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Experimental and CFD Optimization of heat transfer in helically coiled heat exchangers

KEYWORDS: Helical coil Heat exchanger, CFD or computational fluid dynamics, Conjugate heat transfer, Heat transfer optimization, Solid works 2009, Ansys CFX 12.1

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ABSTRACT Enhancement in heat transfer due to helical coils has been reported by many researchers. While the heat transfer characteristics of helical coiled heat exchangers are available in the literature, there exists no published experimental or theoretical analysis of a helically coiled heat exchange considering fluid-to-fluid heat transfer, which is the subject of this work. After validating the methodology of CFD analysis of a heat exchanger, the effect of considering the actual fluid properties instead of a constant value is established. Heat transfer characteristics inside a helical coil for various boundary conditions are compared. It is found that the specification of a constant temperature or constant heat flux boundary condition for an actual heat exchanger does not yield proper modeling. Hence, the heat exchanger is analyzed considering conjugate heat transfer and temperature dependent properties of heat transport media. An experimental setup is fabricated for the estimation of the heat transfer characteristics.

1. INTRODUCTION

It has been widely reported in literature that heat transfer rates in helical coils are higher as compared to a straight tube. 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, food industry, etc. (Xin et al., 1996; Abdulla, 1994; Bai et al.,1999; Jensen and Bergles, 1981; Futagami and Aoyama, 1988; Patankar et al., 1974).

Heat exchanger with helical coils is used for residual heat removal systems in islanded or barge mounted nuclear reactor system, wherein nuclear energy is utilised for desalination of seawater (Manna et al., 1996). The performance of the residual heat removal system, which uses a helically coiled heat exchanger, for various process parameters was investigated by Jayakumar and Grover (1997). The work had been extended to find out the stability of operation of such a system when the barge on which it is mounted is moving (Jayakumar et al., 2002). In all these studies, empirical correlations were used to estimate the amount of heat transfer and pressure drop in the helical coils. The appropriateness of the correlation used in the above work is uncertain for the specific application and in the present work, it is proposed to generate the desired correlations using numerical and experimental work.

Heat transfer and flow through a curved tube is comprehensively reviewed first by Berger et al. (1983) and subsequently by Shah and Joshi (1987). The latest review offlow and heat transfer characteristics is provided by Naphon and Wongwises (2006). The characteristics of flow, pressure drop and heat transfer have been reported by many investigators. The heat transfer enhancement in helical coil systems is reported by Prabhanjan et al. (2004), Berger et al. (1983), Janssen and Hoogendoorn (1978) and Ruthven (1971). Condensing heat transfer and pressure drop of refrigerant R 134A in helicoidal (helical double pipe heat exchanger) is experimentally investigated by Kang et al. (2000). The effect of torsion on the flow in a helical tube of circular cross-section is experimentally investigated by Yamamoto et al. (1995) for a range of Reynolds numbers from about 500 to 20,000.

Most of the investigations on heat transfer coefficients are for simplified boundary conditions such as constant wall temperature or constant heat flux (Prabhanjan et al., 2004; Shah and Joshi, 1987; Nandakumar and Masliyah, 1982). The situation of constant wall temperature is idealised in heat exchangers with phase change such as condensers. The boundary condition of constant heat flux finds application in electrically heated tubes and nuclear fuel elements. However, the case of fluid–fluid heat exchange has not been studied well. An experimental study of a double pipe helical heat exchanger was conducted by Rennie and Raghavan (2005). The double pipe helical coil heat exchangerwas further numerically investigated by Rennie and Raghavan (2006a,b).

CHARACTERISTICS OF HELICAL COIL

Fig. 1 gives the schematic of a helical coil. The pipe has an inner diameter 2r. The coil has a diameter of 2Rc (measured between the centres of the pipes), while the distance between two adjacent turns, called pitch is H. The coil diameter is also called pitch circle diameter (PCD). The ratio of pipe diameter to coil diameter (r/Rc) is called curvature ratio, ι. The ratio of pitch to developed length of one turn (H/2_Rc) is termed non-dimensional pitch, _. Consider the projection of the coil on a plane passing through the axis of the coil. The angle, which projection of one turn of the coil makes with a plane perpendicular to the axis, is called the helix angle.

