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Numerical Analysis of Heat Transfer Enhancement in Pipe-in-Pipe Helical Coiled Heat Exchangers

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Abstract: *These paper focuses on the effect of the inside tubes at constant value of mass flow rate and variation of annulus mass flow rate on effect of Dean Number and overall heat transfer coefficient with constant wall temperature, CFD analysis of a helically coiled heat exchanger. Also deals with the effect of Dean Number with respect to Reynolds Number and Nusselt Number and Overall Heat Transfer coefficient on change of coil configuration of helically coiled tube. The particular difference in this study in comparison with the other similar studies was the boundary conditions for the helical coils. The results indicate that with the decrease the inner coil diameter, the overall heat transfer coefficient is increased.*

Keywords: *Computational Fluid Dynamics, Dean Number, Heat Transfer Correlation. , Helical Coil Heat Exchanger, Nusselt Number.*

I. INTRODUCTION

Helical coils heat exchangers are the most innovative and important types of heat exchanger, because of compact in area and high heat transfer rate. If we are comparing to other types of heat exchanger likes shell and tubes, plate types, etc., but in helical coil heat exchanger have compact in area and they resists high pressure. So many researchers are research on helical coil heat exchanger, they also comparing with other types of heat exchanger; they found helical coil heat exchangers are higher heat transfer coefficient.

Eustice was observed in curved pipe on fluid motion in 1911. Since then numerous studies have been arises on the flow fields in curved pipe by many researchers like Dean (1927, 1928), White (1929), Horlock (1956), Barua (1962), Austin and Seader (1973). Rustum and Soliman were observed the investigation the performance of heat exchanger through CFD in 1990. Shah (2000) was also analyzed vertical mantle types of heat exchanger. Heat transfer coefficients for parallel and counter flow arrangement in a double pipe helical coil heat exchanger were determined experimentally and numerically by Timothy et. al. (2006). they have used ANSYS CFD package PHOENICS 3.3 to carry out the numerical studies. There are so many researches research on fluid flow over helical coil tubes heat exchanger. Fakoor, et.al, has analyzed on coil configuration of vertical helical coil under pressure drop characteristics of Nano fluid flow, they found that helical tubes instead of straight tubes increases the pressure drop exponentially. Pramod Purandare, et al, has carried out at different correlations given by different researchers for helical coil. They found that the helical coil tubes are efficient for low Re. J.S Jayakumar, et. al, also carried out an experimental study and CFD studies on fluid to fluid heat transfer coefficient though a helical coiled tube. They found that CFD predictions values are much reasonably with experimental results for all operating conditions. CFD analysis for turbulent flow and heat transfer on curved pipes has done by Ivaan Di Piazza, et. al. .

After studies on CFD and literatures we found that K- ε model in turbulent; gave better results as compared to the other models in the prediction of nusselt number and overall heat transfer coefficient (OHTC). Basically a study on helical coil tubes has been carried out on heat transfer characteristics of fluid-to-fluid flowing in pipe-in-pipe helical coil heat exchanger (PPHCHE). In helical coil have lot of variation in coil configurations such as pitch circle diameter, coil diameter and pitch variations, curvature ratio so on. The objective of this work is to effect of dean number and surface heat transfer coefficient at different flow parameters at different temperature.

II. NUMERICAL SIMULATION OF PIPE-IN-PIPE HELICAL COIL HEAT EXCHANGER

1.1. Physical model

The heat exchanger was constructed from copper. The outer tube of the heat exchanger has an inner diameter of 16 mm and a wall thickness of 1 mm. The inner tube has a 6 mm and 8 mm diameter and wall thicknesses of 1 mm, which were constructed from standard copper tees and reducers. Coil has a radius of curvature (measured from the center of the inner tube) of 170 mm. Small holes were drilled in the outer tube and tapped so that set screws could be used to ensure that the inner tube was centered prior to the final soldering of the end connections, which then held the inner tube in place.

After soldering the set screws were removed and the holes covered so that the fluid flow in the annulus would not be disturbed. The heat exchanger consisted of one loop. The objective of this work was to determine the heat transfer characteristics for a pipe-in-pipe helical heat exchanger by varying the size of the inner tube and the mass flow rates in both the annulus and in the inner tube. These objectives were carried out for both parallel flow and counter-flow heat exchangers. A computational fluid dynamics package (fluent 14.0) was used to predict the flow and temperature profiles in a double-pipe helical heat exchanger.

