Hydrodynamic characteristics of single phase fluid flow inside a helically coiled tube of small diameter

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ABSTRACT

In this present study hydrodynamic characteristics of single phase fluid flow inside a vertical helically coiled tube of curvature ratio 0.012 is investigated experimentally for the laminar flow regime. Experiments are implemented for water and nitrobenzene. Effect of dean number on friction factor is also discussed. Experimentally measured pressure drop are compared against the values obtained numerically from existing correlations. Experimentally obtained pressure drop shows good agreement with numerical value for water.

Keywords- *Fluid flow, Helically coiled tubes, Microchannels, Minichannels, Pressure drop*

I. INTRODUCTION

Over the last few decades, flow through helically coiled tubes has attracted the attention of many researchers, because of its complex fluid dynamics phenomena. As fluid flows through coiled tubes, due to the curvature of the tubes centrifugal force is generated. Centrifugal force induced secondary flow. The pressure drop for flow in helically coiled tube is higher than the straight tube at the same flow rate and tube length proved by various researchers. Helically coiled tubes have wide variety of applications such as heat exchangers, air conditioning, refrigeration systems, chemical reactors, nuclear reactors, and piping systems due to their compact structure. It can be easily seen that coiled tubes have wide range of industrial processes like heat recovery processes, ultra filtration, rectification and absorption. Potential applications of coiled geometries are discussed in [1].

The aim of present work is to investigate hydrodynamic characteristics of helically coiled tube heat exchanger. Fluid flow Characteristics of nanofluid inside vertical helically coiled tubes for laminar flow experimentally investigated by Pakdaman et al [2]. Experiments were carried out in the coiled copper tubes of 15.6 mm internal diameter with coil diameter ranges from 220-320 mm and coil pitch ranges from 25-95 mm respectively. Pressure drop decreased as the coil to tube diameter ratio increased. Hashemi [3] empirically studied heat transfer and pressure drop characteristics of CuO–base oil nanofluid flow in a horizontal helically coiled tube of curvature ratio and coil pitch 0.044 and 55 mm respectively. There was a noticeable increase in pressure drop of nanofluids compared to that of base liquid for a given helical tube and at a same flow conditions. Kumar et al. [4] experimentally investigated convective heat transfer and friction factor in helically coiled tube of curvature ratio 0.097 with Al_2O_3-water nanofluid. Friction factor increased over particle volume concentration. This was due to increased nanofluid viscosity while increasing particle volume concentration. Performance analysis of helically coiled heat exchangers with circular minichannels of 1mm inner diameter was studied by Kim et al. [5]. The results indicate that pressure drop in low mass velocity from simulation showed good agreement with experimental results. The parametric study on laminar flow through helical coils done by Gupta et al [6] clearly indicated that coil friction factor had significant dependence on coil geometrical parameters. Frictional pressure drops of single phase water flow in two helically coiled tubes at four different helical angles were studied by Guo et al. [7]. The helix angles had insignificant effect on the single phase frictional pressure drop. Patankar et al. [8] studied effect of the Dean number on friction factor and heat transfer in helically coiled pipes for laminar flow. Good agreements of results were obtained in comparison with the experimental data.

Seara et al. [9] implemented numerical investigation on the performance of a vertical helical coil heat exchanger with tube curvature ratio of 0.029. There was large influence of the increasing diameter and the decreasing pitch on the reduction of the pressure drop. Heat transfer and flow characteristics in helically coiled copper tubes with different curvature ratios (0.125, 0.0862, and 0.05) using artificial neural networks was predicted by Beigzadeh and Rahimi [10]. The superior performance of developed neural network for Nusselt number and friction factor was obtained. Mohammed and Narrein [11] investigated thermal and hydraulic characteristics of nanofluid flow in laminar region in a helically coiled tube heat exchanger using CFD methods. Heat transfer and the pressure drop could be enhanced by reducing the helix radius. Pawar and Sunnapwar [12] experimentally investigated the heat transfer characteristic of Newtonian and non Newtonian fluids in helically coiled heat exchanger with curvature ratios 0.0757, 0.064 and 0.055 for laminar and turbulent flow. Correlations were developed for the heat transfer.

