A Review on the Comparison of Rate of Heat Transfer for Helical Coil Heat Exchanger at Multiple Cross-Section using CFD

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Abstract - Enhancing the heat transfer by the use of helical coils has been studied and researched by many researchers, because the fluid dynamics inside the pipes of a helical coil heat exchanger offer certain advantages over the straight tubes, shell and tube type heat exchanger, in terms of better heat transfer and mass transfer coefficients. Various configurations of coil structure are possible, and the configuration in which there is a series of vertically stacked helically coiled tubes is the most common type. This configuration offers a high compact structure and a high overall heat transfer coefficient; hence helical coil heat exchangers are widely used in industrial applications such as power sector, nuclear power generation, food processing plants, heat recovery systems, refrigeration, food industry, industrial HVACs etc. Convective heat transfer between a surface and the surrounding fluid in a heat exchanger has been a major issue and a topic of study in the recent years. In this particular study, an attempt has been made to analyse the effect of Rate of heat transform from a three different cross-sections on the helical tube, where the hot fluid flowing in tube and outer surface of tube having less temperature then hot fluid. Different cross-sections of the pipes are taken into consideration while running the analysis. The contours of pressure, temperature, velocity magnitude and the mass transfer rate from the tubes were calculated and plotted using ANSYS FLUENT 14.5 where the governing equations of mass, momentum and energy transfer were solved simultaneously, using the k-Ɛ two equations turbulence model.

The fluid flowing through the tube was taken as water. Fig. 4.1.1 to 4.1.4 the pressure, velocity, temperature and turbulent dissipation rate is varying with position in given range. The numerical simulation of circular cross-sections calculating the value of mass flow rate is 7.018×10^{-5} kg/s. Similarly Fig. 4.2.1 to 4.2.4 showing the pressure, velocity changes, Temperature variation, turbulent dissipation rate in small ranges and further calculating value of mass flow rate is 1.113×10^{-6} kg/s. Through Fig. 4.3.1 to 4.3.4 getting the value of mass flow rate is 3.793×10^{-6}kg/s. Therefore it is observed that mass flow rate value higher in case of circular cross-sections compare than other two geometric. We know from earlier literature that the increasing in mass flow rate increases the effectiveness and overall thermal conductance of heat exchangers. Hence it may also say that circular cross-section type heat exchanger will give better results in all manners. The losses in pipes and manufacturing irregularities have not been taken in to account.

In present case it may be concluded that mass flow rate of circular cross-section is better than other two geometric configurations.

I. INTRODUCTION

Heat exchange among flowing fluids is one of the mainly physical process of concern, and a selection of heat exchangers are used in unlike type of installations, as in process industries, compact heat exchangers nuclear power unit, Heating Ventilation Air Conditions, food processing, refrigeration, etc. The purpose of constructing a heat exchanger is to get a proficient way of heat transfer from one fluid to another, by direct contact or by indirect contact. The heat transfer occurs by three principles: conduction, convection and radiation. In a heat exchanger the heat transfer through radiation is not taken into consideration as it is small in comparison to conduction and convection. Conduction takes place when the heat flow from the high temperature fluid flows through the adjacent solid wall. The conductive heat transfer can be maximized by taking a least thickness of wall of a highly conductive material. But convection is acting the key role in the performance of a heat exchanger. Forced convection in a heat exchanger transfers the heat from one flowing stream to other stream through the wall of the pipe. The cooler fluid removes heat from the hotter fluid as it flows along or across it.

heat exchangers are generally built of circular tubes ,although elliptical, rectangular or round/flat twisted tubes have also been used in some applications. There is considerable flexibility in design because the core geometry can be varied easily by changing the tube diameter, length, and arrangement. Tubular exchangers can be designed for high pressures relative to environment and high pressure differences between the fluids. Tubular exchangers are used primarily for liquid to liquid and liquid to phase change (condensing or evaporating) heat transfer applications. There are also used for gas to liquid and gas to gas heat transfer applications primarily when the operating temperature and pressure is very high or fouling is a severe problem on at least one fluid side and no other types of exchangers work. These tubular exchangers may be classified as shell-and-tube, double-pipe, and spiral tube heat exchangers. There are all prime surface exchangers except for exchangers having fins.