1.2. Geometry Creation and Mesh generation

A helical pipe of inner tubes diameter 6 mm and 8 mm and annulus inner diameter 16 mm with 1 mm thickness and 6 turns was used as the geometry. A 3-D geometry is created by using ANSYS workbench and schematic view is shown in the Fig. 2. Structured meshing method is used for meshing the geometry. It is meshed into 507740 nodes and 485982 elements as shown in figure 3;

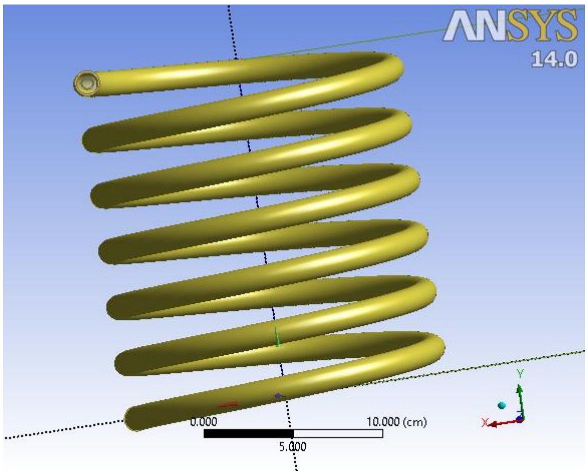

Figure: 2– Pipe-in-pipe helical coil tubes geometry created in Ansys workbench

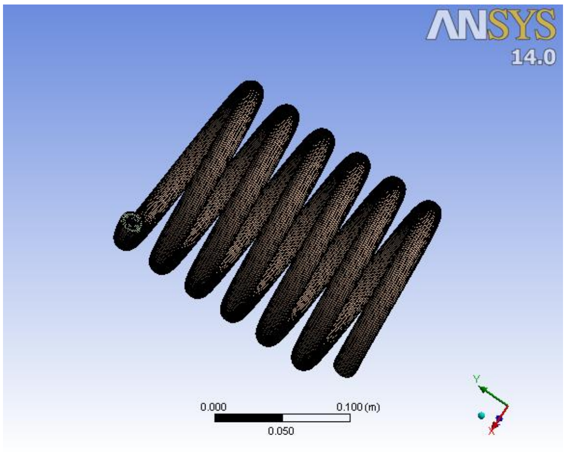

Figure: 3 – Meshing of pipe-in-pipe helical coil tubes geometry

1.3 Fluent Setup

Numerical simulations were carried out using the Commercial CFD software package ANSYS FLUENT 14.0. The first step taken after importing the mesh geometry into FLUENT involves checking the mesh/grid for errors. Checking the grid assures that all zones are present and all dimensions are correct. Once the grid was set, the solver and boundary conditions of the system were then set and cases were run and analyzed.

1.4. Defining the Material Properties

This section of the input contains the options for the materials to be chosen. Water is passing in the pipe-in-pipe helical coil tubes under constant wall temperature condition in the present work. Under materials Tab in FLUENT, fluid considered is water -liquid. Solid (tube wall) material considered for analysis is copper. The selection of material is done. Material selected is water-liquid. The properties of water- liquid is taken as follows:

S.No.	properties	Value
1	Density, ρ	998.2 kg/m^3
2	Specific heat, C_p	4182 J/kg K
3	Thermal conductivity	0.6 W/m K
4	Viscosity, μ	1.003 x 10^{-3} kg/m s

Table.1. properties of water

S.No	properties	Value
1	Density, ρ	8978 kg/m^3
2	Specific heat, C_p	381 J/kg K
3	Thermal conductivity	387.6 W/m K
4	Viscosity, μ	0.001kg/m s

Table.2. properties of Copper

1.5. Boundary Conditions

Water at 333K was used as the working fluid at inlet temperature of inner tubes. The numerical studies were carried out with uniform mass flow rate at the inlet of the pipeline.

