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TO DEDUCTION OF MASS FLOW RATE FOR HELICAL HEAT EXCHANGER AT MULTIPLE CROSS-SECTIONS 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 analyze the effect of mass flow rate 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.

KEYWORDS: Helical coil heat exchanger, CFD or Computational fluid dynamics, Conjugate mass transfer, Geometric configurations, Numerical simulation.

INTRODUCTION

Heat exchangers are one of the mostly used equipment in the process industries. Heat exchangers are used to transfer heat between two process streams. One can realize their usage that any process which involve cooling, heating, condensation, boiling or evaporation will require a heat exchanger for these purpose. Process fluids, usually are heated or cooled before the process or undergo a phase change. Different heat exchangers are named according to their application. For example, heat exchangers being used to condense are known as condensers, similarly heat exchanger for boiling purposes are called boilers. Performance and efficiency of heat exchangers are measured through the amount of heat transfer using least area of heat transfer and pressure drop. A better presentation of its efficiency is done by calculating over all heat transfer coefficient. Pressure drop and area required for a certain amount of heat transfer, provides an insight about the capital cost and power requirements (Running cost) of a heat exchanger. Usually, there is lots of literature and theories to design a heat exchanger according to the requirements.

Helical coil heat exchanger has excellent heat exchanger because of far compact and high heat transfer efficiency. 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 helical tube is higher than that for a straight tube. In addition, a considerable amount of surface can be accommodating in a given space by helically wounded. 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. 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 "spiraling" 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.

LITERATURE REVIEW

Daniel Flórez-Orrego, Walter Arias, Diego Lopez and Hector Velasquez 2012 [1] have worked on the single phase cone shaped helical coil heat exchanger. The study showed the flow and the heat transfer in the heat exchanger. An empirical correlation was proposed from the experimental data for the average Nusselt number and a deviation of 23% was found.

J. S. Jayakumar 2008 [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. Timothy J. Rennie 2004 [3] studied the heat transfer characteristics of a double pipe helical heat exchanger for both counter and parallel flow. Both the boundary conditions of constant heat flux and constant wall temperature were taken. The study showed that the results from the simulations were within the range of the pre-obtained results. For dean numbers ranging from 38 to 350 the overall heat transfer coefficients were determined. J. S. Jayakumar, S. M. Mahajani, J. C. Mandal, Rohidas Bhoi 2008 [4] studied the constant thermal and transport properties of the heat transfer medium and their effect on the prediction of heat transfer coefficients. Arbitrary boundary conditions were not applicable for the determination of heat transfer for a fluid-to-fluid heat exchanger. An experimental setup was made for studying the heat transfer and also CFD was used for the simulation of the heat transfer.

Usman Ur Rehman 2011 [5] studied the heat transfer and flow distribution in a shell and tube heat exchanger and compared them with the experimental results. The model showed an average error of around 20% in the heat transfer and the pressure difference. The study showed that the symmetry of the plane assumption worked well for the length of the heat exchanger but not in the outlet and inlet regions. Nawras H. Mostafa, Qusay R. Al-Hagag 2012 [6] studied on the mechanical and thermal performance of elliptical tubes used for polymer heat exchangers. The mechanical analysis showed that the streamlined shape of the outer tube had an optimal thermal performance. A set of design curves were generated from which a number of geometries of the tube and different materials can be easily selected in order to meet the deformation constraints. A finite element solution was determined for strain as a function of the material of the tube. Amitkumar S. Puttewar, A.M. Andhare 2015[7] focuses on the designing of shell and helical coil heat exchanger and its thermal evaluation with counter flow configuration. The thermal analysis is carried out considering the various parameters such as flow rate of cold water, flow rate of hot water, temperature, effectiveness and overall heat transfer coefficient.

P. P. Gavade, S.S. Malgave, D.D. Patil, H.S. Bhore, V. V. Wadkar,2015 [8] 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. Mandhapati Raju, Sudarshan Kumar 2010 [9] 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. Satish. B. Ingle, Snehal S. Borkar 2016 [10] 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. Swapnil Ahire, Purushottam Shelke, Bhalchandra Shinde, Nilesh Totala 2014 [11] 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. Pramod S. Purandarea, Mandar M. Leleb, Rajkumar Gupta 2012 [12] 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. B. Chinna Ankanna, B. Sidda Reddy 2014 [13] 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.