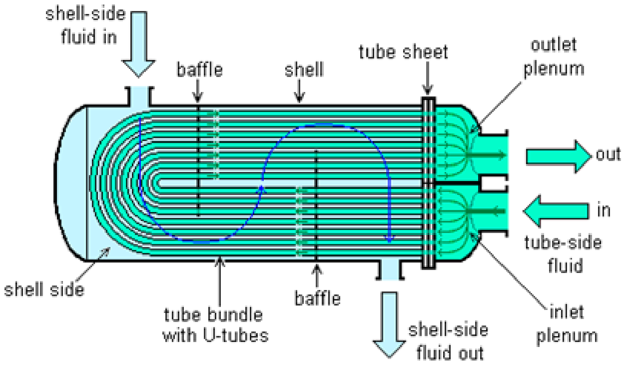

Fig.1.1 Tubular Heat Exchanger

1.2 Double Pipe Heat Exchanger

A typical double pipe heat exchanger consists of one pipe placed concentrically in side another of larger diameter with appropriate fittings to direct the flow from one section to the another section. One fluid flows through the inner pipe and other fluid flows through the annular space. Double-pipe heat exchangers can be arranged in various series and parallel arrangements to meet pressure drop and mean temperature difference requirements. The major use of double pipes exchangers for sensible heating or cooling of process fluids where small heat transfer area required. This configuration is also very suitable for one or both fluids are at high pressure because of the smaller diameter of the pipe. The major disadvantage is that double-pipe heat exchangers are bulky and expensive per unit transfer surface. Inner tube being may be single tube or multi-tubes. If heat transfer coefficient is poor in annulus, axially finned inner tube can be used. Double-pipe heat exchangers are built in modular concept, i.e., in the form of hairpins.

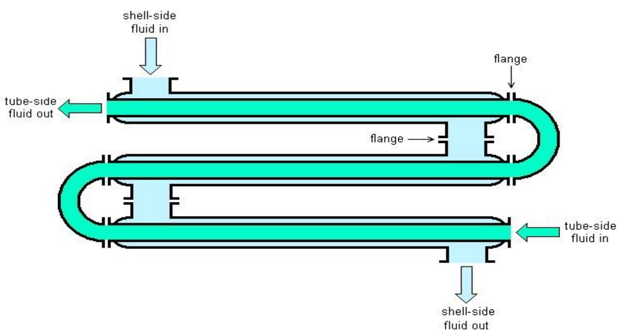

Fig. 1.2 Double pipe heat exchanger

1.3 Shell and Tube Heat Exchanger

Shell and tube heat exchangers are built of round tubes mounted in large cylindrical shells with the tube axis parallel to that of the shell. These are commonly used as oil coolers, power condensers, pre-heaters and steam generators in both fossil fuel and nuclear-based energy production applications. They are also widely used in process applications and in the air conditioning and refrigeration industry. Although they are not specially compact, their robustness and shape make them well suited for high pressure operations. They have larger heat transfer surface area to volume ratio than the most of common types of heat exchangers, and they are manufactured easily for a large variety of sizes and flow configurations. They can operate at high pressures and their construction facilitates disassembly for periodic maintenance and cleaning. The shell-and-tube heat exchangers consist of a bundle of tubes enclosed within a cylindrical shell. One fluid flows through the tubes while the second fluid flows space between the tubes and shell. In shell and tube heat exchanger, the shell side stream flows across between pairs of baffled, and then flows parallel to the tube. There are wide differences between shell-and-tube heat exchangers depending on the application. The main design objectives here are to accommodate thermal expansion, to furnish ease of cleaning, or to provide the least expensive construction. A number of shell side and tube side flow arrangement are used in shell and tube heat exchangers depending on heat duty, pressure drop, pressure level, fouling, manufacturing technique and cost, corrosion control, and cleaning problem. The baffles are used in shell and tube heat exchanger to promote better heat transfer coefficient on the shell side and to support the tubes.

