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Experimental Investigations on Heat Transfer and Fluid Flow Characteristics of Helical Coil Heat Exchangers

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ABSTRACT

The current research investigates the heat transfer and flow characteristics of fully developed laminar flow in helical and conical coil tube in tube heat exchangers. The investigation includes both experimental and numerical studies. Numerical studies have been carried out using the finite volume based software ANSYS Fluent. The major parameters identified to describe the heat transfer characteristics of helical coil heat exchangers are Reynolds number, Prandtl number, Dean number, non-dimensional pitch, pitch circle radius, curvature ratio and cone angle. Overall heat transfer coefficients are calculated, and the heat transfer coefficients are determined using Wilson plot. The numerical scheme is validated with the experimental results obtained from the present study and also with that reported in the literature.

Keywords: Mild Steel (MS), metal arc welding, welding current, arc voltage and welding speed.

1.INTRODUCTION

Heat exchange between flowing fluids is one of the most important physical processes. Heat exchangers are used widely both in daily life and industrial applications such as food processing, heat recovery systems, steam generators in thermal power plants, evaporators and condensers in HVAC applications and refrigeration process, heat sinks, automobile radiators and regenerators in gas turbine engines. In the production and management of energy, 90% of the heat energy used is transported through various types of heat exchangers. In most applications, the size of the heat exchanger is an important factor due to space constraints. The size of the heat exchanger can be reduced by increasing the heat transfer characteristics. The heat transfer rates in helical coil and spiral coil heat exchangers are high compared to straight pipes, especially in the laminar regime. The next section deals with the introduction to heat exchangers and their classification.

1.1 HEAT EXCHANGERS

The heat exchanger is a device used to transfer heat between two or more fluids that are at different temperatures, and the fluids can be single-phase or two-phase. Heat exchangers are classified according to the heat transfer process, flow arrangement and type of construction (figure 1.1). A heat exchanger in which two fluids exchange heat by coming into contact is called a direct contact heat exchanger. Examples of this type are open feed waters heaters, cooling tower, desuperheaters and jet condensers.

1.2 HEAT TRANSFER ENHANCEMENT TECHNIQUES

The design of an efficient heat exchanger has always been significant to equipment designers. The major challenge in designing a heat exchanger is to make the equipment compact and achieve a high heat transfer rate using minimum pumping power. The study of improved heat transfer performance is referred to as heat transfer augmentation, enhancement, or intensification. The heat transfer enhancement enables in reducing the size of the heat exchanger. Generally, heat transfer augmentation techniques are classified into three broad categories (i) passive method, (ii) active method and (iii) compound method.

1.3 TUBULAR HEAT EXCHANGERS

Tubular heat exchangers are used where relatively high pressures must be applied, particularly suitable for heating or cooling highly viscous products. One or more tubes enclosed within a larger tube constitute a tubular heat exchanger. The cooling medium flows through the larger tube. The product flows through the smaller tubes, which is surrounded by the cooling medium.

1.4 APPLICATIONS OF HELICAL COIL HEAT EXCHANGER

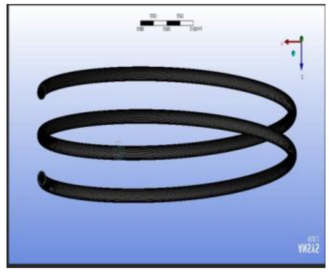
Due to the compact structure and high heat transfer coefficient, helical coil heat exchangers are widely used in industrial applications such as power generation, nuclear industry, process plants, heat recovery systems, refrigeration, chemical processing and food industries etc.

2 EXPERIMENTAL SETUP

The schematic diagram of the experimental setup is shown in figure 3.3. The helical coil heat exchanger was made using standard copper tubes and copper connections. A helical coil heat exchanger with a curvature of 235.9 mm (Rennie et al. 2005) is selected. Commercially available tube sizes are chosen for inner and outer tubes. The inner diameter of the inner tube is 7.9 mm, and the wall thickness is 0.8 mm. The corresponding dimensions of the outer tube are 14.3 mm and 0.8 mm, respectively. The pitch of the coil is three times the outer diameter of the outer tube. At least two coil turns are necessary to fully develop Dean vortices in a helical coil (Saxena and Nigam, 1984).

To get a fully developed flow condition number of turns is selected as two. For a curvature of 235.9 mm and pitch of 48 mm, a coil with two turns gives a length of 2960 mm, and the height of the coil is 96 mm. Two layers of thermal insulations were provided on the outer surface of the heat exchanger. The first layer is polyurethane foam (PUF) insulation, and the second layer is the asbestos rope.