Outflow boundary condition was used at pressure-out let boundary. The wall of the helical coils was assumed to be perfectly smooth with zero roughness height and stationary wall, no slip condition. A constant wall temperature has define through the inlet temperature of hot water in inner pipe, 333K was used at the wall boundary.

Mass flow rate- Inlet Boundary: Inlet condition was taken for the pipe-in-pipe helically coil tubes in inner pipe and the mass flow rate values are varying as 0.028 to 0.112 kg/s. Initial gauge pressure was taken as zero Pascal. Inlet temperature of hot water was taken as 333K at all mass flow rate condition. Inlet section of annulus was also varying the mass flow rate as 0.028 kg/s to 0.112 kg/s at same temperature of inner section inlet temperature. Those conditions were taken parallel flow as well as counter flow.

1.6. Numerical Solution Strategy

The commercial CFD solver FLUENT 14.0 was used to perform the simulations, based on finite volume approach to solve the governing equations with a segregated solver. The second-order upwind scheme was used for discretization of convection terms, energy, and turbulent kinetic and turbulent dissipation energy. This scheme ensures, in general especially for tri or tetrahedral mesh flow domain, satisfactory accuracy, stability and convergence.

Simple algorithm was used to resolve the coupling between mass flow and pressure fields. The convergence criterion is based on the residual value of calculated variables such as mass, velocity components, turbulent kinetic (k), turbulent dissipation energies (ε), and energy. In the present calculations, the initial residual values were set to 10^{-6} for all variables is used. The under-relaxation factors used for the stability of the converged solutions are set at their default values. The numerical simulation was decided as converged when the sum of normalized residuals for each conservation equation and variables was less than the set residual values. The total number of simulations performed was 64 (2 tube diameters x 4 inner flow rates x 4 annulus flow rates x 2 flow directions). The output of the simulations included the inlet and outlet velocities, mass flow rates and enthalpy rates, as well as velocity, pressure, and temperature fields at 30 specified cross-sections.

1.7. Executing the FLUENT Code

Each case must be initialized before the FLUENT code begins iterating towards a converged solution. In this study, the option chosen for initialization was to compute from inlet zones. The number of iterations ranged between 500 and 1000 depending on the case being run and how long it took to converge. Iterations were performed with the default under- relaxation factors for all parameters.

III. RESULTS AND DISCUSSION

From fig. 4 and 5 shows that in both cases have overall heat transfer coefficients that are nearly similar, for the same given flow rates. The ratio of the overall heat transfer coefficients (parallel flow divided by counter-flow) for a give case range from 0.25 to 1, with the majority of the ratios slightly unity, in favor of the counter-flow. The overall heat transfer coefficients increase with increasing inner Dean Number. However, the significance of the increase is a function of the ratio of the mass flow rates. As can be seen in Figure 6, the ratio of the mass flow rates has a significant effect on the overall heat transfer coefficient, raising the overall heat transfer coefficient when the flow rate in the annulus is increased.

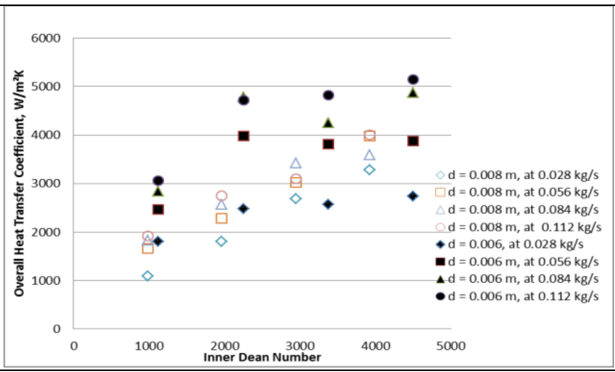

Fig.: 4 Overall heat transfer coefficient versus the inner Dean number in parallel flow.

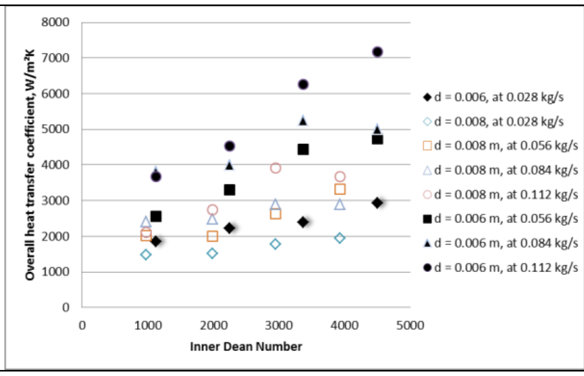

Fig.: 4. Overall heat transfer coefficient versus the inner Dean number in Counter flow.