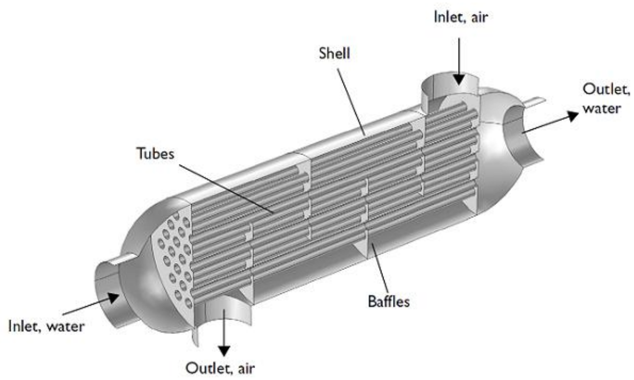

Fig. 1.3 Shell and Tube Heat Exchanger

1.4 Helical Tube Heat Exchanger

Helical tube heat exchanger has excellent heat exchanger because of far compact and high heat transfer efficiency. Helical-tube heat exchangers consist of one or more helically wound coils which are, in circular pattern, connected to header from which fluid is flowed. This helical coil is installed in a shell another fluid is circulated around outside of the tube, leads to transfer the heat between the two fluids. Heat transfer rate associated with a spiral tube is higher than that for a straight tube. In addition, a considerable amount of surface can be accommodating in a given space by spiraling. In helical tube heat exchanger, problem of thermal expansion is not probably occurring and self cleaning is also possible. A helical tube heat exchanger is a coil assembly fitted in a compact shell that to optimizes heat transfer efficiency and space. Every helical coil assembly has welded tube to manifold joints and uses stainless steel as a minimum material requirement for durability and strength. Helical tube heat exchanger uses multiple parallel tubes connected to pipe or header to create a tube side flow. The spaces or gaps between the coils of the helical tube bundle become the shell side flow path when the bundle is placed in the shell. Tube side and shell side connections on the bottom or top of the assembly allow for different flow path configurations. The helical shape of the flow for the tube side and shell side fluids create centrifugal force and secondary circulating flow that enhances the heat transfer on both sides in a true counter flow arrangement. Since there are no baffles are provided in to the system, therefore to lower velocities and heat transfer-coefficients. Performance is optimized. Additionally, since there are a variety of multiple parallel tube configurations are not compromised by limited shell diameter sizes as it is in shell and tube designs. The profile of a helical is very compact and fits in a smaller path than a shell and tube design. Since the tube bundle is coiled, space requirements for tube bundle removal are almost eliminated. When exotic material is required, a helical tube heat exchanger minimizes the material used since manifolds replace the channels, heads and tube sheets of a conventional shell and tube design. Helical tube heat exchanger uses single channel technology, which means that both fluids occupy a single channel, which allows fully counter-current flow. One fluid (hot fluid) enters the centre of the unit and flows towards the periphery. The other fluid (cold fluid) enters the unit at the periphery and moves towards the centre. The channels are curved and have a uniform cross section, which creates "helically" motion within the fluid. The fluid is fully turbulent at much lower velocity than straight tube heat exchangers, and fluid travels at constant velocity throughout the whole unit.

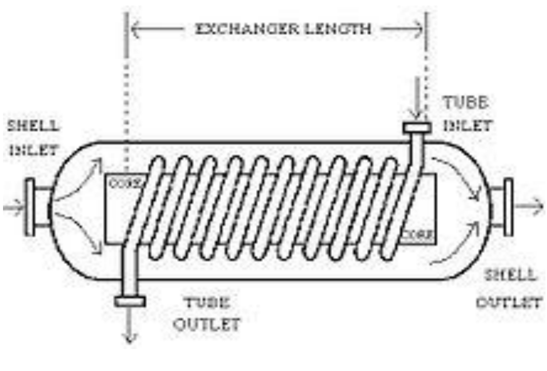

Fig. 1.4 Helical coil heat exchanger

II. LITERATURE REVIEW

[1] *R.Berlin Samuel Raj*-The study deals with the CFD simulation of the shell and tube heat exchanger by using a straight tube and a helical tube and comparing both of its performance based on heat transfer. Straight tube heat exchanger (STHE) have large heat transfer surface area-to-volume ratios to provide high heat transfer efficiency which are mostly used in industries. But the Helical Coil Heat Exchanger (HCHE) is also widely used in industrial applications because it can accommodate greater heat transfer area in a less space, with higher heat transfer coefficients. So both of the STHE and HCHE performances are compared to prove that HCHE is better in usage and the analysis is done using ANSYS Fluent 14.5 software. The model is created using CATIA V5 software.

[1] *Miyer Valdes et al. may 2019* The purpose of this research is to evaluate the effect of twist in the internal tube in a tube-in-tube helical heat exchanger keeping constant one type of ridges. To meet this goal, a Computational Fluid Dynamic (CFD) model was carried out. The effects of the fluid flow rate on the heat transfer were studied in the internal and annular flow. A commercial CFD package was used to predict the flow and thermal development in a tube-in-tube helical heat exchanger. The simulations were carried out in counter-flow mode operation with hot fluid in the internal tube side and cold fluids in the annular flow. The internal tube was modified with a double passive technique to provide high turbulence in the outer region. The numerical results agree with the reported data, the use of only one passive technique in the internal tube increases the heat transfer up to 28.8% compared to smooth tube.

[2] *Nidhi R. Singh et al. 2018*In the present study effect of steam temperature on heat transfer coefficient is studied using ANSYS Fluent (2015). In this study CFD analysis is performed to validate experimental data of condensation heat transfer coefficient. Steam temperature is varied from1030C -1150C and its effect on heat transfer coefficient is done. Three helical coils having different coil diameter is used. It is observed that as saturation temperature of steam increases heat transfer coefficient increases and as coil diameter increases heat transfer coefficient decreases and the percentage of error is within 9-15%

[3] *J. S. Jayakumar [2008]* 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.

[4] *P. P. Gavade, S.S. Malgave, D.D. Patil, H.S. Bhore, V. V. Wadkar,[2015]* Here the fluid which surrounds a heat source receives heat, becomes less dense and rises. The working fluid that is surrounding the high temperature fluid is cooled and then moves in to replace it. After that cooler fluid gets heated and the process continues, resulting convection current. Forced convection in a heat exchanger is the flow of heat from one moving stream to another stream through the wall of the pipe. The low temperature fluid removes heat from the comparatively high temperature fluid as it flows along or across it. If it moves along the hot stream then it's called parallel flow and if they are across then its counter flow.