Amol Andhare, V M Kriplani, J P Modak 2014 [14] 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. Jay J. Bhavsar, V K. Matawala, S. Dixit 2013 [15] 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. Ramnaresh Patel , Dharmendra Yadav 2015 [16] 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. Shiva Kumara, K.Vasudev Karantha 2013 [17] Heat exchangers are the important equipments with a variety of industrial applications including power plants, chemical, refrigeration and air conditioning industries. Helically coiled heat exchangers are used in order to obtain a large heat transfer area per unit volume and to enhance the heat transfer coefficient on the inside surface. This paper deals with the CFD simulation of helical coiled tubular heat exchanger used for cooling water under constant wall temperature conditions.

GEOMETRIC MODELING

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. 1 to 3.

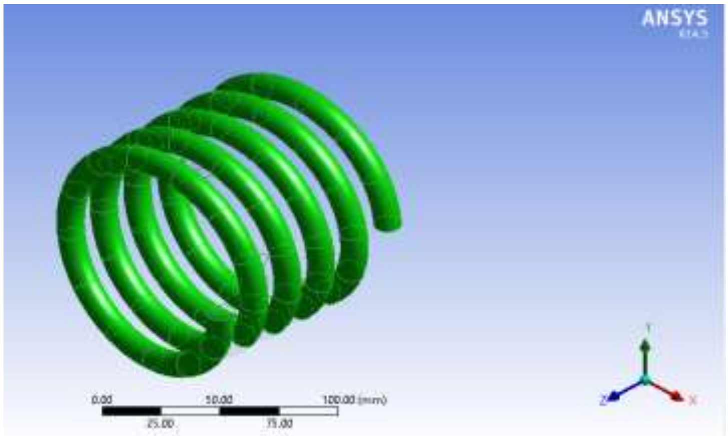

Fig 1: Modeled view of helical coil heat exchanger with circular cross-section

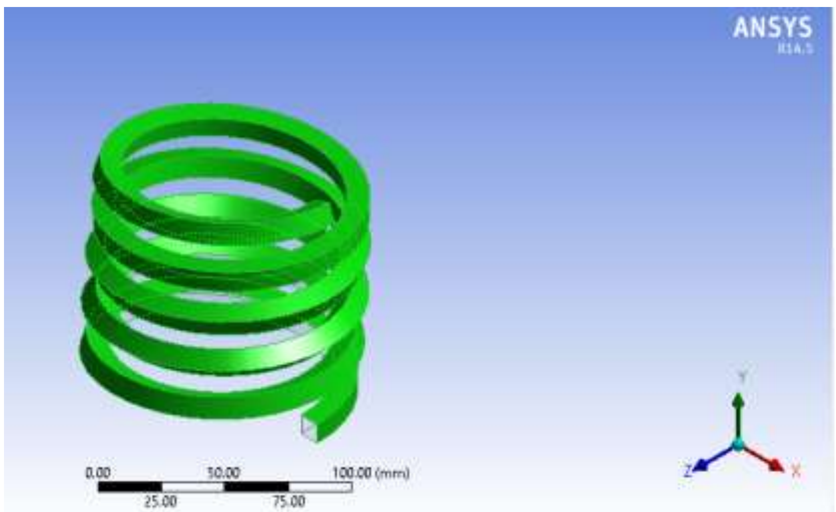

Fig 2: Modeled view of helical coil heat exchanger with rectangular cross-section

