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A REVIEW ON HEAT TRANSFER THROUGH HELICAL COIL HEAT EXCHANGERS

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ABSTRACT

This study presents a brief review of heat transfer through helical coil heat exchangers. Helical coils of circular cross section have been used in wide variety of applications due to simplicity in manufacturing. Enhancement in heat transfer due to helical coils has been reported by many researchers. While the heat transfer characteristics of double pipe helical heat exchangers are available in the literature, there exists no published experimental or theoretical analysis of a helically coiled heat exchanger 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 modelling. Hence, the heat exchanger is analysed considering conjugate heat transfer and temperature dependent properties of heat transport media.

KEYWORDS:Helical coil Heat exchanger, CFD or computational fluid dynamics, Conjugate heat transfer, Heat transfer correlation.

INTRODUCTION

Helical coil heat exchangers are of great use in industrial applications such as power generation, nuclear industry, process plants, heat recovery systems, refrigeration, food industry, etc due to its compact structure and high heat transfer coefficient. Helical coils of circular cross section have been used in wide variety of applications due to simplicity in manufacturing. Flow in curved tube is different from the flow in straight tube because of the presence of the centrifugal forces. These centrifugal forces generate a secondary flow, normal to the primary direction of flow with circulatory effects that increases both the friction factor and rate of heat transfer. The intensity of secondary flow developed in the tube is the function of tube diameter (d) and coil diameter (D). Due to enhanced heat transfer in helical coiled configuration the study of flow and heat transfer characteristics in the curved tube is of prime importance. Developing fluid-to-fluid helical heat exchangers (fluid is present on both sides of the tube wall) requires a firm understanding of the heat transfer mechanism on both sides of the tube wall. Though much investigation has been performed on heat transfer coefficients inside coiled tubes, little work has been reported on the outside heat transfer coefficients.

LITERATURE REVIEW

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. Bai et al., 1999;[1]. 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 [2]. 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 [3]. 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. 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 Shah and Joshi 1987 [4]. The latest review of flow and heat transfer characteristics is provided by Naphon and Wongwises 2006 [5]. Helical coils of circular cross section have been used in wide variety of applications due tosimplicity in manufacturing. Flow in curved tube is different from the flow in straight tube because of the presence of the centrifugal forces. These centrifugal forces generate a secondary flow, normal to the primary direction of flow with circulatory effects that increases both the friction factor and rate of heat transfer. The intensity of secondary flowdeveloped in the tube is the function of tube diameter (d) and coil diameter (D) as presented by Dravid et al [6]. Dueto enhanced heat transfer in helical coiled configuration the study of flow and heat transfer characteristics in the curved tube is of prime importance. Developing fluid-to-fluid helical heat exchangers (fluid is present on both sides of the tube wall) requires a firm understanding of the heat transfer mechanism on both sides of the tube wall. Though much investigation has been performed on heat transfer coefficients inside coiled tubes, little work has been reported on the outside heat transfer coefficients. Ali [7] obtained average outside heat transfer coefficients for turbulent heat transfer from vertical helical coils submersed in water.

Most of the investigations on heat transfer coefficients are for simplified boundary conditions such as constant wall temperature or constant heat flux , Nandakumar and Masliyah, 1982 [8]. Studies helical coil have compact size and higher heat transfer coefficient they are widely used in industrial applications such as food preservation, refrigeration, process plant, power generation, etc. An attempt has been made to study the parallel flow and counter flow of inner higher temperature fluid flow and lower temperature fluid flow, which are separated by copper surface in a helical coil heat exchanger. Helical geometry allows the effective handling at higher temperatures and extreme temperature differentials without any highly induced stress or expansion of joints. This type of heat exchanger consists of series of stacked helical coiled tubes and the tube ends are connected by manifolds, which also acts as fluid entry and exit locations. In this paper, we focus on design parameters and heat transfer conditions of a vaporizer or generator of a simple vapor absorption refrigeration system having flow condition of refrigerant taken as laminar flow, Kapil Dev et al (2014)[11].

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 2*R*c (measured between the centers 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/R*c) is called curvature ratio, δ. The ratio of pitch to developed length of one turn (*H/2πR*c) is termed non-dimensional pitch, λ. 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, α. Similar to Reynolds number for flow in pipes, Dean number is used to characterise the flow in a helical pipe. The Dean number, *De* is defined as,

$$De = Re\sqrt{\frac{r}{R_C}},$$

(1)