[5] *MandhapatiRaju, Sudarshan Kumar [2010]* studied hydrogen refueling in a metal hydride based automotive hydrogen storage system is an exothermic reaction and therefore an efficient heat exchanger is required to remove the heat for fast refueling. In this paper a helical coil heat exchanger embedded in a sodium alanate bed is modeled using COMSOL. Sodium alanate is present in the shell and the coolant flows through the helical tube. A three-dimensional COMSOL model is developed to simulate the exothermic chemical reactions and heat transfer. Due to memory limitations, only a few turns of the coil are included in the computational domain. Practical difficulties encountered in modeling such three dimensional geometries as well as suitable approximations made to overcome such difficulties are discussed. The distribution of temperature and hydrogen absorbed in the bed for a sample case is presented. A parametric study is conducted using COMSOL-Matlab interface to determine the optimal bed diameter, helical radius and helical pitch for maximum gravimetric capacity.

[6] *Satish. B. Ingle, Snehal S. Borkar [2016]* the purpose of this study is to determine the relative advantage of using a helically coiled heat exchanger against a straight tube heat exchanger. It is found that the heat transfer in helical circular tubes is higher as compared to Straight tube due to their shape. Helical coils offer advantageous over straight tubes due to their compactness and increased heat transfer coefficient. The increased heat transfer coefficients are a consequence of the curvature of the coil, which induces centrifugal forces to act on the moving fluid, resulting in the development of secondary flow. The curvature of the coil governs the centrifugal force while the pitch (or helix angle) influences the torsion to which the fluid is subjected to. The centrifugal force results in the development of secondary flow. Due to the curvature effect, the fluid streams in the outer side of the pipe moves faster than the fluid streams in the inner side of the pipe. The difference in velocity sets-in secondary flows, whose pattern changes with the Dean number of the flow. In current work the fluid to fluid heat exchange is taken into consideration, Most of the investigations on heat transfer coefficients are for constant wall temperature or constant heat flux. The effectiveness, overall heat transfer coefficient, effect on effectiveness of heat exchanger, when mass flow rate of hot water is kept constant with vary mass flow rate of cold water are studied and compared for parallel flow, counter flow arrangement of Helical coil and Straight tube heat exchangers. The inner heat transfer coefficient calculated from Wilson plot method and variations of various dimensionless numbers i.e. Reynolds Number, Nusselt's Number and Dean's number are studied. Then Nusselt number and correlation obtained on the basis of inner heat transfer coefficient. All readings were taken at steady state condition of heat exchanger. Copper was chosen as the as metal for the construction of the helical tube. The fluid flowing through the tube was taken as water. The result shows that the heat transfer coefficient is affected by the geometry of the heat exchanger. Helical coil heat exchanger are superior in all aspect studied here. In present paper analysis of counter flow heat exchanger is done.

[7] *Swapnil Ahire, Purushottam Shelke, Bhalchandra Shinde, NileshTotala [2014]* observed heat recovery is the capture of energy contained in fluids otherwise that would be lost from a facility. Heat sources may include heat pumps, chillers, steam condensate lines, hot flue gases from boiler, hot air associated with kitchen and laundry facilities, exhaust gases of the engines, power-generation equipment. Helical coil heat exchanger is one of the devices which are used for the heat recovery system. A heat exchanger is a device used to transfer heat between two or more fluids with different temperatures for various application including power plants, nuclear reactors, refrigeration & air condition system, automotive industries, heat recovery system, chemical processing and food industries. Common examples of heat exchangers in everyday use are air preheaters and conditioners, automobile radiators, condensers, evaporators, and coolers In present paper analysis of counter flow heat exchanger is done and then variations of various dimensionless numbers i.e. Reynolds Number, Nusselt's Number and Dean's number are studied.

[8] *Pramod S. Purandarea, Mandar M. Leleb, Rajkumar Gupta [2012]* studied that helical coil configuration is very effective for heat exchangers and chemical reactors because they can accommodate a large heat transfer area in a small space, with high heat transfer coefficients. This paper deals with the parametric analysis of the helical coiled heat exchanger with various correlations given by

different researchers for specific conditions. The parametric analysis of these various correlations with specific data is presented in this paper.

[9] *B. ChinnaAnkanna, B. Sidda Reddy [2014]* this paper focus on an increase in the effectiveness of a heat exchanger and analysis of various parameters that affect the effectiveness of a heat exchanger and also deals with the performance analysis of heat exchanger by varying various parameters like number of coils, flow rate and temperature. The results of the helical tube heat exchanger are compared with the straight tube heat exchanger in both parallel and counter flow by varying parameters like temperature, flow rate of cold water and number of turns of helical coil.

