties of water and copper tube respectively.

Table No 2.1 Properties of water

Description	Symbol	Value	Units
Density	ρ	1000	kg/m³
Dynamic	μ	0.00100	kg/ms
Specific Heat	Cp	4182	J/kgK
Thermal Conductivity	k	0.6	W/mK

Table No 2.2 Properties of copper tube.

Description	Symbol	Value	Units
Density	ρ	8978	kg/m³
Specific Heat	Cp	381	J/kgK
Thermal Conductivity	k	387.6	W/mK

Table No 2.3 Model dimensions

Coils	Outside Diameter	Inside Diameter	Pitch	Coil Diameter
Units	mm	mm	mm	mm
coil-1	9.525	7.8994	30	
coil-2	7.9248	6.2992	30	210
coil-3	4.7498	3.2512	30	

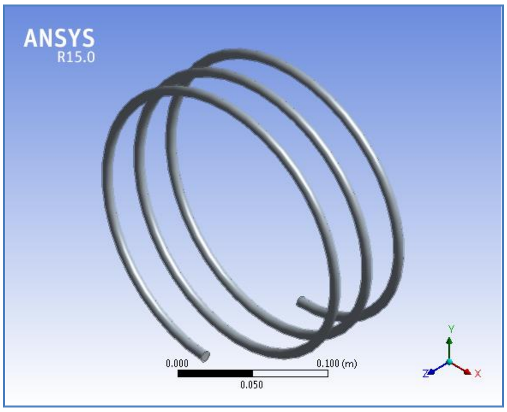

Fig.no 2.1 Geometric model.

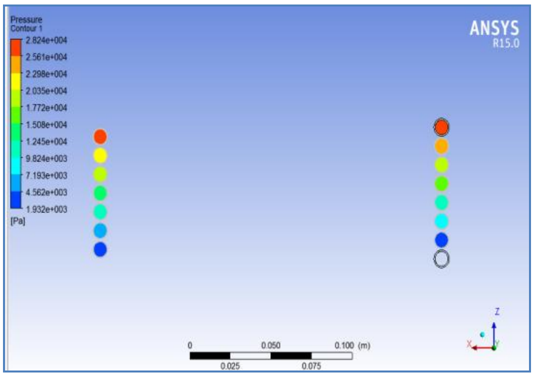

Fig.no 2.2 CFD results

Table No 2.4 CFD Results

Flow rate	30 mm pitch			30 mm pitch		
	Temperature drop[K]			Pressure Drop[Pa]		
	3_8	5_16	3_16	3_8	5_16	3_16
180	9	12	15	2040	2238	2962
200	7	10	14	6549	6943	8338
260	6	10	13	6424	7182	9981
305	5	8	12	8713	9937	14483
340	5	8	11	8451	9946	15539
400	4	7	11	15534	17428	24423
420	4	7	10	21901	24008	31708
460	3	6	9	22212	25851	31642

Table 2.4 shows the CFD results for temperature drop and pressure for various tube diameter configurations with constant pitch and pitch coil diameter as data shows that there is increase in temperature drop as the tube diameter goes on reducing whereas pressure drop goes on increasing.

3. RESULTS AND DISCUSSION.

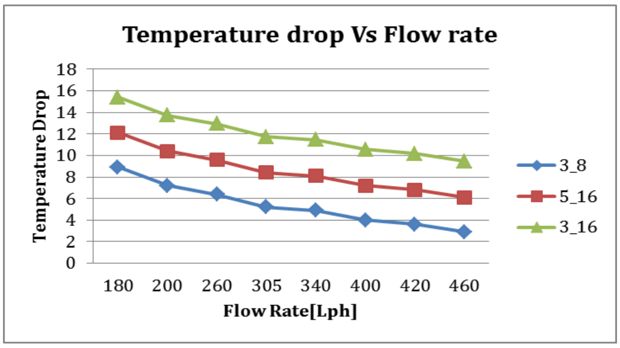

Figure no 3.1 Temperature drop vs flow rate for various tube diameter.

