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Numerical simulation of Pressure Drop through a Compact Helical geometry

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ABSTRACT
Pipes are used in every industrial thermo-fluid equipment and systems, such as tubes, ducts, heat exchangers, air conditioning and refrigerating systems etc. Flatter velocity profiles and more uniform thermal environments are extremely desirous factors for improved performance of these flow reactors and heat exchangers. One means of achieving it in laminar flow systems is to use mixers and flow inverters. In the present study a new device is introduced by changing the dean number of fluid flowing in helically coiled tubes. The objective is to study velocity profile and pressure drop in the proposed device made up from the configurations of changing radius. Pressure drop in straight, helical coil and compact helical geometry configuration were compared using computational fluid dynamics software (FLUENT) results.
Keywords – Pressure drop, compact helical geometry, computational fluid dynamics, laminar flow.

I. INTRODUCTION

Helically coiled tubes are widely used, particularly for cooling or heating fluid streams. The friction factor and heat transfer coefficient are greater than in a straight tube owing to the secondary motion generated by the centrifugal force.

Because of this practical interest, many experimental investigations have been carried out for flow and heat transfer in helical coils.

The single-phase friction factor of pipe flow is the base for determining single-phase friction pressure drop. There are a number of correlations for the single-phase friction factor of pipe flow, whose ranges of validity are described by their corresponding author(s).

The special character of flow in curved pipes has long been recognized. Thompson (1876)[1] noted that centrifugal forces influence the flow in curved pipes and Williams et al. (1902)[2] observed that the maximum in the axial velocity is shifted toward the outer wall of a curved pipe. The first quantitative determinations of the pressure gradient in helical coils were apparently conducted by Grindley and Gibson (1908)[3] with the object of determining the viscosity of gases. Eustice (1910, 1911, 1925)[4] used ink tracers to confirm the existence of secondary motion in pipe bends. A mathematical model for the fluid flow in a curved duct of constant radius (or constant curvature) was introduced by Dean. J. Larrain and C. F. Bonilla (1970)[5] did a theoretical Analysis of Pressure Drop in the Laminar Flow of Fluid in a Coiled Pipe for a Dean number range of less than 16. A numerical simulation for helical tube was done using their experimental data for validation. The results are shown in Fig 1(a). Naphon (2011)[6] numerically and experimentally investigated the heat transfer and flow characteristics of the horizontal spiral-coil tube. It was found that the induced centrifugal force in the spiral-coil tube had a significant effect on the enhancement of heat transfer and pressure drop. Yang and Chiang (2002)[7] experimentally investigated the heat transfer for water flowing through a curved pipe with varying-curvature. The results were compared with those of the straight pipe. Zekeriya Altaç, Özge Altun (2013)[8] in their study numerically investigated combined steady state and developing flow in spiral tube coils under isothermal and laminar conditions. Shah and Joshi[9] have presented extensive reviews of fluid flow and heat transfer in helical pipes. Kim , Yadav , Kim (2014) [10] have studied numerically and experimentally secondary flow characteristics and their dissipation in a 90 degree elbow joint . Saxena and Nigam [11] proposed a new technique, ‘‘bending of helical coils’’, to cause multiple flow inversion at low flow rates. Vimal Kumar, K.D.P. Nigam (2004) [12] characterized flow development and temperature fields in the proposed device made up from the configurations of bent coils. The comparison of the flow fields and temperature fields in the helical tube and bent coil configuration are discussed. Romeo L. Manlapaz & Stuart W. Churchill [13] did their study of laminar flow in helically coiled tubes for dean numbers less than 30. A numerical simulation was done using their experimental data for validation .Numerical results were in accordance with their data shown in Fig.1 (b).