Copper helical coil heat exchanger

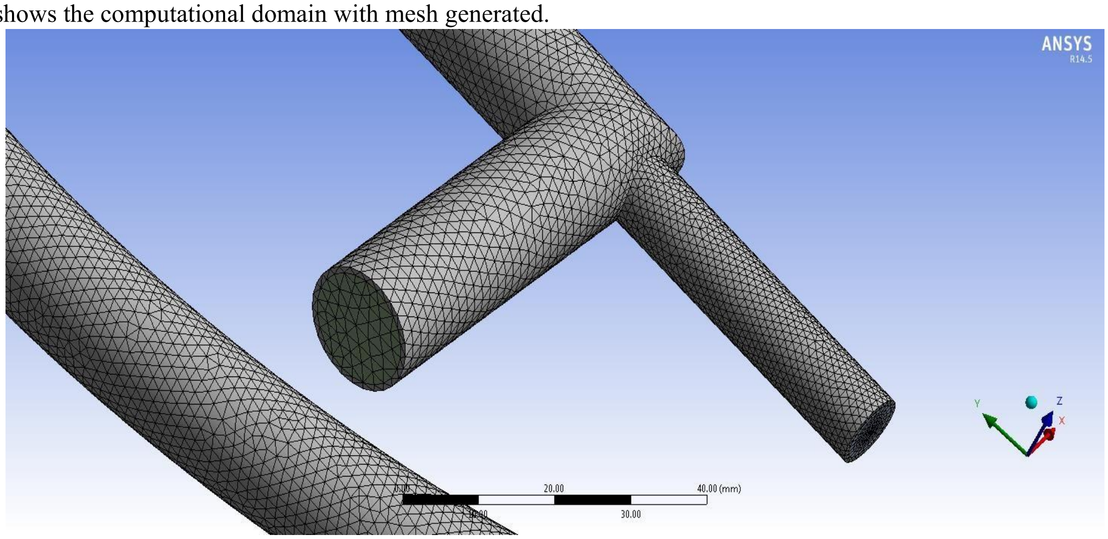


Computational domain

2.1 GEOMETRY MODELLING AND MESHING

The 3D-geometry of the double tube helical coil heat exchanger is modelled using AutoCAD 14.0 and ANSYS 14.5 Design Modeler, and the same is shown in figure

The mesh was created using the meshing module of the ANSYS 14.5 workbench. Initially, a relatively coarser mesh is generated. This mesh contains mixed cells (Tetra and Hexahedral cells), having both triangular and quadrilateral faces at the boundaries. Care is taken to use structured hexahedral cells as much as possible. It is meant to reduce numerical diffusion as much as possible by structuring the mesh in a good manner, particularly near the wall region. Later on, a fine mesh is generated, and inflation layers are provided for all the solid-fluid wall interfaces. Figure 3.5 shows the computational domain with mesh generated.

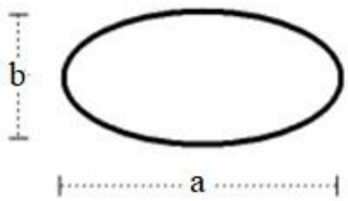


Meshed geometry with end connection

Table 2.21 Dimensions for the study of the effect of inner tube diameter

	do (mm)	di (mm)	t (mm)	Do (mm)	Di (mm)	R (mm)	p (mm)
Case 1	12.7	11.1	0.8	15.9	14.3	235.9	15.9
Case 2	9.5	7.9	0.8	15.9	14.3	235.9	15.9
Case 3	6.35	4.75	0.8	15.9	14.3	235.9	15.9

2.2.2 Major and minor diameter dimensions of three configurations of elliptical cross-section



Major diameter, a (mm)	Minor diameter, b (mm)
10.6	4.60
9.6	5.99
8	7.9

Studies also have been conducted to see the effect of the cross-section of the inner tube on the heat transfer flow characteristics. The following major and minor diameters were used to create three configurations, as in Table 2.2.2. Dimensions of the helical coil heat exchanger with elliptical cross-section are identical to the above cases, except for the inner tube dimensions; further, in all the cases, the heat transfer area of the inner tube is maintained the same. The heat transfer analysis of the tube in tube heat exchanger is solved using Fluent 14.5.