From above figure, it can be shown that increasing the inner Dean number has a greater effect on the overall heat transfer coefficients when the inner flow rate is higher. When flow rates are increased, the overall heat transfer rate will also increase, but the significance of the increase is highly dependent on the annulus flow rates. There is a difference between the overall heat transfer coefficients for the two different tube sizes. There are a couple of reasons why this difference has been observed.

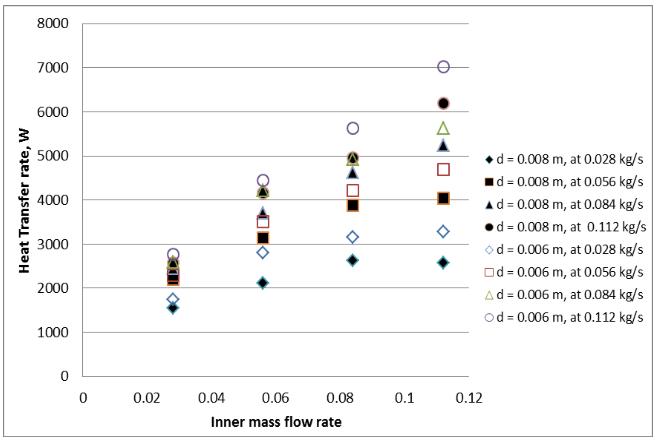

Fig. - 6 Heat transfer rate verses Inner mass flow rate in parallel Flow

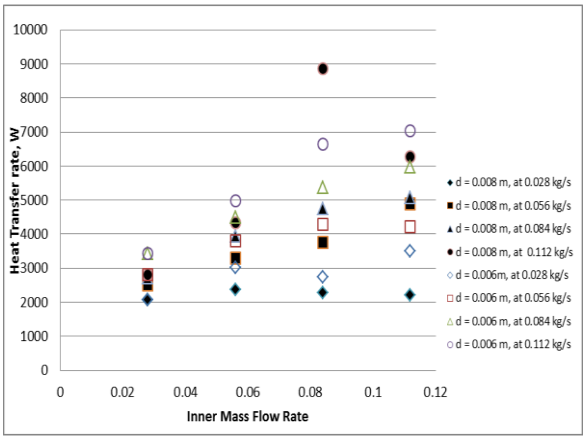

Fig.-7 Heat transfer rate verses Inner mass flow rate in Counter Flow

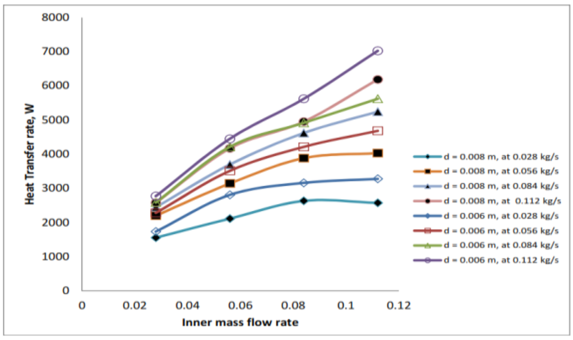

Fig.- 8 Figure: Heat transfer rate verses Inner mass flow rate

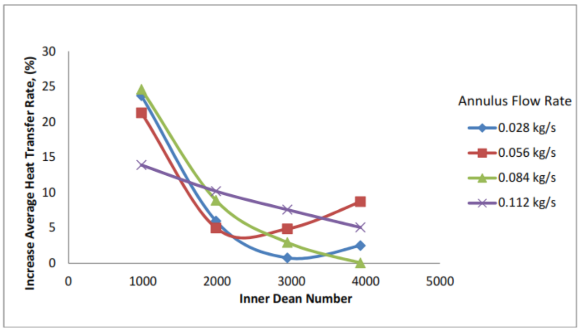

Fig.-9 Percentage increases in heat transfer when comparing parallel and counter flow verses inner Dean Number