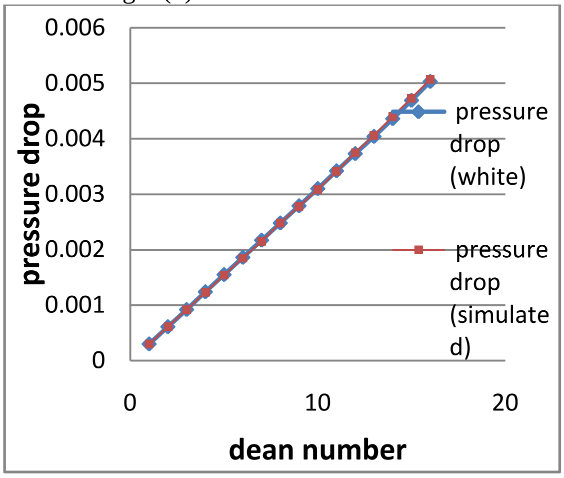

Fig.1 (a)Pressure Drop Vs Dean number for a curved pipe

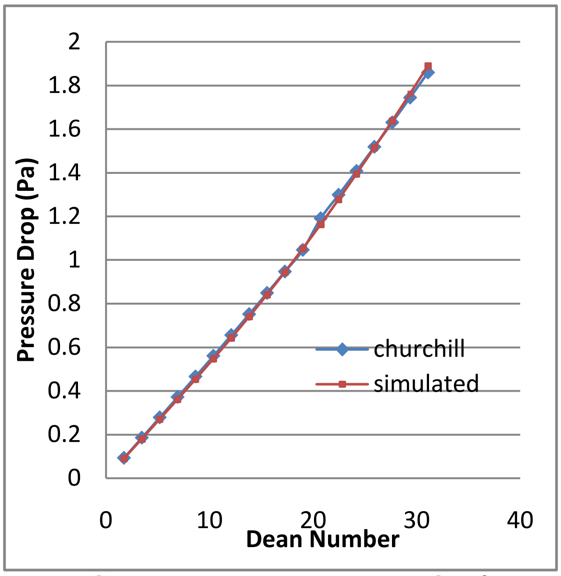

Fig.1(b) Pressure Drop Vs Dean Number for a helical pipe

In the present study, a compact helical geometry is presented. The curvature ratio decreases, thereby the dean number increases, Nigam[12] had highlighted that with an increase in dean number pressure drop increases and so does the inner Nusselt number in the helically coiled tubes. The compact helical geometry is expected to have higher heat transfer coefficient and higher pressure drop than a vertical helix with constant curvature ratio throughout. The present study investigates pressure drop of the compact helical geometry .

II. MATHEMATICAL FORMULATION

The geometry considered and is illustrated in Fig. 2. The circular pipe has a diameter of 2a, and is coiled at a radius Ro for the outer helix and radius R_i for the smaller helix, while the distance between the two turns (the pitch) is reported by p which is kept same for inner and outer helix. The values of the dimensions are given in Table 2.1 In the present study, the Cartesian coordinate system (x, y, z) is used to represent the proposed geometry in numerical simulation. The laminar flow develops down-stream in the helical pipe. The flow is considered to be steady and constant thermal properties are assumed. The differential equations governing the three-dimensional laminar flow in the coiled flow inverter could be written in tensor form in the master Cartesian coordinate system as

Continuity:

$$\frac{\partial u_i}{\partial x_i} = 0$$

Momentum:

$$\frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) - \rho u_j u_i - \delta_{ij} p\right] + \rho g_i = 0$$

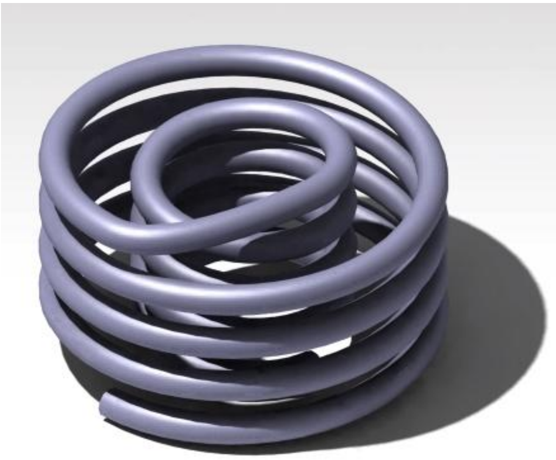

Fig .2. The compact helical geometry

Ro	54mm
Ri	28mm
P	15mm
A	9mm

Table 2.1. Dimensions of the Geometry

The pressure drop was determined for a vertical helix as well (without any change in Radius of curvature) and compared with the compact helical geometry. Total length of the pipe, external Radius of curvature and internal diameter of the pipe was kept constant . The vertical helix is shown in Fig.3.

