CHAPTER 1

INTRODUCTION

Heat transfer enhancement techniques have been one of the main thermal engineering research fields since last decades. Many techniques, such as active, passive and compound methods have been used for the enhancement of heat transfer rate in heat exchangers. Active method involves some external power input for the enhancement of heat transfer. Some examples of active methods include mechanicals aids, induced pulsation by cams and reciprocating plungers, the use of a magnetic field to disturb the seeded light particles in a flowing stream, surface vibration, fluid vibration, electrostatic fields, suction or injection and jet impingement. Passive method generally uses surface or geometrical modifications to the flow channel by incorporating inserts or additional devices. For example, inserts extra component, swirl flow devices, treated surface, rough surfaces, extended surfaces, displaced enhancement devices, coiled tubes, surface tension devices and additives for fluids. Combination of the above two methods are compound methods, such as rough surface with a twisted tape swirl flow device, or rough surface with fluid vibration, rough surface with twisted tapes. Passive heat transfer technique when adopted in heat exchanger proved that the overall thermal performance improved significantly; Liu and Sakr (2013). Passive methods are generally more preferred as compared to other enhancement methods due to their simplicity in manufacturing, lower cost and longer operating life.

To improve the heat transfer performance is a chief task in heat exchanger design. A helical coil is one of the most important passive enhancement techniques. It is widely used in heat transfer applications. The phenomena in coiled ducts have attracted much attention from researchers. Secondary flow motion induced by the coil curvature is the more significant phenomena in coiled tubes. Different numerous studies have been conducted to investigate the fluid flow and heat transfer characteristics inside helical coil because of their important applications in various fields.

Flow in curved pipe was first investigated by Dean (1927a, 1927b). The steady motion of incompressible fluid flowing through fully developed laminar flow in a toroidal pipe was considered in the analysis and reported that flow due to curvature depends on dimensionless number termed as Dean number, defined as the ratio of centrifugal force to inertial force. The centrifugal force due to the curvature of the tube exhibits in the secondary flow development which enhanced the heat transfer. The phenomenon was more beneficial; especially in laminar flow regime.

In several studies like Garimella et al (1988), Prabhajan et al. (2002) , Yang and Chiang (2002), Kumar et al. (2006). Hashemi and Behabadi (2012), Elsayed et al. (2012), Pakdaman et al. (2013) etc, it has been proved that helical coils are superior to straight tubes.

The research on the single phase fluid flow and heat transfer characteristics in helical coil and heat exchanger with micro sized tubes is very limited while significant amount of research had been done for conventional sizes helical coil and heat exchanger. The use of micro diameter tubes in helical exchanger has the potential of increasing the heat transfer rate due to increased surface area per unit volume and increased heat transfer coefficients. However, there is penalty of increase in pressure drop associated with reducing tube diameters. There are very limited experimental studies on helical coils of micro-diameter tubes. Therefore, an investigation into fluid flow and heat transfer in helical coils of micro-diameter tubes for laminar flow is performed to provide knowledge on hydrodynamic and thermal characteristics.

1.1 Classifications of tubes

In order to study the fluid flow and heat transfer in helical coils of micro-diameter tubes, it is necessary to characterize the size of the tubes. Large numbers of investigation has been done on the classification of channel or tube by various researchers. Different authors have suggested different classifications.

According to Mehendale et al. (2000) the following classifications have been proposed for various ranges of channel dimensions, “d_i”.

$1\mu m \langle d_i \langle 100\mu m$: Microchannels

$100\mu m \langle d_i \langle 1\ mm$: Minichannels

$1\ mm \langle d_i \langle 6\ mm$: Compact Passages

$6\ mm \langle d_i$: Conventional Passages

Kandlikar and Grande (2003) adopted a different classification for various ranges of channel dimensions, "d_i" being the smallest channel dimension:

$1\mu m \langle d_i \langle 10\mu m$: Transitional Microchannels

$10\mu m \langle d_i \langle 200\ \mu m$: Microchannels

$200\ \mu m \langle d_i \langle 3\ mm$: Minichannels

$3\ mm \langle d_i$: Conventional Passages

An easier classification was suggested by Obot (2003) based on the hydraulic diameter rather than the smallest channel dimension. Obot classified channels of diameter under 1 mm ($d_i \langle 1\ mm$) as micro-channels, which was also adopted by many other researchers such as Bahrami and Jovanovich (2006), Bahrami et al. (2006), Bayraktar and Pidugu (2006), Cetin (2010) etc. This classification is also adopted for the present study of fluid flow and heat transfer in helical coils of micro-diameter tubes. This classification is also more appropriate for the purpose of this thesis.