2.2 BOUNDARY CONDITIONS

Mass flow boundary conditions are applied at the inlets, and pressure outlet boundary conditions are specified at the outlets. The hot and cold fluids flow in the counterflow configuration. The adiabatic boundary condition is applied at the outer surface of the heat exchanger. The interface boundary condition is used at the solid-fluid interfaces, and the heat transfer is computed using the conjugate heat transfer algorithm available in Fluent.

The effect of temperature on the properties of water, like thermal conductivity (k_f), viscosity (μ_f), and specific heat (C_p), are considered using the following equations.

$$k_f = -1.273+0.013T-2.82e\text{-}5T^2+2.083e\text{-}8T^3 \quad (2.23)$$

$$\mu_f = 0.078-6.51e\text{-}4T+1.834e\text{-}6T^2-1.735e\text{-}9T^3 \quad (2.24)$$

$$Cp = 4181-0.19T+0.00125T^2+4.167e\text{-}5T^3 \quad (2.25)$$

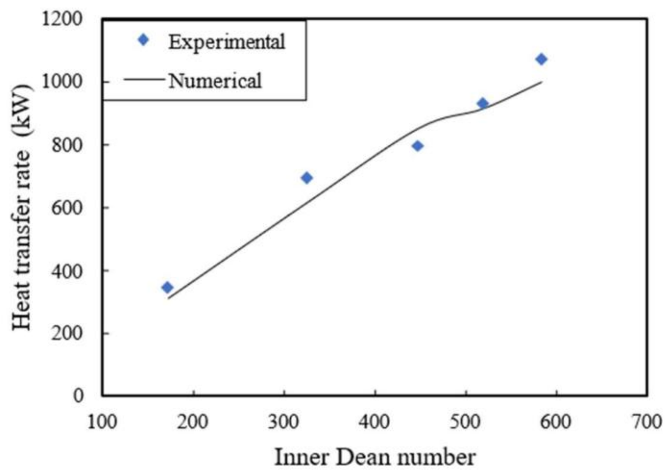
$$\rho = 1000.8-0.0283T-0.0051T^2-1.002e\text{-}5T^3 \quad (2.26)$$

3.RESULTS AND DISCUSSION

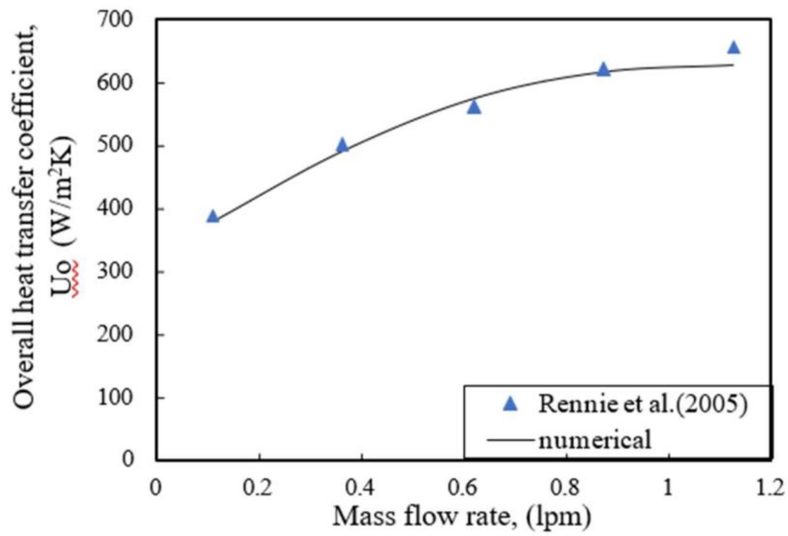
Experimental and numerical investigations have been carried out to study the effect of Reynold number, Prandtl number, Dean number, non-dimensional pitch, the diameter of the inner tube and cross-section of the inner tube on the heat transfer and flow characteristics of a double tube helical coil heat exchanger. The flows in both the inner tube and annulus are laminar, and the flow configuration is counter flow. In the numerical study, the pitch is varied from 16 mm to 144 mm, maintaining the length and radius of curvature the same.