It was observed that only a few studies have been done on small sized helical tubes. As there is no work reported in a helical coiled tube with curvature ratio of 0.012, therefore, in this present study, an experimental investigation has been carried out to study hydrodynamic characteristics of fluid flow in a vertical helically coiled tube.

II. EXPERIMENTAL SETUP

Fig. 1 shows a schematic diagram of the experimental set up. The setup consists of a test section, peristaltic pump, storage tank and manometer. The experimental set-up is well instrumented. The test section as shown in fig. 2 provided with a helical coil of 0.72 mm inner diameter (d_i) and 1.5 mm outer diameter (d_o) with 3 turns, the coil diameter (D) and the coil pitch are 60 mm and 10 mm respectively. The coil had a length (L) of 0.655 mm. The helical coil was formed from straight copper tube. Care was taken to preserve the smoothness of the inner surface and circularity of the coil cross section during the bending process. A peristaltic pump is used to circulate fluid within the closed cycle. A U tube manometer is used to measure the pressure drop across the coiled tube.

Water and nitrobenzene are used as working fluid in this study. In the present study water is considered as reference fluid. Density (ρ) of water and nitrobenzene are 1000 kg/m^3 and 1200 kg/m^3 respectively. Water and nitrobenzene have viscosity 1cp and 2.02 cp respectively. Fluid from storage tank was pumped through the coiled tube. Flow rate is measured directly from the time required to fill the glass vessel. The present experiments are conducted for single phase laminar flow. The experimental apparatus is designed to study the fluid flow characteristics of working fluids over the length of the test section for $N_{Re} = 555 - 2038$ and $N_{De} = 60 - 222$

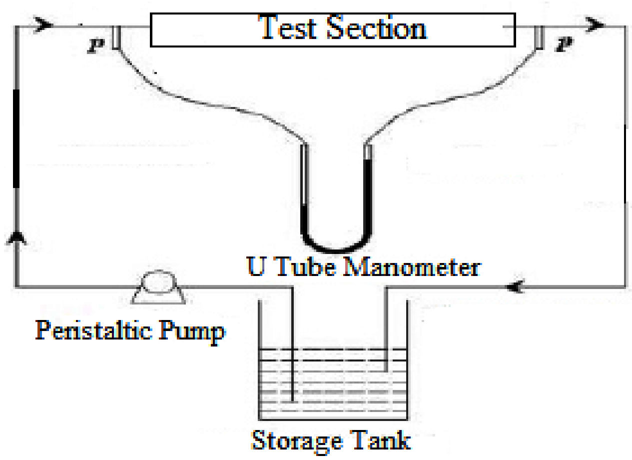


Fig.1. Experimental Setup

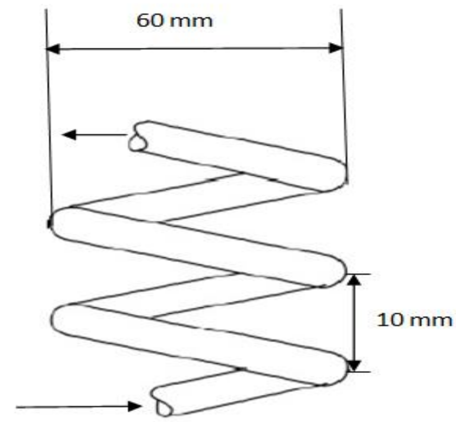


Fig. 2. Test Section

III. HYDRODYNAMIC ANALYSIS

The friction factor for laminar flow inside helical coiled tube in the range of Dean number ($30 < N_{De} < 300$) and curvature ratio ($0.0097 < d/D < 0.135$) is correlated as: Srinivasan et al [13].

$$f_c = \frac{32}{N_{Re}} \quad (1)$$

or

$$f_c = 5.22\left(N_{Re}\sqrt{\frac{D}{d}}\right)^{-0.6} \quad (2)$$

The pressure drop of fluid flowing inside the coiled tube is calculated as [14]

$$\Delta p = f_c \rho \frac{LV^2}{2d_i} \quad (3)$$

Where, V is velocity of working fluid.