1.2 Helical coil

Due to its geometrical configuration helical coil have a more complex flow pattern. The centrifugal force due to curvature developed secondary flows, defined as flows perpendicular to the axial direction, this phenomenon assist in mixing the fluid and enhance the heat transfer. Helical coil with secondary flow is shown in Figure 1.1.

The main differences in heat transfer and fluid flow characteristics between helical coils and straight tubes are related to this secondary flow effect caused by centrifugal forces. The secondary flow phenomenon improves the heat transfer. There was little mixing of fluid inside a straight tube heat exchangers in the laminar flow regime, thus the application of curved tubes in laminar flow heat exchange processes can be highly beneficial. These situations can be easily seen in the food processing industry for the cooling and heating of either highly viscous liquid food, such as pastes or purees, or for products that are sensitive to high shear stresses; Rennie (2004).

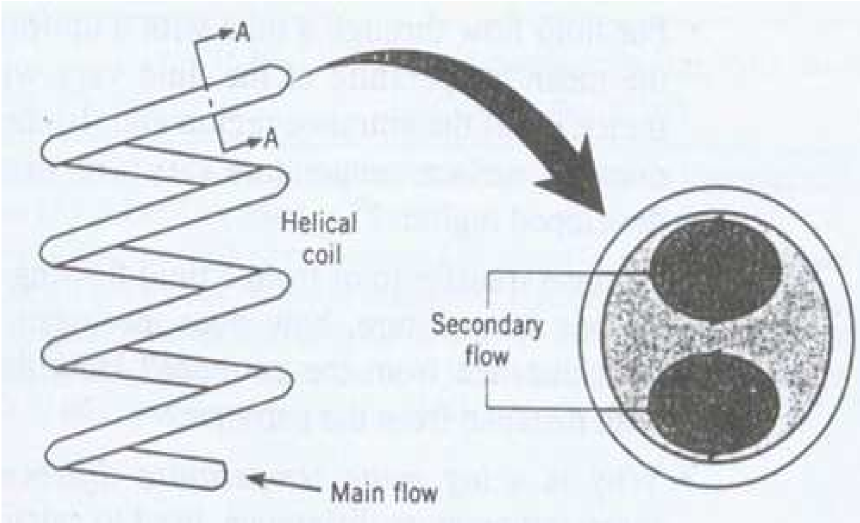

Fig.1.1 Helical coil with secondary flow

Heat exchanger with helical coils is used to transfer thermal energy between two or more fluids, between a solid surface and a fluid, or between solid particles and a fluid, at different temperatures and in thermal contact. Heat exchangers are used in a wide variety of applications. These involve power production, process, chemical and food industries, electronics, environmental production engineering, waste heat recovery, manufacturing industry, air conditioning, refrigeration and space applications; Cetin (2010).

Heat exchangers with helical coil offer distinct advantages, such as compactness, easy maintenance, improved thermal efficiency and lower installed cost. The exchangers also are suitable for less demanding applications, such as boiling, condensing, heat recovery and basic heat exchange.

Number of the studies involving helical coils and heat exchanger has mainly focused on two major boundary conditions; constant wall temperature and constant heat flux; Shah and Joshi (1987) and Prabhanjan et al. (2004). In the present study, fluid flow and heat transfer study has been carried out at constant heat flux boundary conditions in laminar regime.

1.3 Objectives

It has been found from extensive literature survey (chapter 2) that significant experimental and numerical research has been reported for conventional and mini size helical coil and heat exchanger. However, very limited fluid flow and heat transfer studies have been reported in the literature for small helical coils with diameters less than1 mm. Micro-diameter tube in helical configurations leads to beneficial improvement in the heat exchanger. Application of micro channel heat exchangers of different configurations including coils is growing day by day in fields like electronic devices, computers, artificial organs etc.

In view of the above it has been planned to investigate flow and heat transfer characteristics in helical coils of micro-diameter tubes with the following objectives:

- To experimentally study the fluid flow and heat transfer characteristics in helical coils of micro-diameter tubes to understand its hydrodynamic and thermal behaviour.
- To validate the experimental results with well known correlations available in the published literature.
- To carry out parametric sensitivity study of helical coil.
- To propose a suitable generalized correlation for friction factor and Nusselt number.