i.VALIDATION OF THE NUMERICAL SCHEME

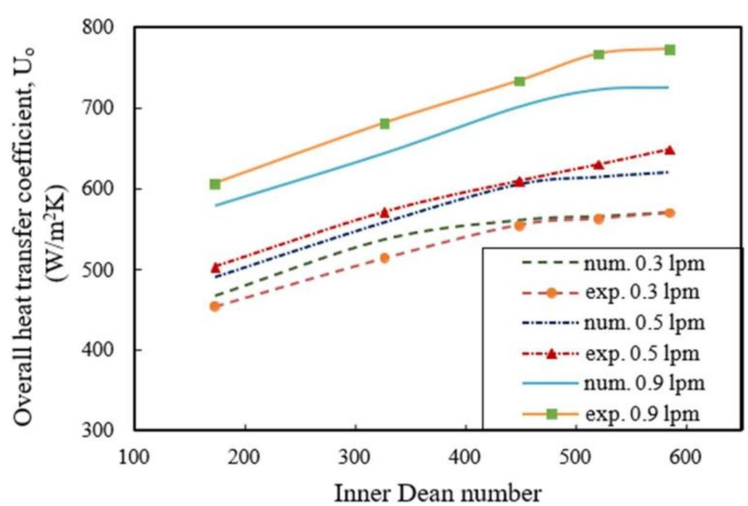
Figure 3.8 shows the variation of heat transfer rate with the Dean number in the inner tube obtained from the present experimental studies. Here the pitch of the coil is 48mm. The inner flow rate varies from 0.3 to 0.9 lpm keeping the mass flow rate through the annulus constant. The results obtained from numerical studies are also shown for comparison. There is a fair agreement between the result obtained from experimental and numerical studies, and the maximum deviation is only 10%. Heat transfer rate increases by 75 % when the Dean number is increased from 325 to 600. The increase in a secondary flow ensures proper mixing of the fluid inside the tube.



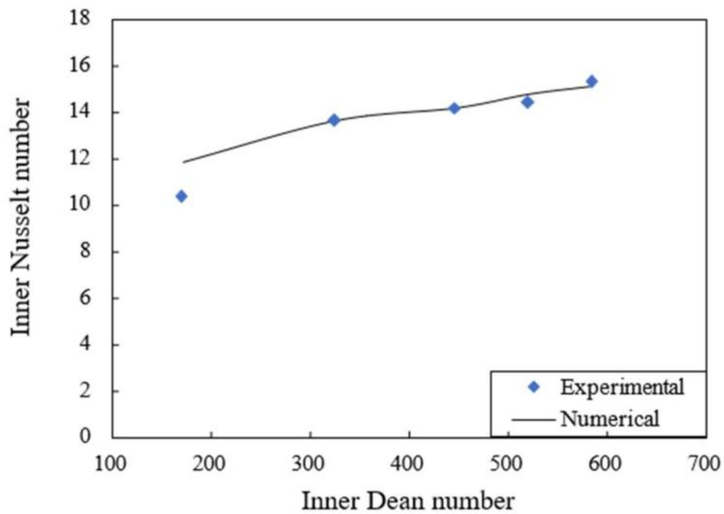
Effect of inner Dean number on the heat transfer rate



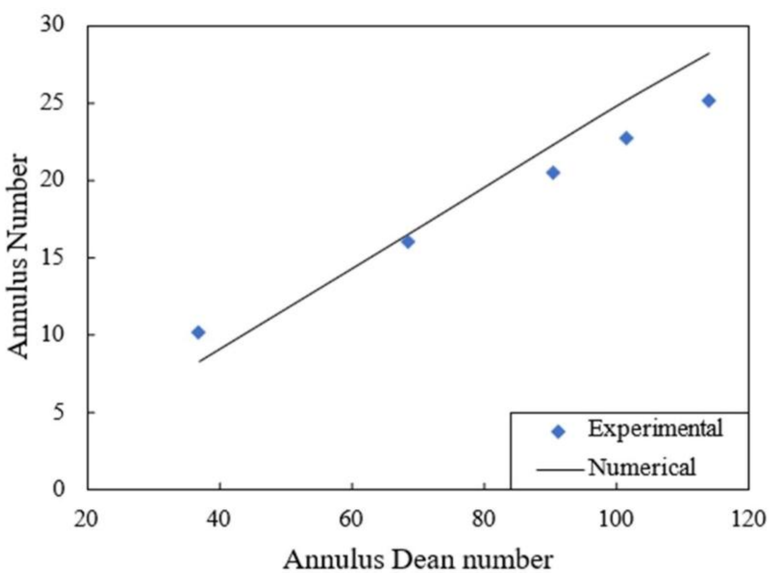
Variation of overall heat transfer coefficient with the inner mass flow Rate



