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CFD Analysis of Tubular and Sector-By-Sector Helical Coil Heat Exchanger

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Abstract- A heat exchanger may be defined as an equipment which transfers the energy from a hot fluid to a cold fluid, with maximum rate and minimum investment and running cost. The rate of transfer of heat depends on the conductivity of the dividing wall and convective heat transfer coefficient between the wall and fluids. The heat transfer rate also varies depending on the boundary conditions such as adiabatic or insulated wall conditions. Heat exchange between flowing fluids is one of the most important physical processes of concern, and a variety of heat exchangers are used in different type of installations, as in process industries, compact heat exchangers nuclear power plant, HVACs, food processing, refrigeration, etc. The purpose of constructing a heat exchanger is to get an efficient method of heat transfer from one fluid to another, by direct contact or by indirect contact.

Keywords- Tubular, sector-by-sector helical coil heat exchanger, heat transfer

I. INTRODUCTION

Tubular heat exchangers are built of mainly of circular tubes although some other geometry has also been used in different applications. This type of construction offers a large amount of flexibility in design as the designing parameters like the diameter, length and the arrangement can be easily modified. This type is used for liquid-to-liquid (phase changing like condensing or evaporation) heat transfer.

Again, this type is classified into shell and tube, double pipe and spiral tube heat exchangers.Heat exchange between flowing fluids is one of the most important physical processes of concern, and a variety of heat exchangers are used in different type of installations, as in process industries, compact heat exchangers nuclear power plant, HVACs, food processing, refrigeration, etc. The purpose of constructing a heat exchanger is to get an efficient method 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. The double pipe or the tube in tube type heat exchanger consists of one pipe placed concentrically inside another pipe having a greater diameter. The flow in this configuration can be of two types: parallel flow and counter-flow. It can be arranged in a lot of series and parallel configurations to meet the different heat transfer requirements. Of this the helically arranged stands out as it has found its place in different industrial applications.

As this configuration is widely used, knowledge about the heat transfer coefficient, pressure drop, and different flow patterns has been of much importance. The curvature in the tubes creates a secondary flow, which is normal to the primary axial direction of flow. This secondary flow increases the heat transfer between the wall and the flowing fluid. And they offer a greater heat transfer area within a small space, with greater heat transfer coefficients. Study has been done on the types of flows in the curved pipes, and the effect of Prandtl and Reynolds number on the flow patterns and on Nusselt numbers. The two basic boundary conditions that are faced in the applications are constant temperature and the constant heat flux of the wall.

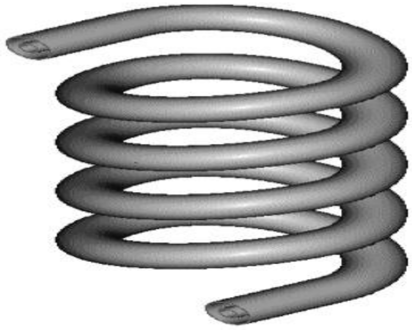

Fig. 1 Double pipe helical coil

II. RESEARCH METHODOLOGY

Computational domain

The details of the heat exchangers and their geometrical variables are shown in Fig. 2. As it can be seen from this figure, these helical coil heat exchangers are made from two sectors that are connected via one of their plane surfaces thus; they are called sector-by-sector heat exchangers. Indeed the heat exchanger is divided into two parts using a spiral plate. According to Fig. 2ϴ is the sector angle. Thus, the heat exchanger involves two sectors and the water flows through the each sectors. Therefore, a sector consists of warm water and the other consists of the cold water.

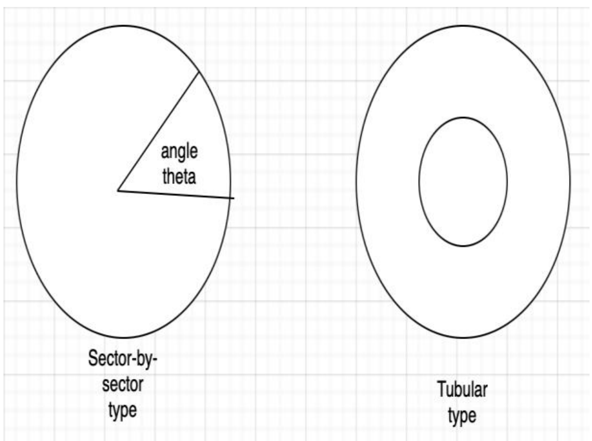

Fig. 2 Schematic of computational domain

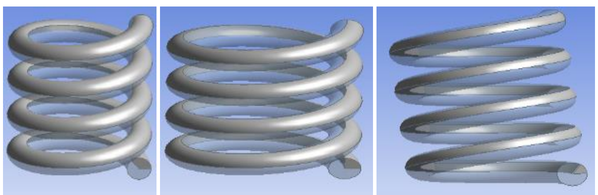

Fig. 3 Computational domain for CFD

Table 1: Operating and Geometrical parameters used for CFD analysis (Abu-Hamdeh et al. (2020**)**