Similar to Reynolds number for flow in pipes, Dean number is used to characterize the flow in a helical pipe. The Dean number, De is defined as,

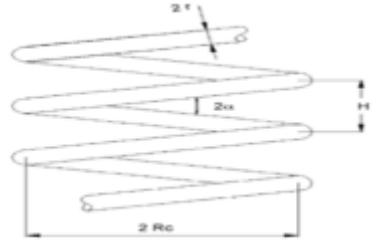

Fig. 1 Basic geometry of Helical Spring

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$$De = Re\sqrt{r/Rc}$$

Where, Re is the Reynolds number = 2ruavP/μ.
Many researchers have identified that a complex flow pattern
exists inside a helical pipe due to which the enhancement in heat transfer is obtained. The critical Reynolds number for the transition from laminar
to turbulent flow in helical coils is a function of the coil parameters. The critical Reynolds number may be determined using the correlation by Schmidt (1967).

$$Re_{cr} = 2300\left[1 + 8.16\left(\frac{r}{Rc}\right)^{0.46}\right]$$

For curvature ratios less than 1/860, the critical Reynolds number becomes equal to that of a straight tube.

2. DESCRIPTION OF PHYSICAL PROBLEM

The Helical Coil Heat Exchanger is considered in this study. From Experimental results heat transfer calculation of helical coil heat Exchanger were calculated. After Experimental work modeling of helical coil heat exchanger done in Solid works 2009.CFD Analysis of helical coil heat exchanger carried out in readily available CFD software Ansys CFX.

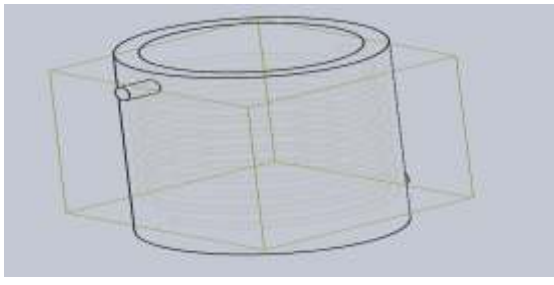

Fig.2 Assembly of Helical Coil Heat Exchanger

3. EXPERIMENTAL SETUP

3.1 HELICAL COIL TEST SECTION

The pipe used to construct the helical section has 10mm i.d. and 12.7mm o.d. The tube material is SS 316. The Pitch Circle Diameter (PCD) of the coil is 300mm and tube pitch is 30mm. The remaining parts of the setup are made of SS 304.
The helical coil is enclosed in a vessel to simulate the shell side of heat exchanger. The details are given in Fig. 2.
The helical coil test section is connected to a loop, which provides the necessary flow through the tube and shell side of the test section and the required instrumentation. Fig. 3 illustrates the loop used for the estimation of heat transfer coefficient.

A tank with electrical heaters is provided to heat the water to be circulated through the helical coil. There are three heaters, with a total power of 5000W. A controller is provided to maintain the temperature of water at the inlet of the test section at the set value. The hot fluid from the tank is pumped through the test section using a centrifugal pump of 1/2 hp power rating. Flow rate of hot fluid is measured using a rotameter. Both inlet and outlet temperatures of the hot fluid are measured by using RTDs and the values are available on digital displays.

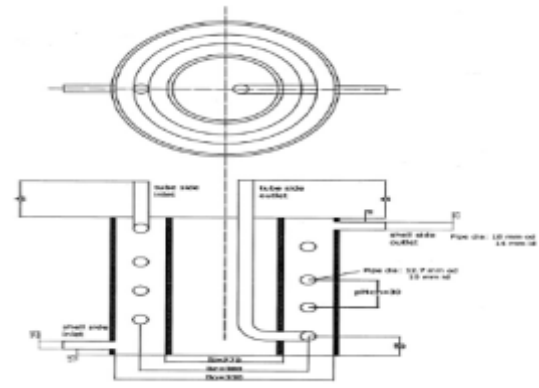

Fig.3 Schematic of the Helical Coil test section.