Figure 8 and figure 9 shows the relationship between the heat transfer rate and the mass flow rate in the inner tube for the case of parallel flow and counter flow. The data points are also indicated into the four different mass flow ratios and the two different tube sizes. This allows for a more intuitive understanding of the effectiveness of the different mass flow ratios and tube sizes on the heat transfer rate than the plots of heat transfer coefficients versus the inner Dean number. For any given inner mass flow rate, there are eight different values, corresponding to the different combinations of mass flow rates and tube sizes. Increasing the tube size resulted in a decrease in the total heat transfer rate. Furthermore, increasing the tube size decreases the cross-sectional area for fluid flow in the annulus, resulting in an increased flow velocity, opposite to that found in the inner tube.

1.2. **Inner Nusselt numbers**

The inner Nusselt numbers are presented in Figure 10 and figure 11. These values are the average inner Nusselt number at each Dean number (average of parallel flow and counter-flow values). The data are compared to the correlation of Manlapaz- Churchill correlation (1981). Manlapaz- Churchill correlation (1981) developed their correlation based on numerical data with a constant wall temperature. In order to calculate these correlations, Prandtl numbers were essential for the flow. These were evaluated using the arithmetic mean temperature of the corresponding fluid (average of inlet and outlet temperatures). Decent agreement between the experimental and literature values indicate that the use of existing correlations for heat transfer in helical coils could be used to estimate inner heat transfer rate in a pipe-in-pipe helical coil heat exchanger.

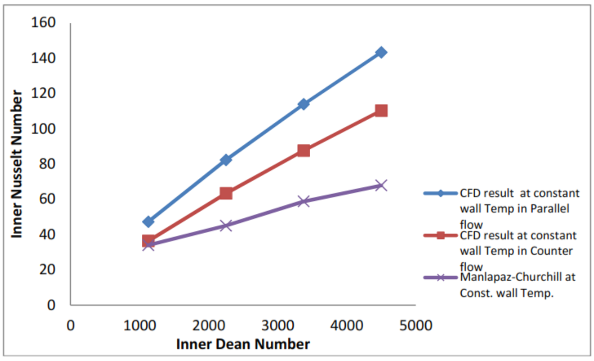

Fig.-10 Inner Nusselt Number verses Inner Dean Number of Small coil

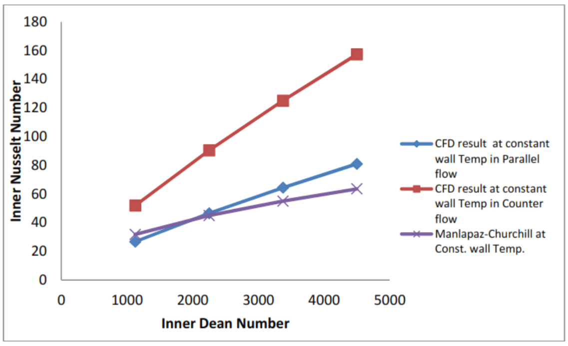

Fig.-11 Inner Nusselt Number verses Inner Dean Number of Large coil

IV. CONCLUSION

A computational fluid dynamics package (Fluent-14.0) was used to numerically investigation to the heat transfer characteristics of a pipe-in-pipe helical heat exchanger for both parallel flow and counter-flow. Validation runs were performed with the boundary conditions of constant wall temperature. After the analysis of pipe-in-pipe helical coil heat exchanger; some conclusion are found:

1. Overall heat transfer coefficients were calculated for inner Dean Numbers. The results show an increasing overall heat transfer coefficients as the inner Dean number is increased; however, flow conditions in the annulus had a stronger influence on the overall heat transfer coefficient.
2. Overall heat transfer coefficient of the small coil diameter is higher in both flow (parallel and counter flow) conditions with high velocity.
3. Increasing the tube size result is to be found decrease in the total heat transfer rate.
4. The inner Nusselt numbers are shows that the slightly difference between the parallel flow condition of the large coil but in small coil condition the value is very high.
5. All the studies have found in counter flow configuration is much better then in parallel flow configuration.
6. Further work needs to be done to quantify this effect on coil configurations.

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