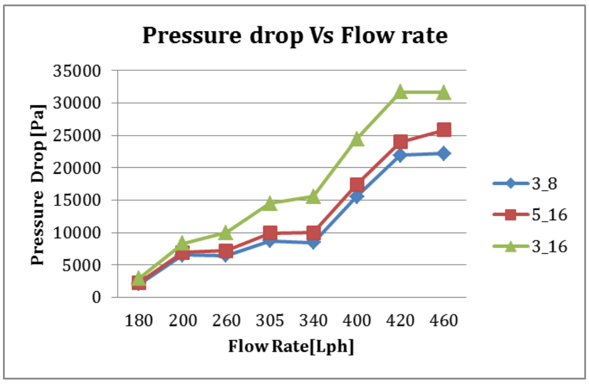

Figure no 3.2 Pressure drop vs flow rate for various tube diameter.

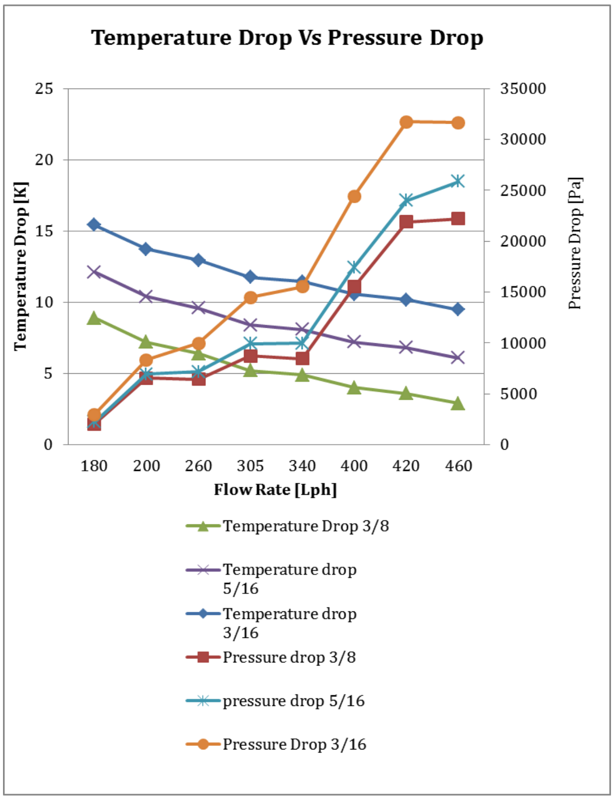

Figure no 3.3 Temperature drop & Pressure drop vs flow rate for various tube diameter.

Figure no 3.1 ,3.2 and 3.3 shows the temperature drop and pressure drop Vs flow rate rate for tube with 3/8 inches ,5/16 inches and 3/16 inches diameter.

As in Figure 3.1 we can observe that nature of curve is same for all tube dimension. Temperature drop goes on reducing as the flow rate goes on reducing. Figure 3.2 shows the pressure drop goes on increasing as the flow rate increase.

Figure 3.3 show combine temperature and pressure drop vs flow rate for different tube diamter. Its is been observed that temperature and pressure drop is optiumun at fkow rate between 300 lph to 350 lph.

4. CONCLUSIONS

Heat transfer characteristics of the heat exchanger with helical coil are also studied using the CFD code. Analysis has been carried out both for the constant wall temperature and constant wall heat flux boundary conditions. Fluid particles are found to undergo oscillatory motion inside the pipe and this causes fluctuations in heat transfer rates. Studies have been carried out by varying pipe diameter with constant pitch circle diameter and pitch. Their influence on 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. It was observed that the variation in tube diameter has greater influence on temperature drop and pressure drop. As the tube diameter goes on reducing the temperature drop increased along with loss of pressure also takes place i.e. pressure drop occur due to which pumping power increases. Temperature drop is maximum for lower flow rate and goes on reducing as the flow rate increases. Whereas pressure drop is directly proportional to flow rate. Optimum range for flow rate of water through helical coiled tube is 300 lph to 350 lph.

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BIOGRAPHIES

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