Comparative Study of a Helical Coil Heat Exchanger by Using CFD

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Abstract— Enrichment of heat transfer rate due to helical coil heat exchanger has been reported by many researchers. Helically coiled heat exchangers are used in order to obtain a large heat transfer area per unit volume and to increase the heat transfer coefficient on the inside surface. This paper deals with the PCD analysis of helical coiled tubular heat exchangers by CFD simulation. Because the geometry is very important factor to enhance heat and mass transfer for any type of heat exchanger. The results are validated by the results obtained by Mr. Shiva Kumar and Mr. K. Vasudev Karath's research, And CFD results are also compared with the result obtained by the simulation of helical coil tubular heat exchanger of the same length and different pitch circle diameter over single mass flow rate underneath identical boundary condition taking by Mr. Shiva Kumar. Results determined that as we increase PCD from 40 to 60 pressure drop is decreasing due lesser centrifugal force on fluid particles hence the heat transfer rate is also decreased.

Key words: Helical coil heat exchanger, PCD, CFD or computational fluid dynamics and ANSYS 14.5

I. INTRODUCTION

Many researches shows that helical coil heat exchanger are preferable to straight tube heat exchanger when employed in heat transfer applications. Flow through a helical coiled tube has observed wide applications including power plants, refrigeration and air conditioning equipment, chemical and food processing industries. Fluid flowing through a coiled tube will experience a centrifugal force. As a result of this it induces a secondary flow in the tubes. This secondary flow in the tubes has significant ability to increase the heat transfer. Because of the secondary flow consisting of two vortices perpendicular to the axial flow direction the heat transfer will occur not only by diffusion in the radial direction but also by convection. Contributions of this secondary convective transport dominate throughout the overall process and enhance the rate of heat transfer per unit length of the tube.

The first approximation of steady motion of incompressible fluid flowing through a coiled tube was investigated by (Dean W.R, 1927). It was observed that reduction in the rate of flow due to the curvature depends on the variable $k = 2\frac{Re2r}{R}$ for low velocities and small values of $\frac{r}{R}$. He concluded that the flow in curved pipes is more stable than flow in a straight pipe. **Mr. Shiva Kumar, K. vasudev karanth (2013)** have worked on both straight tube and helical tube heat exchanger. They saw that temperature drop for helical coiled heat exchanger is higher than the straight tube heat exchanger. This is because of curvature effect of the helical coil. Fluid flow in the outer layer of the pipe moves faster than the fluid flow in the inner layer. This dissimilarity in the velocity will lay in a secondary flow by which heat transfer will be increased. **[1], Fakoor, et.al (2013)** studied the pressure drop feature of nano fluid passes inside a vertical helical coiled tube for laminar flow state. Experiments were conducted by differencing the pitch circle diameters and also the tube diameters Results shows that using helical tubes instead of straight tubes increases the pressure drop very rapidly. **[2], S.D.Sancheti., DR. P.R.suresh (2012)** carried out that the use of constant values for the thermal and transport properties of the heat transport medium results in projection of inaccurate heat transfer coefficient. Also for projection of heat transfer in a condition of fluid-to-fluid heat transfer ,as it occurs in the case in a heat exchanger, arbitrary boundary situation such as constant wall temperature constant heat flux are not applicable. In this condition it is essential to model the equipment considering conjugate heat transfer. **[3], Pramod purandare (2012)** studied that a comparative analysis of the different correlations given by different researchers for helical coil heat exchanger. They distinguish that the helical coils are efficient for low Re. Also the proportion of tube diameter to coil diameter should be large enough for large intensities of secondary fluid run inside the tubes. **[4], Ivaan Di piazza (2010)** deals with computational results for turbulent flow and heat transfer along curved pipes. Nusselt number and pressure drop were calculated by using different turbulent models. Out of those RSM-ω gave better results when compared to the other models in the projection of nusselt number and heat transfer. **[5], J.S.jayakumar (2008)** carried out an experimental study of fluid to fluid heat transfer though a helical coiled tube. Heat transfer characteristics were also studied using CFD code fluent. They observed CFD predictions match reasonably with experimental results for all operating conditions. **[6], Rahul Karath, Nitin Bhardwaj, R.S. Jha (2009)** has deals with the geometry of the heat exchanger. And worked with improving a correlation for heat transfer coefficient for stream between concentric helical coils. They have increase the gap between concentric coils when compared with the experimental results data. And found that coil gap and tube diameter is the most important parameters for the heat transfer coefficient. **[7], Spindle DigVijay D, Dange H.M. (2013)** Studied with the experimental evaluation of cone structured helical coil heat exchanger. The comprehensive conclusions belonging to the comparative analysis between the cones structured coil & simple helical coil are presented. It is found that the inner Nusselt number, Convective heat transfer coefficient and overall heat transfer coefficient increases when the coil side fluid flow rate increases. From comparative experimental analysis for the conical coil &simple helical coil it is found that the inner Nusselt number, convective heat transfer coefficient & overall heat Transfer coefficient is higher in case of conical coil than that of simple helical coil. From comparative experimental Analysis, it is observed that the effectiveness of heat exchanger is on higher side in conical coil than that of simple helical coil. It was observed that the heat transfer rates are 1.18 to 1.38 times high for the cone shaped helical coil than that of simple helical coil. [**8], R. Thundil Karuppa Raj, Manoj Kumar S., Aby Mathew C. (2014)**