[10] *AmolAndhare, V M Kriplani, J P Modak [2014]*In the present work the convective heat transfer coefficients of a helical coil heat exchanger are investigated experimentally. Three helical coils of different curvature ratio and pitch are arranged horizontally in a shell and are tested for counter flow arrangement. Hot water is made to flow through the helical coil and the cold water through the shell. The tube side and shell side flow rates were altered and appropriate instruments were used to measure the flow rates and temperatures of both the fluids. Tube side and shell side convective heat transfer coefficients were calculated using Wilson plots. Based on the curvature ratio and pitch ratio separate empirical correlations are proposed for tube side and shell side for 75 test runs. The calculated convective heat transfer coefficients of tube side and shell side those obtained from the consideration of curvature ratio and pitch ratio are compared and were found in good agreement.

[11] *Jay J. Bhavsar, V K. Matawala, S. Dixit [2013]* studied Spiral tube heat exchangers are known as excellent heat exchanger because of far compact and high heat transfer efficiency. An innovative spiral tube heat exchanger is designed for particular process engineering. A new arrangement for flow of hot and cold fluids is employed for design, hot fluid flows in axial path while the cold fluid flows in a spiral path. To measure the performance of the spiral tube heat exchanger, its model is suitably designed and fabricated so as to perform experimental tests. The paper gives analysis of spiral tube heat exchanger over the shell and tube heat exchanger.

[12]*RamnareshPatel ,DharmendraYadav [2015]* studied Enlarging the transformation of heat by the use of Shell And Tube heat exchanger has been studied and researched by many researchers, because the dynamics of fluid inside the pipes of a Shell And Tube heat exchanger offer certain advantages over the shell and tube type, straight tubes heat exchanger, in terms of better transformation of heat and mass transfer coefficients. Various configurations of configuration are possible, and the structure in which there is a series of vertically unstructured Shell and Tube is the most common type. The one end of the tubes act as the inlet and other end act as outlet manifolds, which serve the purpose for the entry and exit of hot as well as cold fluid. This configuration offers a high compact configuration and a high overall heat transfer coefficient; hence Shell And Tube heat exchangers are extensively used in industrial applications such as power sector like nuclear power generation plants, power plants, heat recovery systems, refrigeration and air conditioning industries, food processing plants, food industry, industrial HVACs etc.

III. METHODS AND MODULING ANALYSIS

3.1 Modeling

The modeled heat exchanger used for present simulation is helical coil type with circular, rectangular & triangular cross-sections. The modeled assembly consists of inlet, exit and surface of helical coil heat exchanger. Inlet area and outlet area of heat exchanger kept constant while cross-section of heat exchanger has been varied. Modeling of heat exchanger has been done in Ansys ICEM CFD 14.5. The 3-D view of heat exchanger of different cross-section is shown from fig. 3.1.1 to 3.1.3.

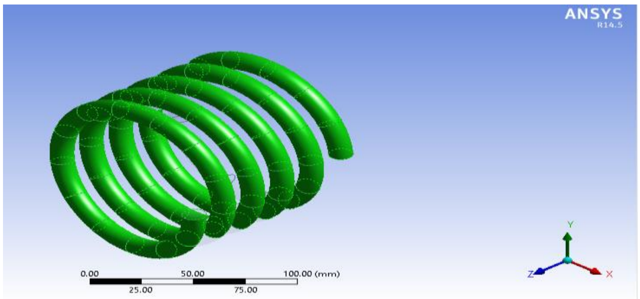

Fig 3.1.1: Modeled view of helical coil heat exchanger with circular cross-section

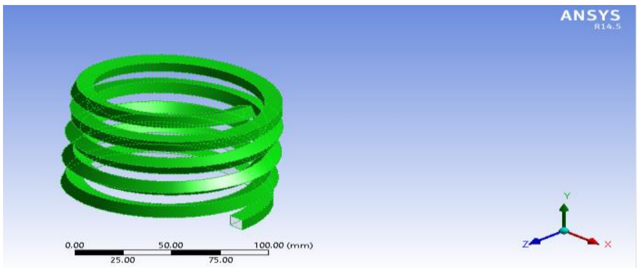

Fig 3.1.2: Modeled view of helical coil heat exchanger with rectangular cross-section

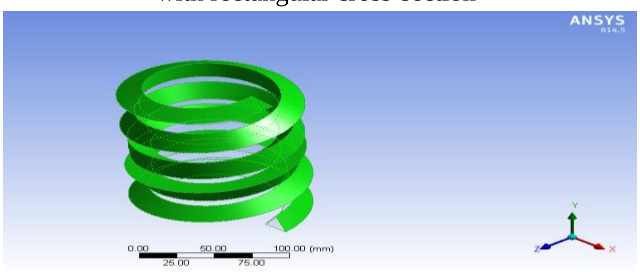

Fig 3.1.3: Modeled view of helical coil heat exchanger with triangular cross-section

3.2 Mesh generation

The geometry made is divided into small parts for analysis which is called mesh and the process of doing it is called meshing. The shape of mesh elements in 2-D can be triangular or quadrilateral and in 3-D, it can be tetrahedral, hexahedral or prism depending upon dimensions of the specified geometry. The shape and size of the mesh elements can be varied. The size of mesh depends upon geometry, accuracy required, computational power of the system and memory. The complete heat exchanger consists of one domain named flow region.