IV. RESULTS AND DISCUSSIONS

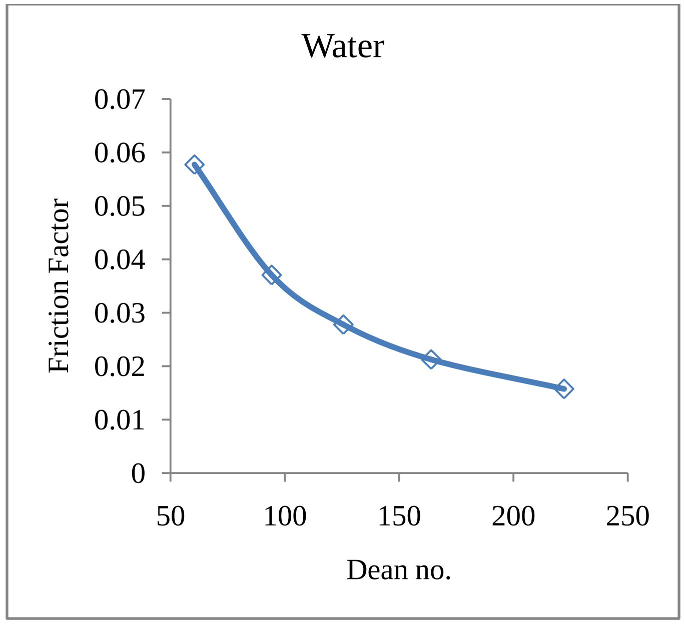
The experiments are conducted for single phase laminar flow within the Reynolds number ranges from 555 to 2038. A hydrodynamically fully developed condition is assumed for numerical calculations. Experimentally measured pressure drop are compared against the values obtained numerically by Srinivasan et al [13] correlations as given in above equations. Effect of Dean no. on friction factor is presented in fig. 3. It can be observed that friction factor decreases as Dean No. increases. It is true in both water and nitrobenzene cases. Friction factor is more in nitrobenzene as compared to water. Comparative study of experimental and numerical pressure drop for water across the coiled tube is predicted in fig. 4. It is noticeable that as the Reynolds no. increases pressure drop increases. From fig. 4 it can be easily observed that experimental results shows good agreement with the numerical results. But for higher Reynolds no. experimental pressure drop is larger than the numerical pressure drop.

Fig. 5 represents comparison of experimental and numerical pressure drop for nitrobenzene. Pressure drop due to nitrobenzene follows same trend as of water. Since nitrobenzene is more viscous than water so pressure drop is more as compared to water. Pressure drop due to nitrobenzene is 28% greater than water. It can be concluded that as viscosity of fluid increases pressure drop increases. Numerically obtained pressure drop is higher than experimental pressure drop for nitrobenzene as observed in fig. 5. Numerical pressure drop is 33% greater than experimental value.

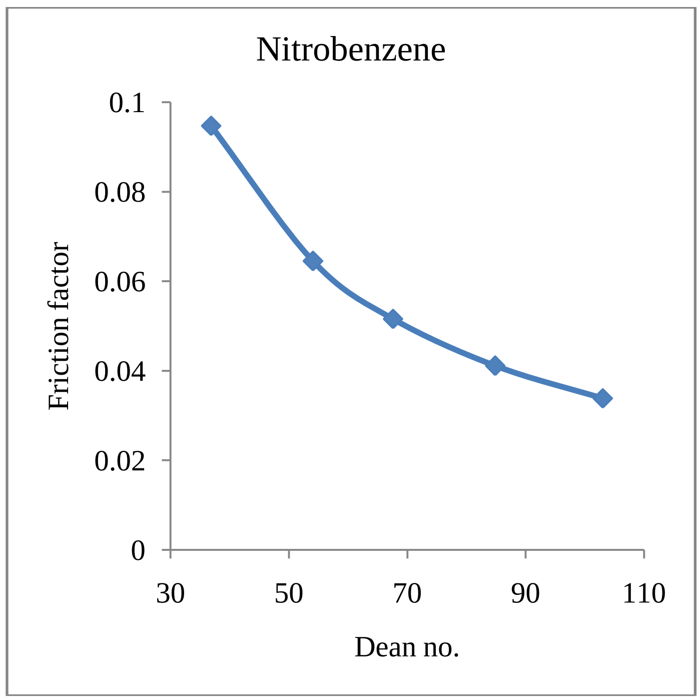
V. CONCLUSIONS

Hydrodynamic study of single phase fluid in helically coiled tube is successfully presented in this study. The key conclusion can be summarized as:

- Friction factor decreases as Dean number increases. It’s true in both cases.
- Experimental data shows good agreement with numerical results in case of water.
- Pressure drop is higher in nitrobenzene as compared to water, because nitrobenzene is more viscous than water.
- Pressure drop due to nitrobenzene is 28% greater than water.
- Numerically obtained pressure drop for nitrobenzene is 33 % higher than experimental value.



(a)



(b)

Fig. 3. Effect of friction factor on Dean no. (a) Water (b) Nitrobenzene

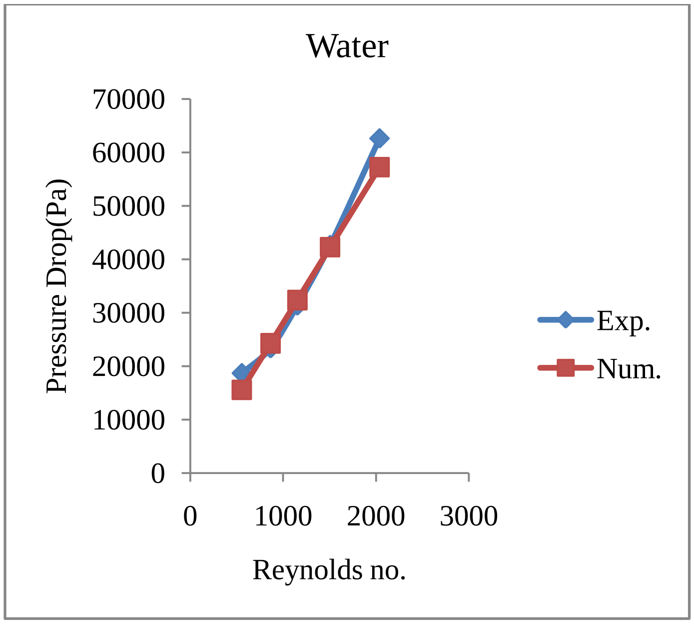


Fig. 4. Comparative study of Pressure drop for Water

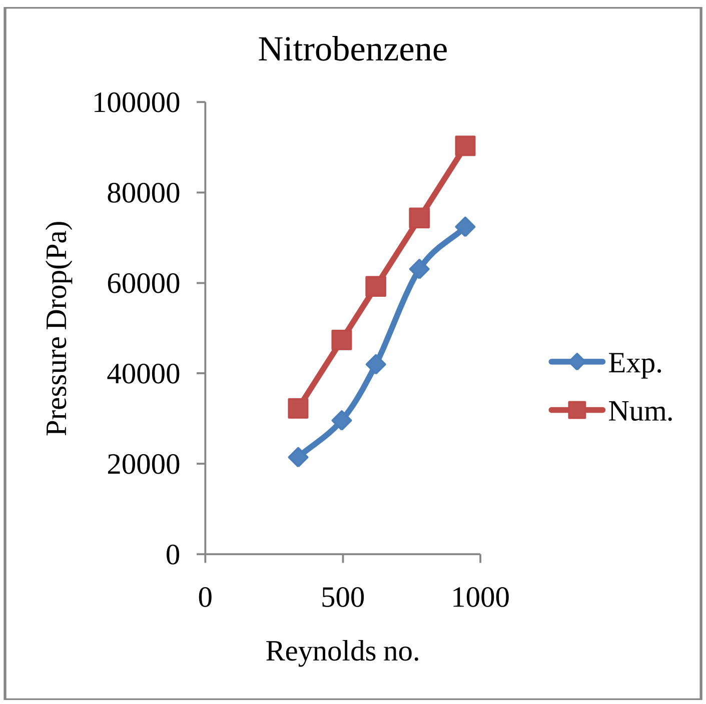


Fig. 5. Comparative study of Pressure drop for Nitrobenzene

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