Cooling water from a constant temperature tank is circulated through the shell side. Its flow rate, inlet and outlet temperatures are measured. Flow rate of cooling water is kept constant. Its flow is adjusted such that the rise in temperature of the cooling water is approximately 3 to 5 C.

3.2. EXPERIMENTAL PROCEDURE

Measurements are taken only after the temperatures attain steady values. Experiments are conducted for Six different flow rates through the coil and for three different values of temperature at the inlet of the helical pipe. During the course of each set of experiments, the flow rate through the shell side is kept constant, which ensures a constant heat transfer coefficient on the shell side. The experiment is carried out by changing the flow rate through the tube.

4. MODELLING OF HELICAL COIL HEAT EXCHANGER IN SOLIDWORKS

After performing Experiments, the modeling has been performed on the Solid works 2009 version and then after the analysis work has been performed on the ANSYS 12.1 version.

Solid works is a computer graphics system for modeling various mechanical designs for performing related design and manufacturing operations. The system uses a 3D solid modeling system as the core, and applies the feature base parametric modeling method. In short solid works is a feature based parametric solid modeling system with many extended design and manufacturing applications.

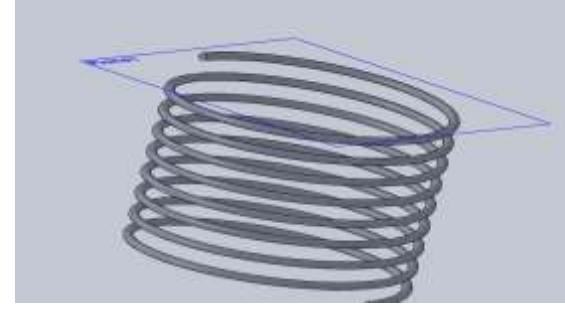

Fig. 4 Cavity of Helical Pipe inner fluid (N2 Gas)

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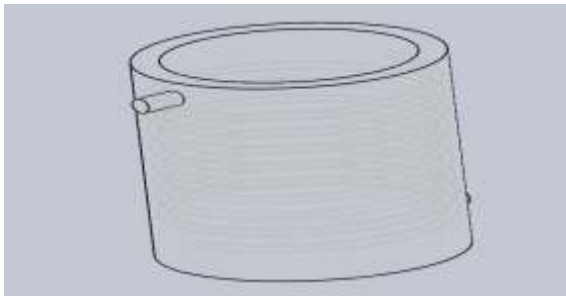

Fig.5 3D Modeling of Helical Coil Heat Exchanger in the solid works.

5. CFD ANALYSIS OF HELICAL COIL HEAT EXCHANGER

CFD provides numerical approximation to the equations that govern fluid motion. Application of the CFD to analyze a fluid problem requires the following steps. First, the mathematical equations describing the fluid flow are written. These are usually a set of partial differential equations. These equations are then discretized to produce a numerical analogue of the equations. The domain is then divided into small grids or elements. Finally, the initial conditions and the boundary conditions of the specific problem are used to solve these equations.

All CFD codes contain three main elements:

(1) A pre-processor, which is used to input the problem geometry, generate the grid, and define the flow parameter and the boundary conditions to the code.

(2) A flow solver, which is used to solve the governing equations of the flow subject to the conditions provided. There are four different methods used as a flow solver:

- Finite Difference Method
- Finite Element Method
- Finite Volume Method
- Spectral Method

(3) A post-processor, which is used to massage the data and show the results in graphical and easy to read format.

Computational fluid dynamics readily complements the previous dimensions of pure experiment & theory. Computational fluid dynamics in principle, allows the practical solution of the Exact Governing equitation of applied Engineering problems.