Operating and Geometrical parameters	Value / Range
Velocity of fluid, u	1.6-3.8 m/s
Temperature of cold water, Tc	283.15 K
Temperature of hot water, Th	353.15 K
Pitch, p	20 mm
Height of coil, H	80 mm
Diameter of inner tube, di	6 mm
Diameter of outer tube, do	12 mm
Sector angle	30-150°

Governing differential equations

Continuity equation

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

Momentum Equation

$$\frac{\partial}{\partial x_i}\left(\rho u_i u_j\right) = -\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] + \frac{\partial}{\partial x_j}\left(-\rho \overline{u_i' u_j'}\right) \tag{2}$$

Energy equation

$$\frac{\partial}{\partial x_i}(\rho u_i T) = \frac{\partial}{\partial x_j}\left[(\Gamma + \Gamma_t)\frac{\partial T}{\partial x_j}\right] \tag{3}$$

Boundary Condition

On all the walls of the coil, no-slip boundary conditions were assigned. At the inlet, uniform velocity with an inlet temperature of cold fluid 300 K and at the exit, invariable pressure (atmospheric pressure) boundary conditions were assigned. All the other edges were assigned as walls with insulated boundary conditions, as shown in Fig. 3.3. The outer side wall was assumed to be adiabatic.

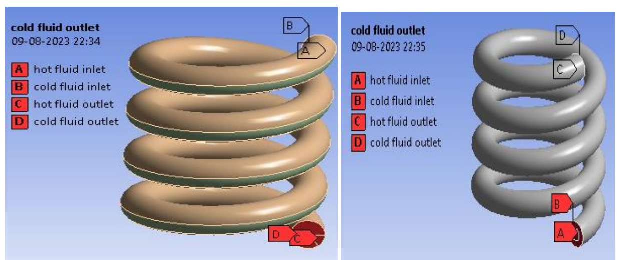

Fig. 4 Boundary condition for CFD analysi

CFD Modelling
Commercially available ANSYS FLUENT v 15.0 was the CFD software employed to solve the concerned general differential equations numerically. This software numerically simulates using finite element method.

III. RESULTS AND DISCUSSION

Temperature Profile
In a helical coil tube heat exchanger, temperature variation refers to the changes in temperature that occur as a fluid flow through the coils of the heat exchanger. This variation can occur both along the length of the coil and across the cross-sectional area of the coil.The flow rate of the fluids (hot and cold) through the coil affects how much heat is transferred and how quickly the temperature changes. Higher flow rates can lead to smaller temperature differences along the coil.The initial temperatures of the hot and cold fluids entering the heat exchanger impact the temperature difference driving the heat transfer. A larger initial temperature difference usually results in greater temperature variation along the coil.

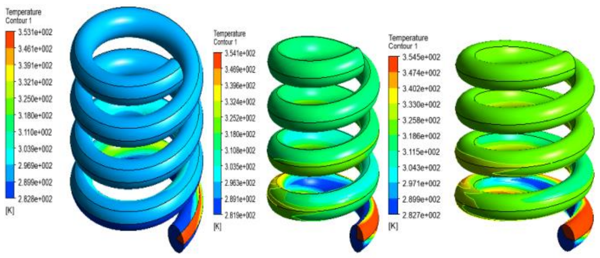

Fig. 5: Temperature profile in sector-by-sector coil type heat exchanger

Effect of Sector Angle on Nusselt number
Effect of sector angle on Nusselt number is shown in Fig 6. The horizontal x-axis represents Reynolds number and y-axis represents Nusselt number. It is seen that increase in sector angle results in increase in Nusselt number and it is maximum at 150°. This may be due to the fact that at higher values of sector angle, reattachment of free shear layer might not occur and rate of heat transfer enhancement is not proportional to that of friction factor.