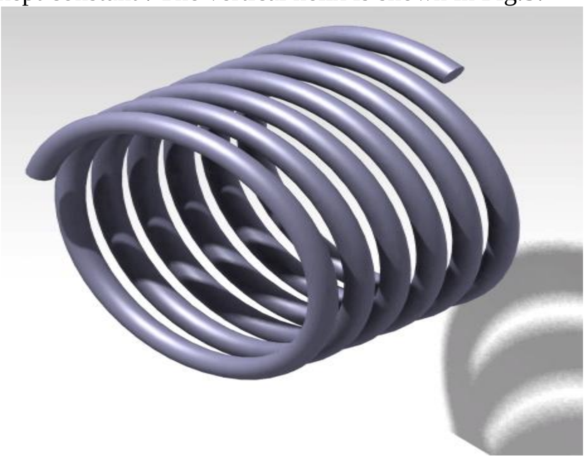

Fig.3. Vertical Helix

2.1 Boundary conditions

No-slip boundary condition, At the inlet a fully developed duct flow velocity profiles and a fixed pressure at the outlet of compact helical geometry were employed. The diffusion flux at the outlet for all variables in the exit direction is set to zero.

III. NUMERICAL COMPUTATION

3.1. Numerical method

The governing equations for flow through the proposed geometry were solved in the master Cartesian coordinate system with a control-volume finite difference method (CVFDM) similar to that introduced by Patankar. Fluent program is used as a numerical solver for the present three-dimensional simulation.

3.2. Grid system

A structured grid system is used to discretize the governing equations. The convection term in the governing equations was modeled with the bounded second-order upwind scheme. The SIMPLE algorithm is used to resolve the coupling between velocity and pressure. To accelerate the convergence, the under-relaxation factor for the pressure, p, is 0.3; that for the velocity component in the i-direction, u_i is 0.5; and that for body force is 0.8.

Number of elements	632772
Number of Nodes	137449
Patch Independence	On
Skewness	0.587

3.3. Convergence criteria

The numerical computation is considered converged when the residual summed over all the computational nodes at nth iteration, Rn, satisfies the following criterion: 10^{-5}.

IV. Results and Discussion

4.1 Description of Pressure Drop

Axial flow development was obtained for compact helix geometry. Reynolds number is varied from 200 to 2000. The physical properties during the simulation were kept constant.

The pressure drop comparison is shown in the graph in Fig.4. The velocity profiles for the geometry are also shown in Fig.5b.

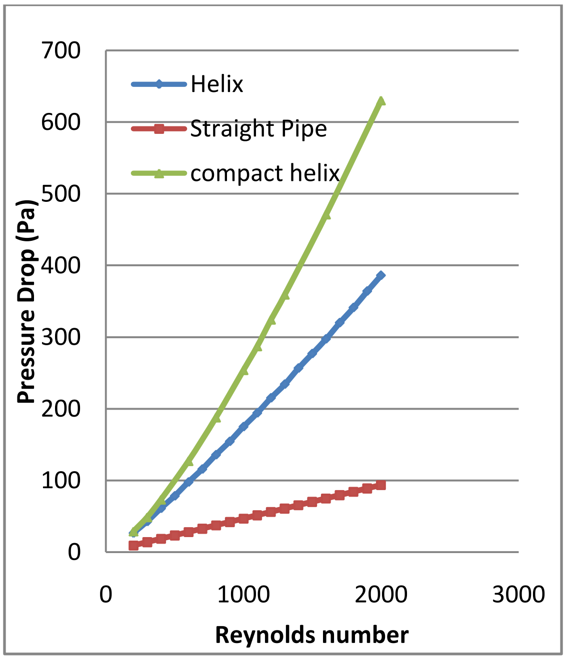

Fig.4. Pressure Drop vs Reynolds number comparison for a straight pipe , helical pipe and compact helical geometry

4.2 Description of velocity profile

Fig.5b. represents the development of velocity field after 180° by making velocity contours at the yz plane. The velocity field is characterized by two longitudinal Dean-type vortices and the axial velocity contours show the familiar C-shape. It is also seen that the maximum velocity is shifted towards the outer wall of the helical coil. In a helix when the radius of curvature decreases the Dean number increases. It is observed that the velocity is more distributed in the case of compact helical geometry. In case of vertical helix it is more concentrated and becomes fully developed and change is observed after introduction of radius of curvature of helix. The radial mixing between the fluid elements is much higher than that of straight tube and straight helix. A comparison can be made in velocity profile , as shown in Fig 5.a and Fig.5.b.