3.3 Meshing of Domains

Helical heat exchanger domain is enclosed by inlet and outlet surfaces. Triangular elements have been used for 2 D geometry and tetrahedral elements have been used for 3D fluid flow region for the mesh generation.

Table - 3.3.1: Mesh Data for Helical Coil Heat Exchanger for different cross-section

Cross-sections	No. of Elements	Element Type
Circular	29568	Quadrilateral
Rectangular	32310	Quadrilateral, Trias
Triangular	17284	Trias

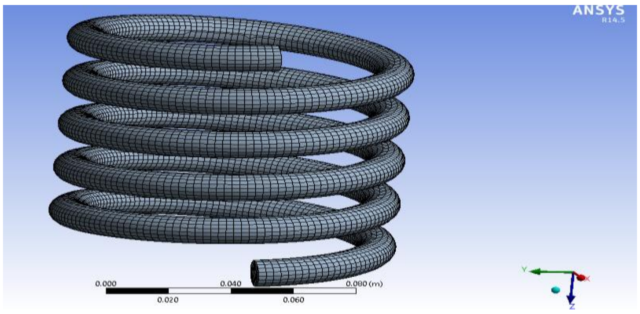

Fig 3.3.2: Meshing of helical coil heat exchanger with circular cross-section

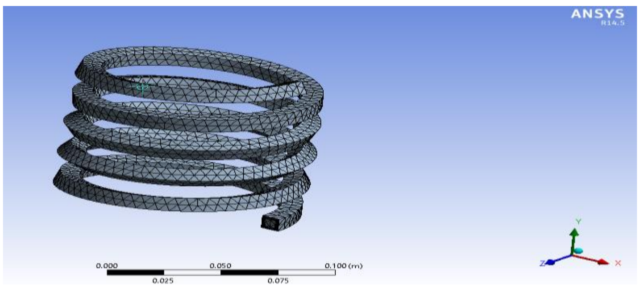

Fig 3.3.3: Meshing of helical coil heat exchanger with Rectangular cross-section

3.4 Domain Properties

The mesh is converted into the required format and is imported to Ansys CFX-14.5. The properties of domains and fluid are defined in ANSYS CFX Pre 14.5. The summary of Flow domain properties are given in Table 4.4.

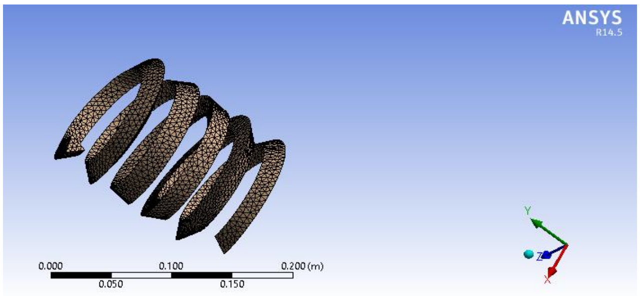

Fig 3.3.4: Meshing of helical coil heat exchanger with triangular cross-section

Table – 3.4.1: Helical Coil Heat Exchanger Domain Properties

Location	***Helical Coil Heat Exchanger***
Domain Type	Fluid Domain
Fluid List	Water
Coordinate Frame	Coord 0
Reference Pressure	0 [atm]
Buoyancy Option	Not Buoyant
Domain Motion Option	Stationary
Mesh Deformation Option	None
Turbulence Model	k-Epsilon
Turbulence Wall Function	Scalable
Density of Water	998.2 kg/m^3
Combustion	None
Thermal Radiation	None

3.5 Boundary Conditions

Boundary conditions are used according to need of the model. The inlet and outlet conditions are defined as velocity inlet and pressure outlet. As this is a cross flow with one tube so there are respective inlet and outlets. The walls are separately specified with respective boundary conditions. No slip condition is considered for wall. The details about all boundary conditions can be seen in the table below:

Table 3.5.1 Boundary Conditions

-	Boundary condition type	Velocity Magnitude	Temperature
Inlet	Velocity Inlet	0.5 (m/s)	350
Outlet	Pressure Outlet	0.5 (Pascal)	300

3.6 Geometrical Dimensions

Table 3.6.1: Geometrical Dimensioning

S.No.	Geometry	Dimension (mm)	Area (mm^2)
1	Circular	d= 12, t=1	113
2	Rectangular	l=11.3, b= 10	113
3	Triangular	H=15.03, B=15.03	113

IV. RESULT

Pressure contours and velocity stream lines were obtained using insert contour and insert streamline commands of menu bar in ANSYS CFX-Post. The contours of Static Pressure, Static Temperature, and velocity magnitude and for each geometry have been shown below.