has studied on helical coil heat exchanger usind cfd and found that the heat removed is directly proportional to the Nusselt number, (i.e.) as the Nusselt number increases the heat removed from the working fluid also increases and for the same Dean numbers. **[9], Revendra Verma, Hitesh Kumar (2014)** has study and deals with temperature of the wall and shows the effect on the heat transfer rate, with the helical coil pitch analysis of helical coil heat exchanger with specific data. In this paper, also comparison the thermal characteristics i.e. heat transfer rate and inside heat transfer coefficient in existing experiment and simulation with CFD software. **[10], R. Thundil Karuppa Raj, Manoj Kumar S., Aby Mathew (2014)** numerical analysis of helical coil heat exchanger using CFD techniques deals with CFD investigation was carried out to study the heat transfer enhancement characteristics of air flow inside a circular tube with a partially decaying and partly swirl flow efforts are taken to optimize the helically coiled tube with respect to heat transfer and flow parameters for various coil pitch. Analysis of heat exchanger is done using conjugate heat transfer. The 3-dimensional flow through the helically coiled tube is considered which would overcome the anisotropic flow properties that would arise due to complex turbulence phenomenon and flow deviations. **[11], Mohammed Abu Elazam, Ahmed Ragheb, Ahmedd Elsaty, Mohammed Teamah (2012)**computational Analysis for the effect of the tapper angle and helical pitch on the heat transfer characteristics of the helical coils and found that change in angle changes the effect of heat transfer. [**12], Sajid Hussein Ali Al – Abbasi, (2014)**studies with CFD analysis of enhancement of turbulent flow heat transfer in a horizontal circular tubes with different inserts. [13], In the present paper a helical coil heat exchanger was modelled and simulated using computational fluid domain for cooling hot water by applying fixed wall temperature boundary conditions. Heat transfer parameters like temperature drop, Nusselt number, pressure drop, and heat transfer rate heat transfer coefficient were calculated. Simulation results were compared with the analytical results using the correlations developed by different researchers. Also the simulation results of the helical coil were compared with the results obtained by **Mr. Shiva Kumar and K. Vasudev.**

II. GEOMETRY AND PARAMETERS OF HELICAL COIL

The geometry of the helical tube or coil of Experimental Setup is shown in Fig.1; the bottom radius of curvature is denoted (R), the pipe diameter (d), the helical pitch circle diameter as (D), the straight height (h),coil pitch (increase of height per rotation, p).