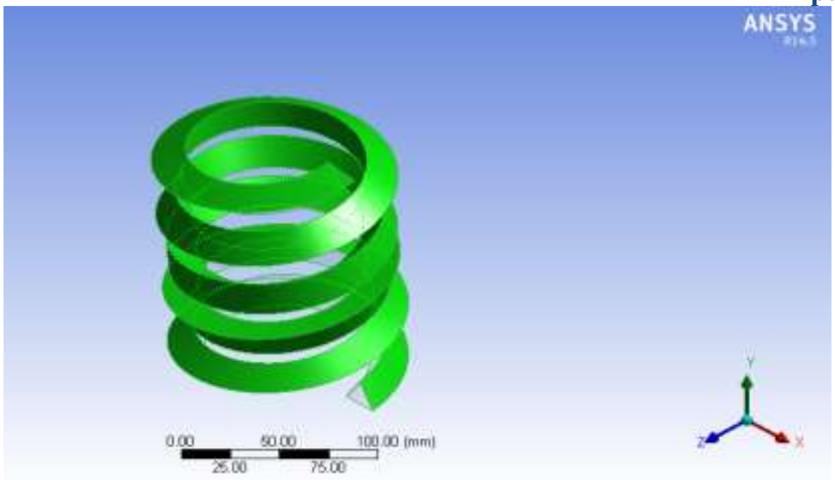

Fig 3: Modeled view of helical coil heat exchanger with triangular cross-section

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 1. Boundary Conditions

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

RESULTS AND CONCLUSION

Three different cross-sections of helical coil heat exchanger have been analysed and their mass flow rates variations has been evaluated at constant parameters. Only inlet velocity has been taken into consideration with value of 0.5 m/s.Each cross-section has been taken a area of fluid type and the fluid which is taken, is water with reference pressure as 1 atmospheric. Heat transfer option has been set to none, fluid temperature 77°C and turbulence model κ-ϵ has been taken for the domain. We know that the Density of water is defined as 998.2 kg/$m^3$and kinematic viscosity as 0.8926 $X10^{-6} m^2/s$. The outlet of heat exchanger reference pressure is set equal to 0.5 Pascal (gauge). Consider the inlet and outlet area of the heat exchanger is $1.13x10^{-5}m^2$. Surface of heat exchanger is taken to be smooth and no slip condition is taken.High resolution advection scheme with second order upwind numeric for 200 iterations were given. The timescale control was set to Auto Timescale. The RMS residual target was set to $1x10^{-5}$for termination of the calculations. After completion of the iterations results are obtained. The variation of the pressure and velocity using pressure contours and velocity streamlines respectively on the surface of the draft tube could be observed.