4.1 Circular Cross-section:

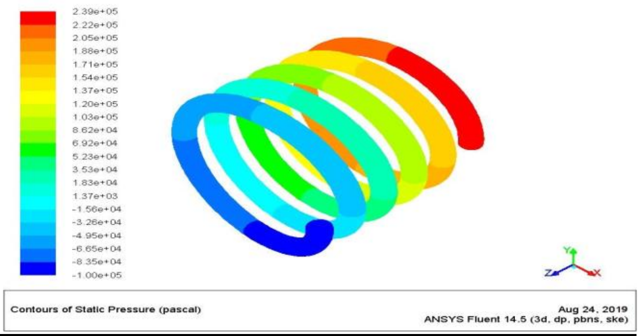

Fig. 4.1.1 Pressure contours for Circular Cross-sections

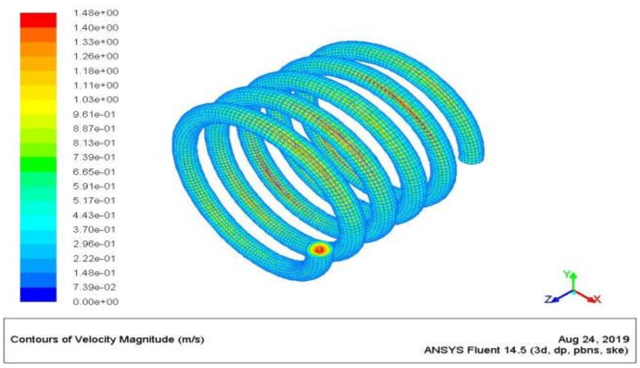

Fig. 4.1.2 Velocity Magnitude for Circular Cross-sections

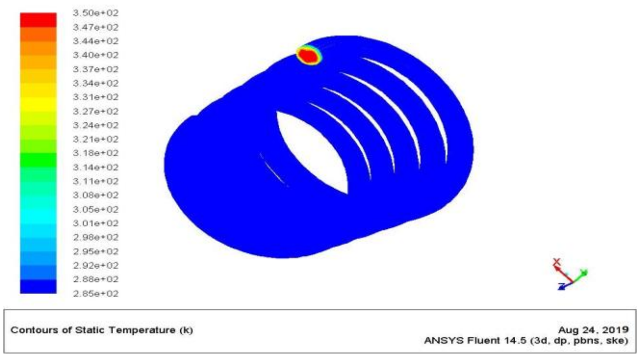

Fig. 4.1.3 Temperature Contour for Circular Cross-sections

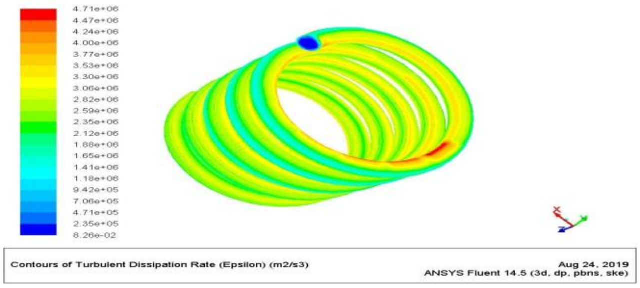

Fig. 4.1.4 Contours of Turbulent Dissipation Rate for Circular Cross-sections

4.2 Rectangular Cross-sections

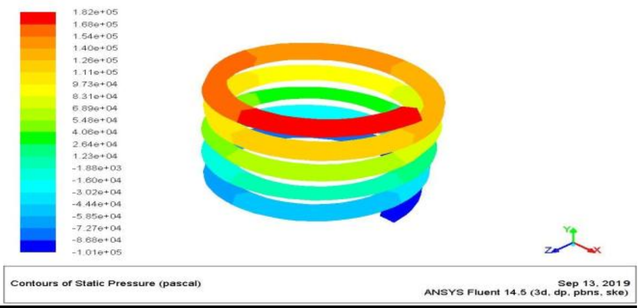

Fig. 4.2.1 Pressure contours for Rectangular Cross-sections

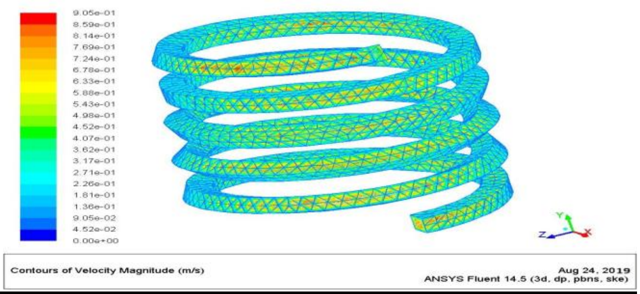

Fig. 4.2.2 Velocity Magnitude for Rectangular Cross-sections

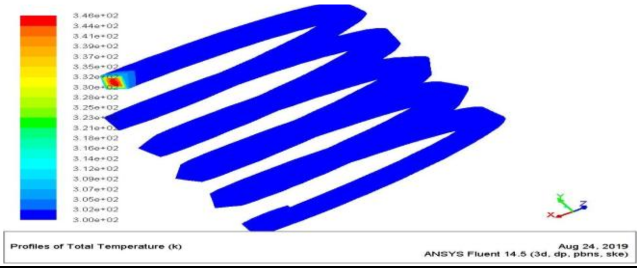

Fig. 4.2.3 Temperature Contour for Rectangular Cross-sections

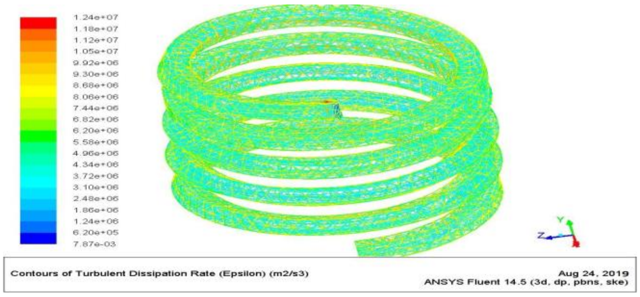

Fig. 4.2.4 Contours of Turbulent Dissipation Rate for Rectangular Cross-sections

4.3 Triangular Cross-sections

Fig. 4.3.1 Pressure contours for Triangular Cross-sections

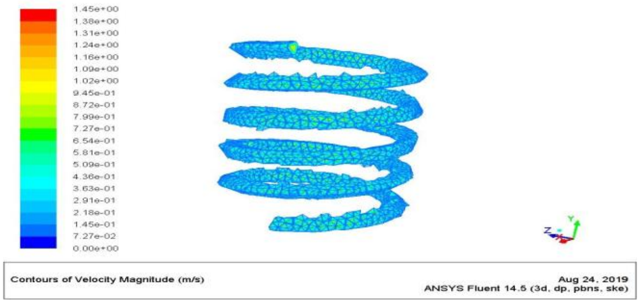

Fig. 4.3.2 Velocity Magnitude for Rectangular Cross-sections

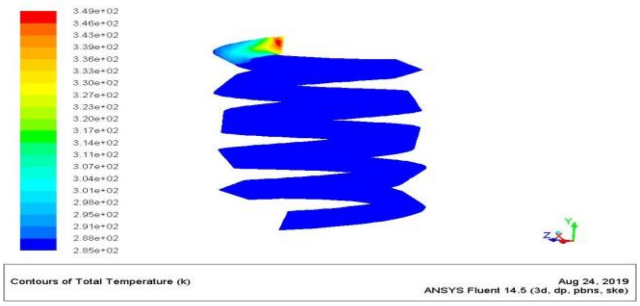

Fig. 4.3.3 Temperature Contour for Triangular Cross-sections

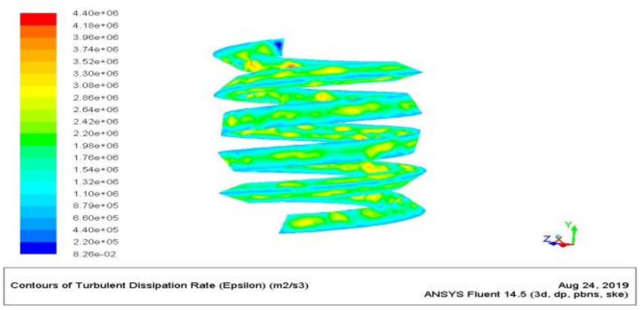

Fig. 4.3.4 Contours of Turbulent Dissipation Rate for Triangular Cross-sections

V. CONCLUSION