Where, *Re* is the Reynolds number = $2ru_{av}\rho/\mu$.
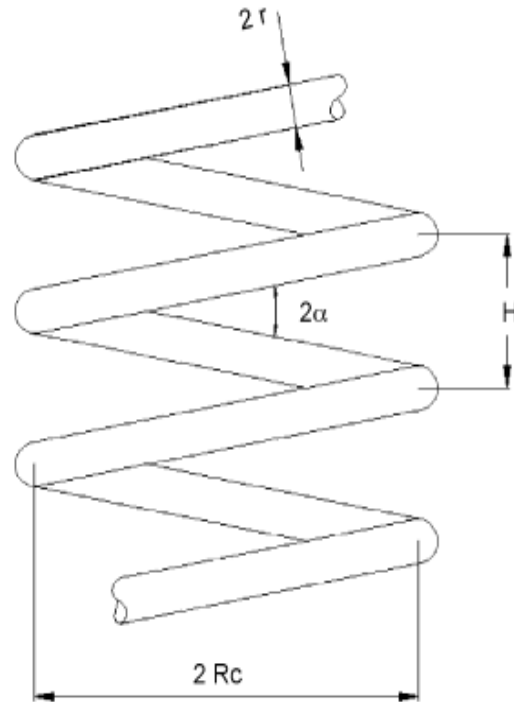
Fig. 1 – Basic geometry of a helical pipe

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 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. 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).

$$Re_{cr} = 2300 \left[1 + 8.6 \left(\frac{r}{R_c} \right)^{0.45} \right]$$

(2)

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

EXPERIMENTAL SET-UP OF HELICAL COIL HEAT EXCHANGER

The schematic of the experimental set-up used for the present investigation is shown figure 2. The set-up consisted of the following components; Helical coil , Shell, Heater, Flow measuring devices, Cold water source **S.S. Pawar** et al [9].
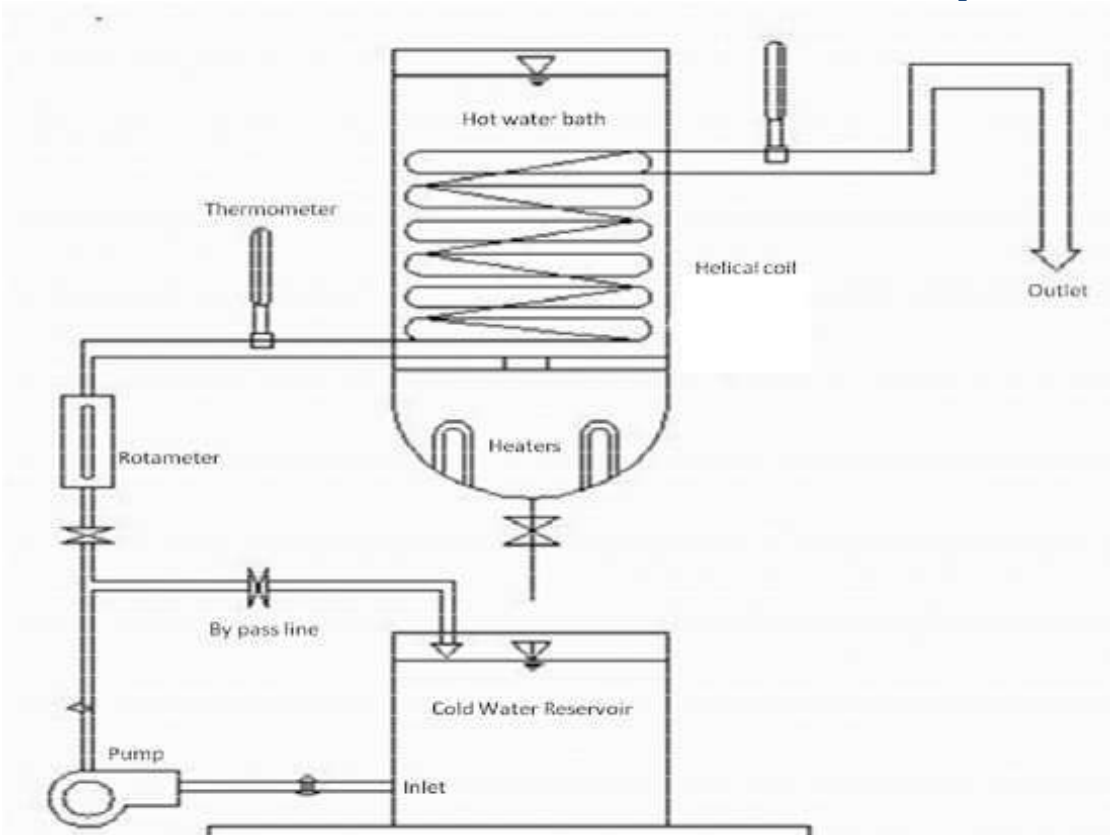
Fig. 2: Schematic of Helical Coil Heat Exchanger

The reservoir and the vessel were filled with water after which the water from the reservoir tank was pumped through the coil by using centrifugal pump. The flow rate of the water was measured by using a rotameter. Flow rate for each reading was verified by noting down the time taken by the water from the outlet of the coil to fill a measuring cylinder of 1 liter to reduce the error in the flow measurements. As the water passed through the coil it was heated by the water in the vessel equipped with two heaters. Inlet and outlet temperature of the water as well as the vessel temperature were noted down only after the system was allowed to come to a steady state condition. A temperature of 55℃ was maintained to carry out the experiments in isothermal conditions. As soon as the required temperature was attained, the first reading was taken and the remaining readings were taken at a time interval of 15 minutes.