Computational fluid dynamics is the art of replacing the governing nonlinear partial differential equations with numbers and advancing these numbers in space and or time to obtain a final numerical description of the complete flow field at interest. The end product of CFD is indeed a collection of numbers, in contrast to a class form analytical solutions.

Following step describes the general methodology adopted for solving problem of helical coil heat exchanger.

The 3D geometry of the helical coil heat exchanger and flow domain was created in Solid works 2009. A grid was generated within the flow domain. Unstructured Grid was used for meshing. Generated grid is a Unstructured mesh consisting total number of Nodes (48923) and total number of Elements (98347) . Numerical conditions need to be applied at the boundaries of the flow domain and zones.

Details of the refined mesh are shown in fig.6



Fig.6 Meshing Geometry in ANSYS

Many investigators have applied different Heat trsnsfer models for the simulation of helical coil heat exchanger. In the present work, Heat transfer model was used to consider the heat transfer effect.

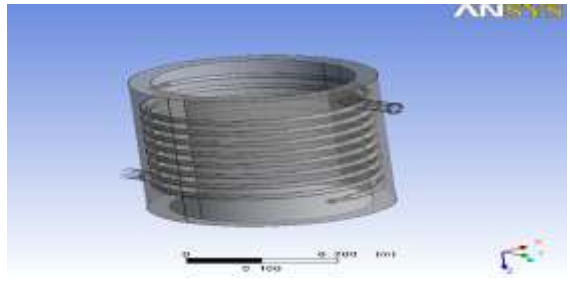

Fig.7 Helical Coil Heat Exchanger in ANSYS CFX PRE

Define Three Domains:-
Domain 1:- Outer Cavity
Domain Type:- Stationary Domain(Fluid)
Fluid: - H2 gas
Heat Transfer Model: - Total Energy

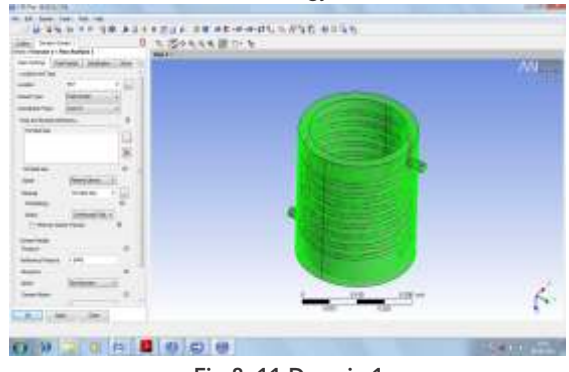

Fig 8. 11 Domain 1

Domain 2:- Pipe
Domain Type: - Stationary Domain (Solid)
Material: - Steel
Heat Transfer Model: - Total Energy



Fig 9. 12 Domain 2

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Domain 3:- Inner Cavity
Domain Type:- Stationary Domain(Fluid)
Fluid :- N2 gas
Heat Transfer Model: - Total Energy



Fig 10. 13 Domain 3

6. RESULTS AND DISCUSSION:

The numerical study was carried out for helical coil heat exchanger using heat transfer model in readily available CFD Software ANSYS CFX 12.1.

1) QUALITATIVE ANALYSIS



Fig 11. Temperature Contour

Temperature profile of the hot fluid is given in Fig. 11. The effect of cross flow in the shell region is visible from the temperature contours.



Fig 12. Pressure Contour

Pressure profile of the hot fluid is given in Fig. 12. The effect of pressure in the shell region is visible from the pressure contours.