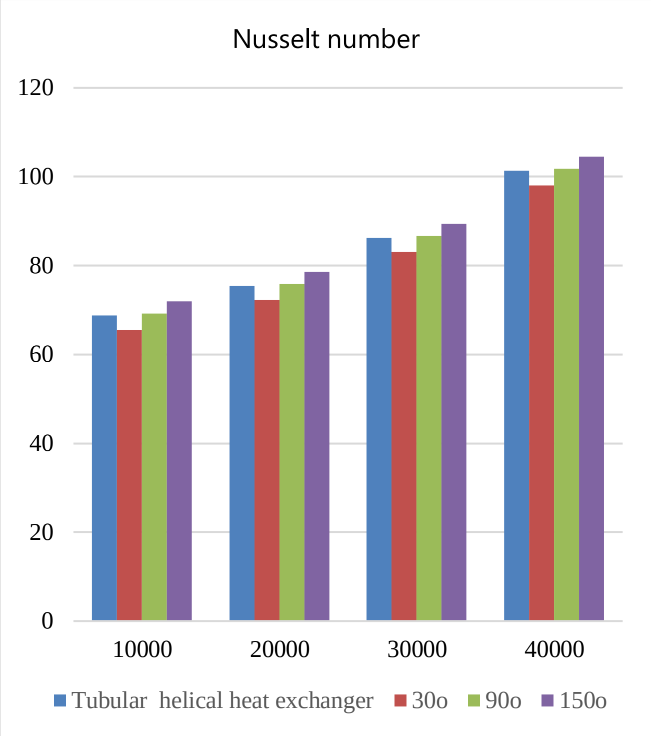

Fig. 6: Variation of Nusselt number at different sector angle

Effect of Sector Angle on Friction Factor

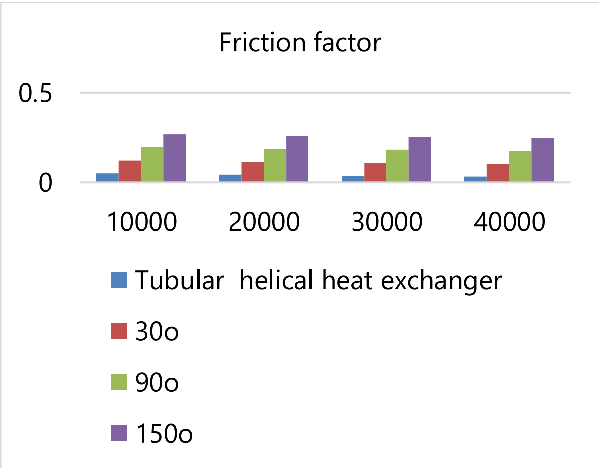

Fig. 7: Variation of Friction factor at different sector angle

Effect of sector angle on friction factor is shown in Fig. 7. The horizontal x-axis represents Reynolds number and y-axis represents friction factor. It is seen that increase in sector angle ratio results in increase in friction factor and it is maximum at 150°. This may be due to the fact that at higher values of sector angle, pumping power is required more.The pressure drop across the heat exchanger is closely related to the friction factor. As the fluid flows through the narrower cross-sectional area of the coil with a higher sector angle ratio, it encounters increased resistance, leading to a greater pressure drop. This pressure drop represents the energy loss due to fluid friction. The observation that the friction factor is highest at a sector angle of 150 degrees might be due to a combination of factors, including the specific coil geometry and flow conditions. This angle might represent a point where the trade-off between pressure drop and heat transfer effectiveness reaches a maximum. Beyond this angle, further increases in sector angle might lead to even higher pressure drops without substantial improvements in heat transfer efficiency.

IV. CONCLUSION

It is seen that increase in sector angle results in increase in Nusselt number and it is maximum at 150°. This may be due to the fact that at higher values of sector angle, reattachment of free shear layer might not occur and rate of heat transfer enhancement is not proportional to that of friction factor. The sector angle, which defines the angular extent of the coil's cross-section, can influence the flow patterns and turbulence levels within the coil. Higher sector angles can lead to more complex flow behavior, including greater interaction between the fluid and the coil's surfaces. This enhanced interaction can promote better heat transfer, resulting in a higher Nusselt number.

1. Free shear layers can form at the edges of fluid flow, especially in curved or swirling flows. These shear layers can affect the heat transfer and fluid dynamics within the heat exchanger. In the context of your observation, at higher sector angles, the flow patterns might inhibit the reattachment of free shear layers. This can lead to improved mixing and convective heat transfer, contributing to the higher Nusselt number.
2. It is seen that increase in sector angle ratio results in increase in friction factor and it is maximum at 150°. This may be due to the fact that at higher values of sector angle, pumping power is required more. In a helical coil heat exchanger, this ratio can impact the flow dynamics, pressure drop, and consequently, the friction factor and pumping power required. In a helical coil heat exchanger, as the sector angle ratio increases, the cross-sectional area of the coil's flow passage decreases. This reduction in cross-sectional area can lead to increased flow velocity, especially when the same flow rate is maintained. Higher flow velocity increases the likelihood of fluid friction against the coil's walls, resulting in a higher friction factor.

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