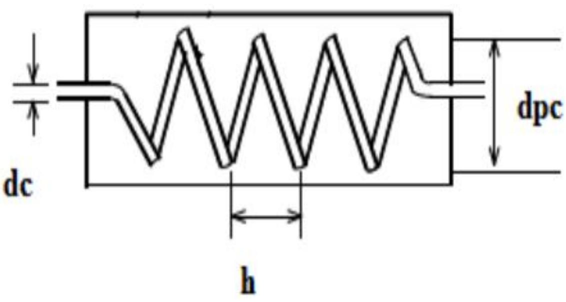

Fig. 1: Helical coil heat exchanger geometry

S.NO.	Dimensional parameters	Dimension
1	Pitch circle diameter	40mm,50mm,60mm
2	Tube diameter	10mm
3	Tube length	1000mm
4	Tube pitch	15mm
5	Working fluid	Water
6	Constant wall temp.	293k
7	Average hot water temp.	332k
8	Mass flow rate	0.02kg/sec

Table 1: Dimensional & operating parameters of the helical coil heat exchanger

III. NUMERICAL SIMULATION

For numerical solution choosing the solver for the problem from Pressure Based and density based solver using Fluent cade (14.5).the governing equations are partial differential equations for mass momentum and energy are solved for steady state flows. Velocity pressure coupling is carried out using the Pressure Implicit with Splitting of Operators (PISO) algorithm. Using second order upwind scheme for discretization. All equations are presented in Cartesian tensor notation.

This section is a summary of the governing equations used in CFD to mathematically solve for fluid flow and heat transfer, based on the principles of conservation of mass, momentum, and energy.

A. Conservation Equations:

The conservation laws of physics form the basis for fluid flow governing equations (previously listed as Equations 1-3 in Section 2.1: Governing Equations and Numerical Schemes). The laws are:

1) Law of Conservation Of Mass:

Fluid mass is always conserved. (Equation 1)

$$\frac{\partial(\rho u_i)}{\partial x_i} = 0. \quad (1)$$

2) Newton's 2^nd^ Law:

The sum of the forces on a fluid particle is equal to the rate of change of momentum. (Equation 2)

$$\frac{\partial}{\partial x_i}(\rho u_i u_j) = \frac{\partial}{\partial x_i}\left(\mu \frac{\partial u_j}{\partial x_i}\right) - \frac{\partial p}{\partial x_j}. \quad (2)$$

3) First Law of Thermodynamics:

The rate of head added to a system plus the rate of work done on a fluid particle equals the total rate of change in energy. (Equation 3)

$$\frac{\partial}{\partial x_i}(\rho u_i T) = \frac{\partial}{\partial x_i}\left(\frac{k}{C_p}\frac{\partial u_j}{\partial x_i}\right). \quad (3)$$

The fluid behaviour can be characterised in terms of the fluid properties velocity vector u (with components *u*, *v*, and *w*in the *x*, *y*, and *z* directions), pressure *p*, density *ρ*, viscosity *μ*, heat conductivity *k*, and temperature *T*. The changes in these fluid properties can occur over space and time. Using CFD, these changes are calculated for small elements of the fluid, following the conservation laws of physics listed above. The changes are due to fluid flowing across the boundaries of the fluid element and can also be due to sources within the element producing changes in fluid properties. This is called the Euler method (tracking changes in a stationary mass while particles travel through it) in contrast with the Larangian method (which follows the movement of a single particle as it flows through a series of elements).