EFFECT OF PITCH CHANGE ON HEAT TRANSFER CHARACTRITICS

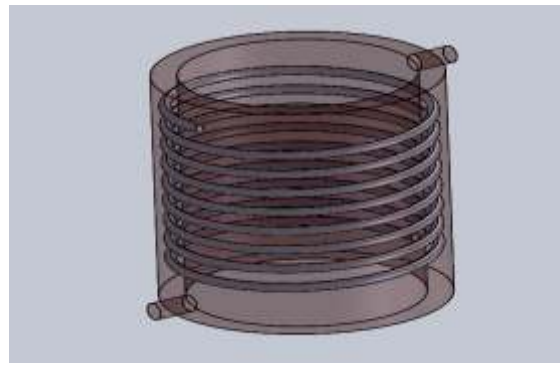

Fig 13 Existing Helical Coil Heat Exchanger (Pitch 30 mm)

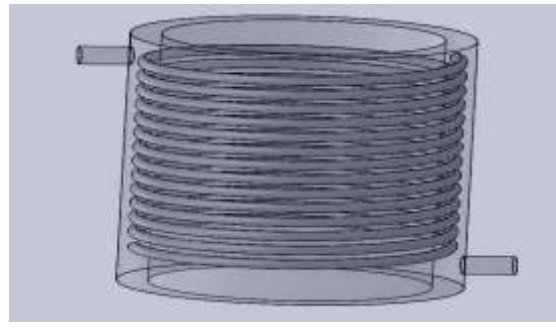

Fig 14. Pitch Changed Helical Coil Heat Exchanger (Pitch 20 mm)



Fig 15. Pitch Changed Meshed Model

2) QUANTITATIVE ANALYSIS

We were carried out numerical analysis for different velocity keeping inlet constant and get the results which shows in the below graph.

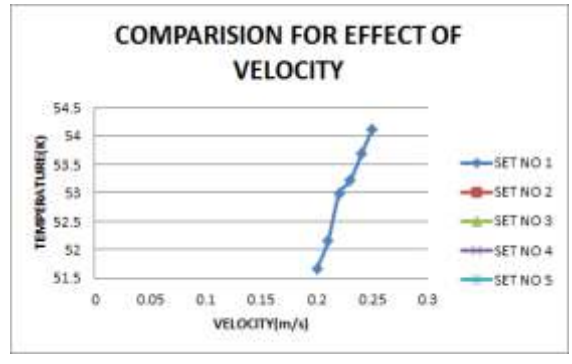

Fig 16 Comparison for Effect of Velocity

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As Stated in Problem Definition, Achieving our challenge for increasing mass flow rate of liquid nitrogen without increasing Overall circuit of Nuclear Reactor cooling. We have increased velocity in Existing Helical Coil Heat Exchanger and analyzed a result which shows that as the velocity increase heat transfer decreases.

We were carried out CFD analysis on the pitch changed model as given in Fig.15 and found below results as shown in the below graph.

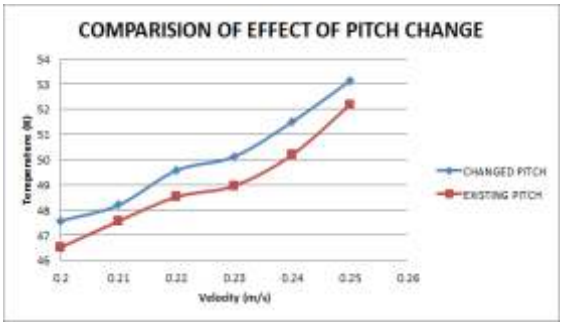

Fig 17 Comparison of effect of pitch change

For Recover Heat Transfer Value we have decrease Pitch and analyze results which show that as the pitch decrease heat transfer increases.

7. CONCLUSION

A computational study has been accomplished to determine the effects of heat transfer in the helical coiled heat exchanger. It is concluded that the CFD analysis results fairly matches with the Experimental Results. This shows that CFD Analysis is a powerful tool to replace costly experiment and lengthy calculation.

A comparison with experimental results and CFD simulations has proven that for increasing mass flow rate of liquid nitrogen without increasing Overall circuit of Nuclear Reactor cooling. By increasing velocity in existing helical coil heat exchanger and analyzed a result which shows that as the velocity increase heat transfer decreases and decrease Pitch and analyze results which shows that as the pitch decrease heat transfer increases

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