Hot water from heater flows inside the tube where it loses heat to cold water flowing through shell. The entry and exit of cold water in shell kept at top so shell should be filled completely and complete coil must be immersed in water. The flow of cold water is controlled by rotameter at the entry in shell, this cold water then carries heat to drainage. Hot water mass flow rate controlled after the exit of helical coil. This is done to get parallel flow and counter flow configurations. Heat transfer and thermodynamic analyses of a helically coiled heat exchanger using different types of Nano fluids were investigated by Khairul et al. [4]. Copper helically coiled of 9 mm inner diameter, 116 mm coil diameter and 18 mm coil pitches for 10 turn were analysed. The increment of particle volume fraction and volume flow rate of Nano fluids could enhance heat transfer coefficient and reduce the entropy generation rate.Hashemi and Behabadi [5] experimentally investigated heat transfer and pressure drop characteristics of CuO base oil Nano fluid flow forReynolds number 10–150 in a horizontal helically coiled copper tube of curvature ratio 0.044 and coil pitch 55 mm under constant heat flux.

E. Ibrahim et al. [12] investigated on Experimental Study of Forced Convection over Equilateral Triangle Helical Coiled Tubes in this experimental study he was focused on the investigation of the heat characteristics of an equilateral triangular cross-sectioned helical tube under uniform heat flux boundary condition. The experiments were performed

using groups of equilateral triangles helical tubes. Nine helical coiled-tubes of equilateral triangular cross sectioned with various pitches and coil diameters are used.

METHODOLOGY

Heat loss from the hot water in the vessel to the cold water passing through the coil is give as

$$Q = \dot{m}Cp(T_{out} - T_{in})$$

(3)

overall heat transfer coefficient can be calculated as

$$U_o = \frac{Q}{A_o \Delta T_o}$$

(4)

As per D.G Prabhanjan [13] the overall heat transfer coefficient can be described in terms of thermal resistances for a cylindrical tube as

$$Uo = \frac{1}{\left[\frac{1}{ho} + \frac{r_o \ln\left(\frac{r_o}{r_i}\right)}{k} + \frac{r_o}{r_i h_i}\right]}$$

(5)

Nusselt number, Nui, of the coil, given as

$$N_{ui} = 0.021 \, Re^{0.85} Pr^{0.4} \left(\frac{ri}{R}\right)^{0.1}$$

(6)

The inside heat transfer coefficient, hi, was determined from

$$h_i = \frac{N_{ui}k}{2r_i}$$

(7)

The wall temperature, Tw, was then determined from,

$$Tw = \frac{Q}{A_i h_i} + T_{bulk}$$

(8)

The outside heat transfer coefficient was then calculated from the equation as

$$h_o = \frac{Q}{A_o(T_v - Tw)}$$

(9)

Ao is the outside surface area of the coil, Tv is the vessel temperature and Tw is the wall temperature.

RESULTS AND DISCUSSION

Sreejith K et.al [15] found that the effectiveness of helical coil heat exchanger is found to be higher when compared to that of the straight tube heat exchanger for all the inlet temperatures Figure 3 gives the variation of effectiveness with inlet temperature of hot water for both helical coil and straight tube heat exchangers.
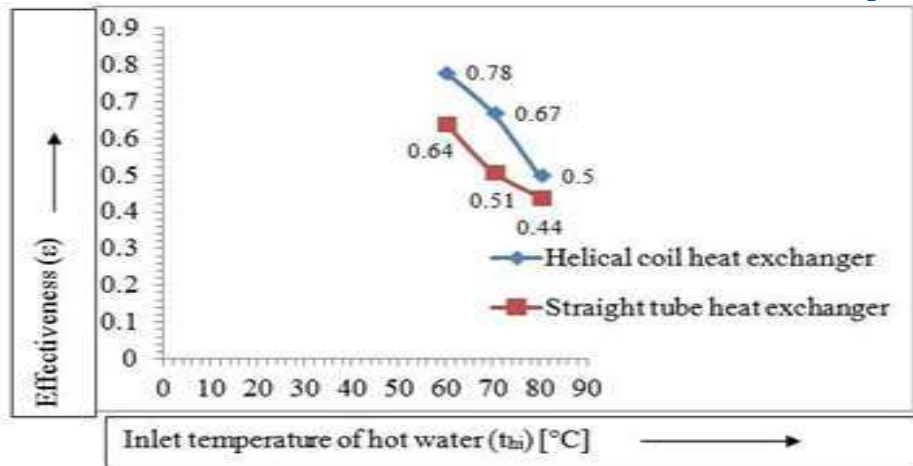
Fig 3 Variation of Effectiveness with Inlet temperature of hot water

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