IV. CFD MODELLING OF HELICAL COIL HEAT EXCHANGER

The 3d model of the helical coil was carried out by using unigrafics Nx-7.5 and exporting to the parasolid format .X_T. Tubes of diameter 10mm, pitch circle diameter 40 mm, 50 mm, and 60 mm was created by sweep tool with approximated length 1000mm.this part indicated solid wall and hollow portion of the tube and then import in the ansys fluent14.5.the three dimensional domain modelled using fine grid mesh for all model as shown in fig 1, 2 and 3. Fine grid independence test was performed to check the validity of the quality of the mesh on the solution. Now parameter and boundary conditions was imposed on the wall of the tube. Fluid is made to cool down as it flows down as it flows along the tube by specify wall temperature of 293k. At the tube outlet, a pressure outlet boundary is enforced. Conservation equation were solved for controlled volume to yield the velocity and temperature fields for the water flow in coil. CFD analysis was carried out using realizable k-ε model with standard wall functions.

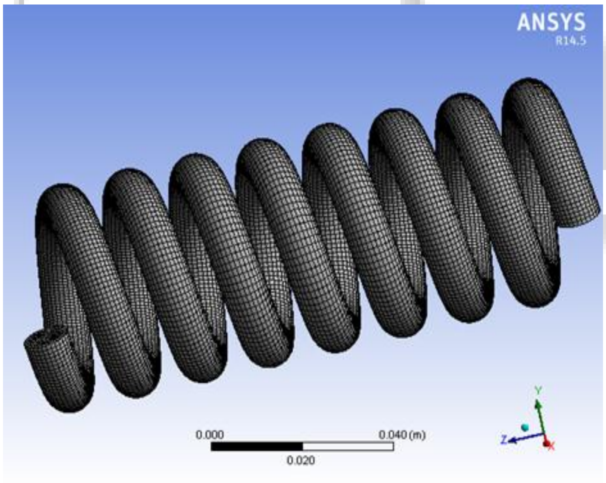

Fig. 2: Meshed model PCD 40mm

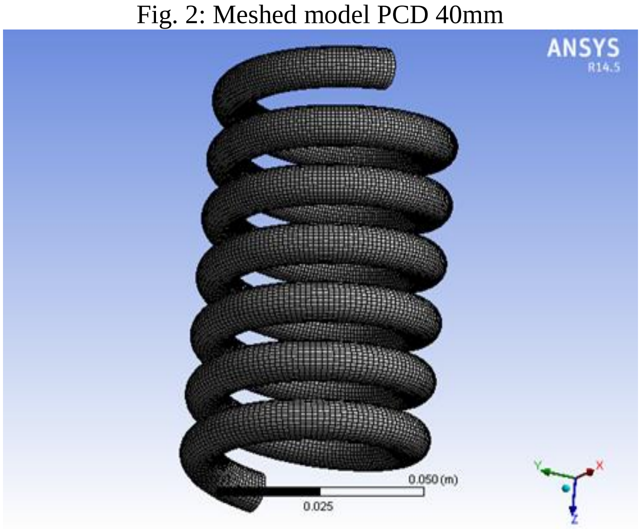

Fig. 3: Meshed model PCD 50mm

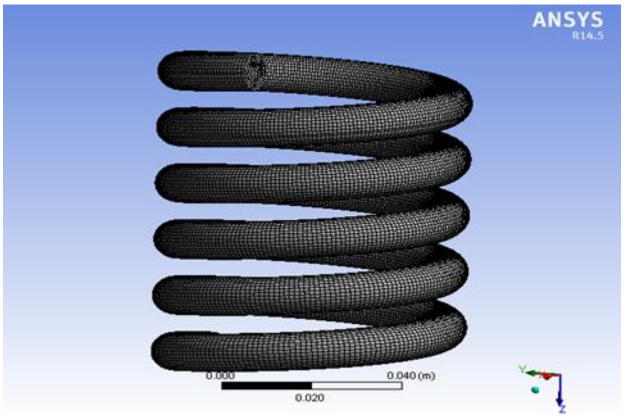

Fig. 4: Meshed model PCD 60mm

V. RESULT AND DISCUSSIONS

CFD computations were done for a mass flow rate 0.02 kg/s for different pitch circle diameters 40mm, 50mm and 60mm respectively.as pitch circle diameter increases there is decrease in pressure drop and heat dissipation rate decreases because of curvature effect.as curvature ratio decreases centrifugal force decrease which effects the heat transfer rate.it is clearly shown into the graph as pitch circle diameter increases curvature effect on the helical coil heat exchanger decreases.