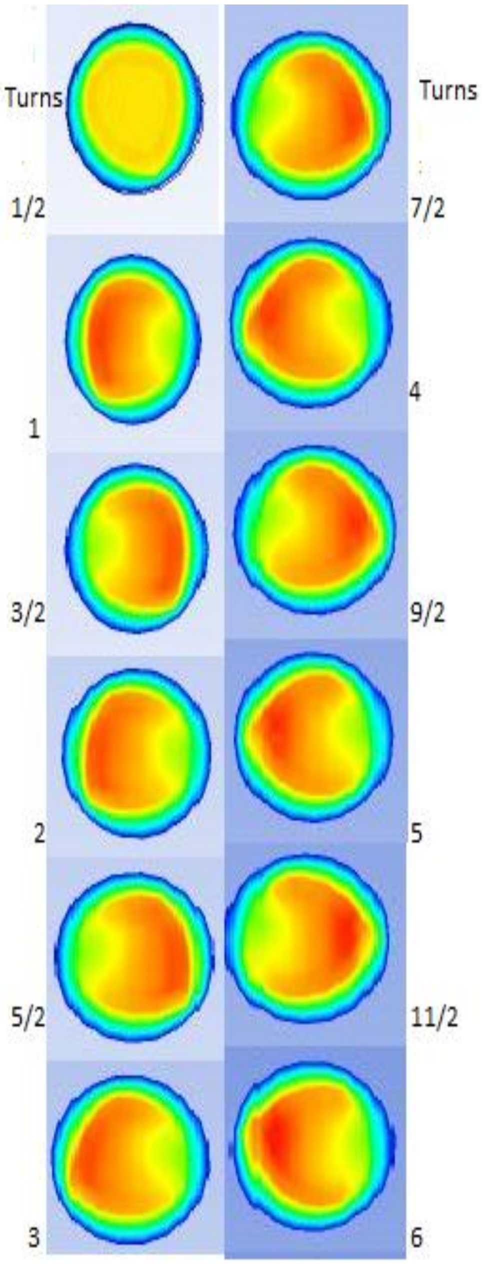

Fig.5.(a) Velocity contours of vertical helix

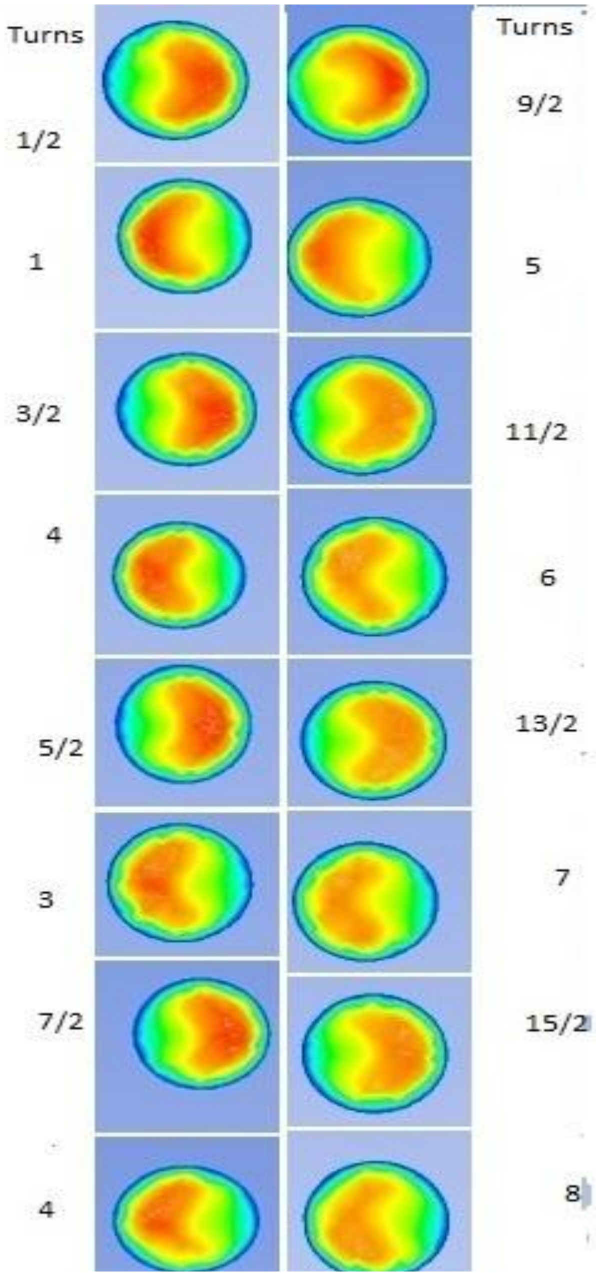

Fig.5.(b) Velocity contours of compact helix

V. Conclusion

Pressure drop and velocity profile in straight helix and compact helical geometry for the same length of pipe has been numerically simulated with a control volume finite difference method (CVFDM). The pressure drop has gone up by 40% in compact helical geometry in comparison to straight helix. The heat transfer coefficient determination of the geometry is pending investigation.

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