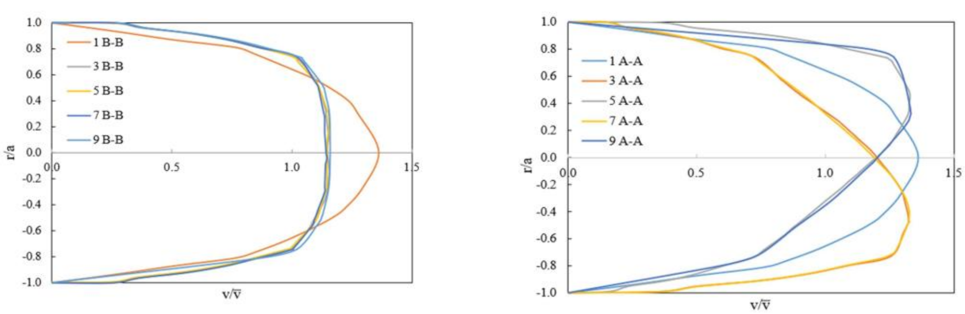
Effect of inner Dean number on overall heat transfer coefficient



Effect of inner Dean number on inner Nusselt number



Effect of annulus Dean number on annulus Nusselt number



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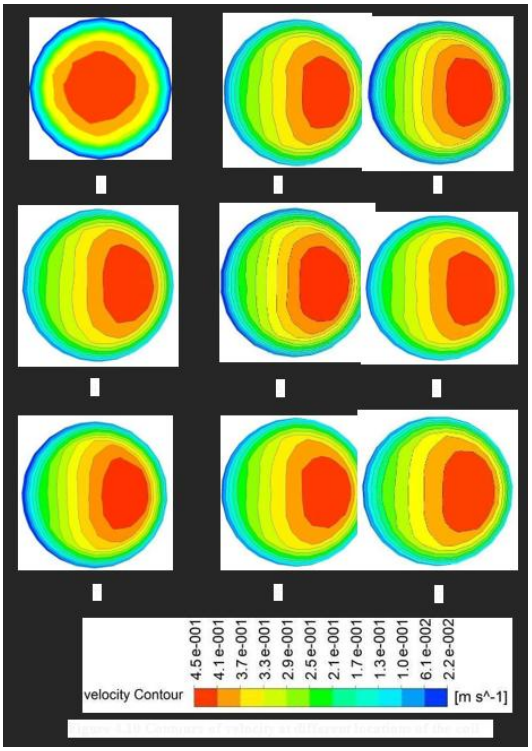
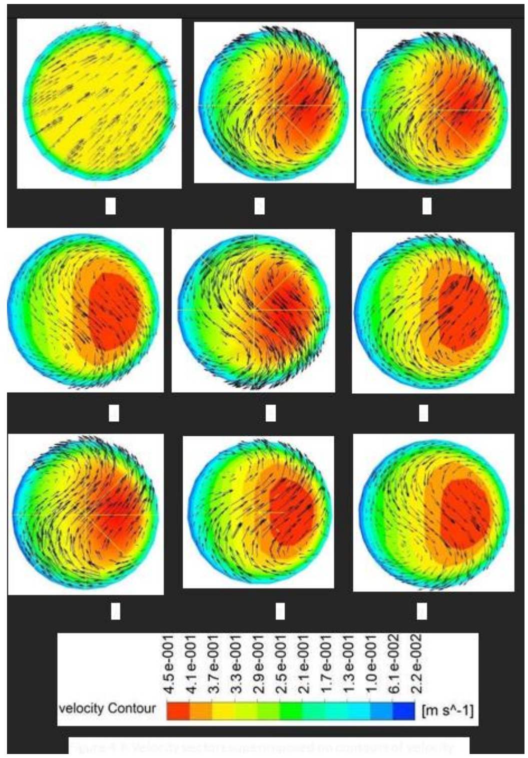
(a) (b)

Velocity profile at various locations (a) line B-B (b) line A-A





Contours of velocity at different locations of the coil Velocity vectors superimposed on contours of velocity

5. CONCLUSIONS

Experimental and numerical investigations have been carried out to study the heat transfer and flow characteristics in a double tube helical coil heat exchanger. The effect of Reynold number, Prandtl number, Dean number, non-dimensional pitch, the diameter of the inner tube and cross-section of the inner tube are studied. The numerical results of the present study agree satisfactorily with the experimental data. The heat transfer behavior of a helical heat exchanger is significantly affected by two major parameters, namely Dean number and torsion. The secondary flow is stronger at higher Dean numbers.

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