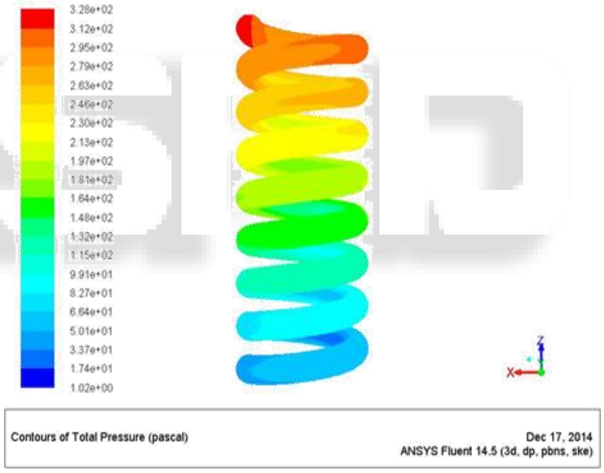

Fig. 5: Total pressure for PCD 40mm

Fig. 6: Total pressure PCD 50mm

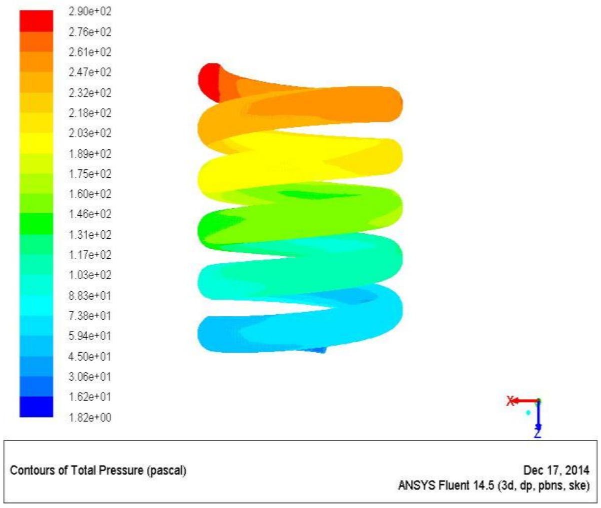

Fig. 7: Total pressure for PCD 60mm

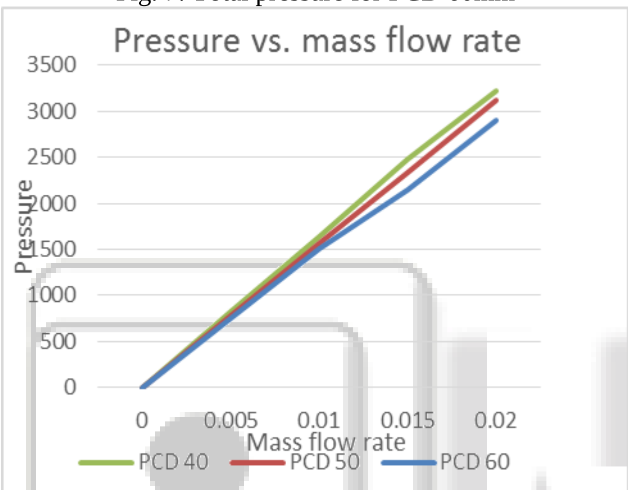

Fig. 8: Mass flow rate vs. pressure drop

Fig 8.Shows pressure vs. mass flow rate graph as pitch circle diameter increases there is decrease in total pressure due to lesser centrifugal force which affect the heat dissipation rate hence the heat transfer rate is also decreased. Variation of temperature due to pitch circle diameter 40mm and 60mm shown in images.