Contours

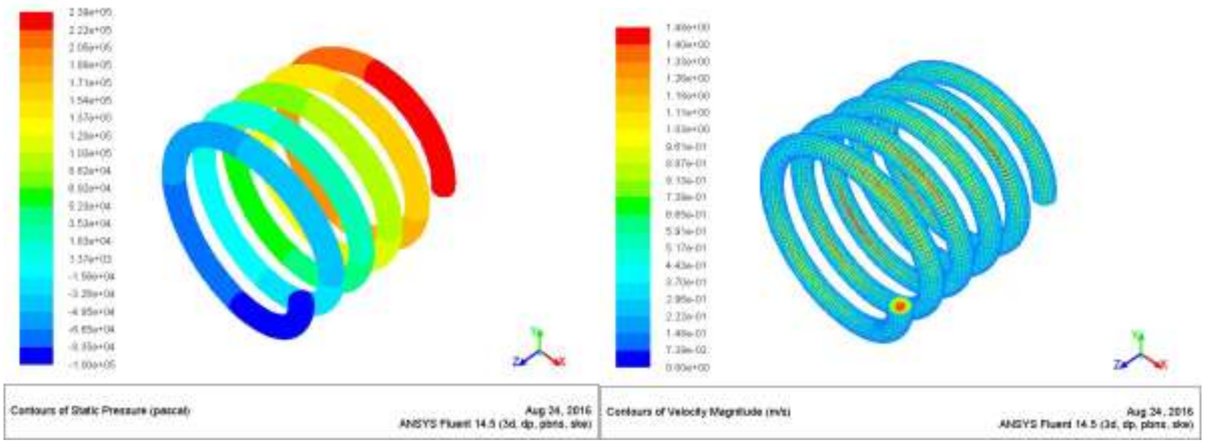

Fig. 4 Pressure & Velocity Contours for Circular Cross-sections

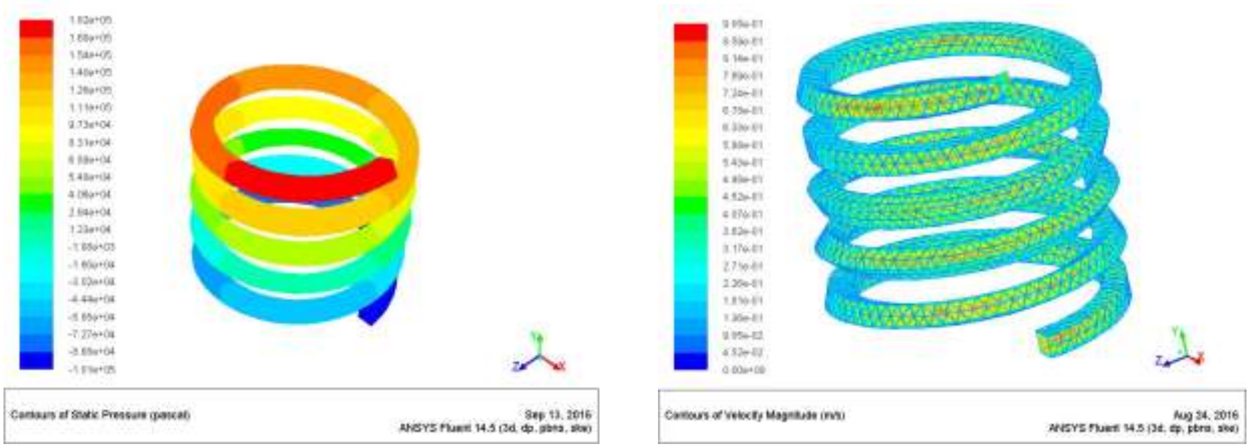

Fig. 5 Pressure & Velocity Contours for Rectangular Cross-sections

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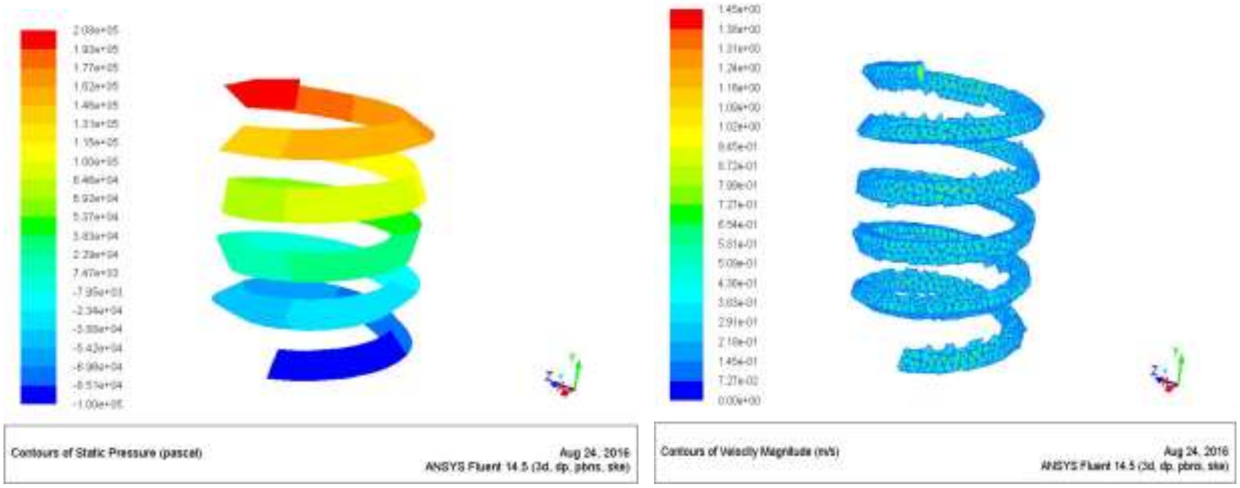

Fig. 6 Pressure & Velocity Contours for Triangular Cross-sections

CONCLUSION

The pressure is reducing with very small amount in fig.4, and consequently velocity is varying. This calculate that the value of mass flow rate is 7.018×10^{-5} kg/s . Fig. 5 shows the pressure and velocity changes in small ranges and further calculating value of mass flow rate is 1.113×10^{-6} kg/s. Fig. 6 shows slowly variation in pressure and velocity and calculating the value of mass flow rate is 3.793×10^{-6}. Also found that pressure is being reducing and respectively velocity is increasing under small variations because it is inversely proportional to each other as seen in Figures 4 to 6.

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.

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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