The computation and comparison of different mass flow rate of various geometric configurations using CFD will help to optimize shape of cross-sections of helical heat exchanger. In this dissertation Computational Fluid Dynamics (CFD) approach has been used to predict the optimum cross-section of different cross-section of helical coil heat exchanger at same initial velocity.

Fig. 4.1.1 to 4.1.4 the pressure, velocity, temperature and turbulent dissipation rate is varying with position in given range. The numerical simulation of circular cross-sections calculating the value of mass flow rate is $7.018\text{x}10^{-5}$ kg/s. Similarly Fig. 4.2.1 to 4.2.4 showing the pressure, velocity changes, Temperature variation, turbulent dissipation rate in small ranges and further calculating value of mass flow rate is $1.113\text{x}10^{-6}$ kg/s. Through Fig. 4.3.1 to 4.3.4 getting the value of mass flow rate is $3.793\text{x}10^{-6}$kg/s. Therefore it is observed that mass flow rate value higher in case of circular cross-sections compare than other two geometric. We know from earlier literature that the increasing in mass flow rate increases the effectiveness and overall thermal conductance of heat exchangers. Hence it may also say that circular cross-section type heat exchanger will give better results in all manners. The losses in pipes and manufacturing irregularities have not been taken in to account.

In present case it may be concluded that mass flow rate of circular cross-section is better than other two geometric configurations.

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