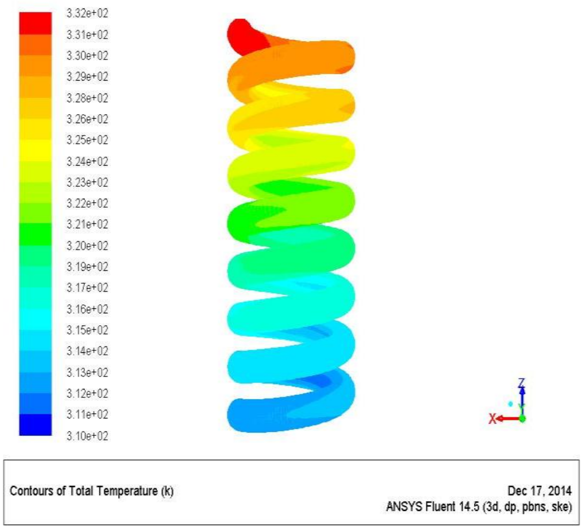

Fig. 9: Total temperature for PCD 40 mm

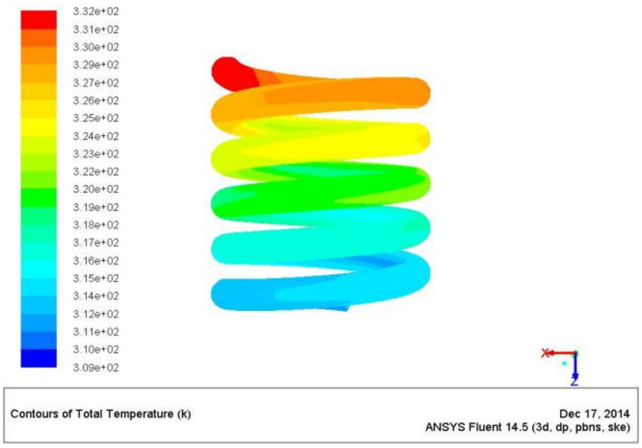

Fig. 10: total temperature for PCD 60mm

The effect of temperature drop clearly shown in to the heat transfer coefficient.

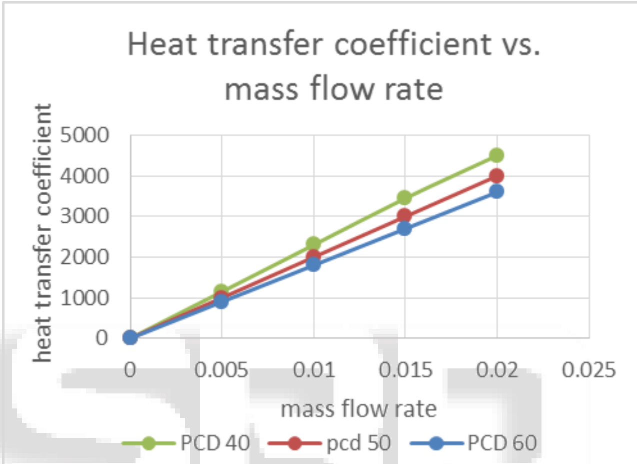

Fig. 11: the variation of heat transfer coefficient for different PCD at varying mass flow rates. As expected heat transfer rate is proportional to the mass flow rate. From graph it is revealed that as mass flow increases heat transfer coefficient also increases.

VI. CONCLUSION

In the present work computational fluid dynamic analysis for a helical coil heat exchanger was carried out and the results of heat transfer parameters have been compared with the Mrs. Shiva Kumar's research under similar operating conditions and different geometrical conditions like different pitch circle diameters and a mass flow rate. CFD results are validated by the correlations used by the Shiva Kumar and different researchers. There was close agreement between the CFD predicted and correlation results. Simulation results shows that while we increase the PCD from 40 to 60 pressure drop is decreasing due lesser centrifugal force on fluid particles hence the heat transfer rate is also decreased. Heat transfer rate, pressure drop, Nusselt number and heat transfer coefficient are higher in case of increased PCD in identical conditions.

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