ABSTRACT
Horizontal spiral coil tube is a compact coil in one plan. The hydrodynamics of such coil is unique since it is governed by its curvature ratio variation. As coil is developed in one plan it has innermost coil diameter and it increases as tube coil move outward. The curvature ratio depends on coil pitch. In this paper horizontal spiral coil tube (HSTC) is investigated for laminar flow region for flow through tube (Re less than 2100). The HST coil in copper is fabricated from copper tube of diameter 9.13 mm O.D.; HST coil of five turns in horizontal plane with pitch of ‘2d’ is developed and has curvature ratio (d/dc) varies from 0.22 to 0.065 as compared to constant curvature ratio in vertical helical coil. The hydrodynamic performance of HST coil is compared with vertical helical coil.

INTRODUCTION
The development of U tube, limpet coil, curved tube coils is the results of thermal design needs for process applications; the vertical helical coils have been developed for same and have extensive application. These coils have constant curvature ratio with varied number of turns. The pressure drop in helical coil is governed by curvature ratio d/dc of coil diameter number of turns of coil. Various heat transfer applications require compact coil; results in development of HSC tube, it is coil geometry with varied curvature ratio in one plane. In this experimental investigation hydrodynamic characteristic of vertical helical coil of diameter 60 mm, 188 mm and HSC tube is studied for laminar flow condition where flow through tube is Re<2100.

LITERATURE REVIEW
In literature most studies for curved tubes are concerned with vertical helical coiled tubes. Very little information is available on horizontal spirally coiled tube and HSTC heat exchanger. Researches have studied different vertical helical coils. Paisarn Naphon, Somchi Wongwises have reviewed the literature for three main categories of curved tubes: vertical helical coiled tubes, spirally coiled tubes and other coiled tubes. Although numerous studies on horizontal helical heat transfer performance is available in literature there are few references for horizontal spirally coiled tube where the curvature ratio variation (d/dc) is 0.1 and below. They have investigated tube coil having coil diameter variation from 150 mm to 400 mm and tube diameter is 9.5 mm OD. In this experimental investigation horizontal spiral coil tube of 8 mm ID and 9.13mm O.D. tube having curvature ratio (d/dc) variation of 0.24 to 0.067 is investigated for its hydrodynamic characteristics and compared with vertical helical coil.

THEORY
Fluid Flow through curved tubes is a result of various forces acting on the fluid element; these forces are viscous, buoyancy and centrifugal.[6]. The physical properties of fluid govern the net result of forces. The study suggests that the centrifugal force is predominant. There are secondary flows due to centrifugal force acting on the fluid element. The magnitude of centrifugal force is governed by fluid physical properties and curvature ratio (d/dc). Since the curvature ratio contributes toward the flow pattern in tube higher curvature ratio results in higher secondary flow that is local turbulence. High initial curvature ratio has significant ability to generate turbulence which helps to enhance heat transfer rate.

Table 1: Details of horizontal spirally coiled tube

<table>
<thead>
<tr>
<th>Description</th>
<th>A</th>
<th>B</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube I.D.</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Tube O.D.</td>
<td>9.1mm</td>
<td>9.1mm</td>
<td>9.1mm</td>
</tr>
<tr>
<td>Number of turns</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Initial coil diameter</td>
<td>30mm</td>
<td>40mm</td>
<td>50mm</td>
</tr>
<tr>
<td>Inlet pressure</td>
<td>1 kg/cm²</td>
<td>1 kg/cm²</td>
<td>1 kg/cm²</td>
</tr>
<tr>
<td>Material of construction</td>
<td>Copper</td>
<td>Copper</td>
<td>Copper</td>
</tr>
<tr>
<td>Pressure drop measurement</td>
<td>Pizometer</td>
<td>Pizometer</td>
<td>Pizometer</td>
</tr>
<tr>
<td>Least count of pizometer</td>
<td>1 mm</td>
<td>1 mm</td>
<td>1 mm</td>
</tr>
</tbody>
</table>

In order to compare the pressure drop characteristics with vertical helical coil, the helical coils with 60 mm
and 188 mm coil diameter are fabricated from copper tube. The length of coil is maintained constant as 2 meters.

Tube coils have process application, and heat transfer area governs the tube length. There is an option to develop the vertical helical coil or horizontal spiral coil. Hence there is a need to compare the pressure drop characteristics of coils developed from the same length of tube. The geometrical and operational details of vertical helical coils under investigation is as given in Table 2.

### Table 2: Details of Vertical helical coil.

<table>
<thead>
<tr>
<th>Description</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube I.D.</td>
<td>6 mm</td>
<td>6 mm</td>
</tr>
<tr>
<td>Tube O.D.</td>
<td>6.3 mm</td>
<td>6.3 mm</td>
</tr>
<tr>
<td>Tube length</td>
<td>2000 mm</td>
<td>2000 m</td>
</tr>
<tr>
<td>Coil diameter</td>
<td>60 mm</td>
<td>188 mm</td>
</tr>
<tr>
<td>Inlet pressure</td>
<td>1 kg/cm² g</td>
<td>1 kg/cm² g</td>
</tr>
<tr>
<td>Material of construction</td>
<td>Copper</td>
<td>Copper</td>
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<tr>
<td>Least count of pizometer</td>
<td>1 mm</td>
<td>1 mm</td>
</tr>
</tbody>
</table>

### Coil surface model for HSC tube

For different study of HSC tube geometrical model is consider as the circular tube with constant radius of curvature (coil) and coil radius increases as number of turns increases as coil development take place from the centre of coil. The details are as indicated in Fig. 2. It has been considered that in theoretical model each coil of turn is assumed as linear spiral, where radius

\[ R = R_0 + \alpha \theta \]  

And \( \theta \) is the angular position of a point from a fixed line; \( \alpha \) is the rate in change of radius. \( m \) is section of coil and \( n \) is number of turn of coil

![Fig 2: Geometrical representation of Horizontal Spiral Tube coil](image)

### Experimental apparatus for Hydrodynamic-SHCT

For hydrodynamic study vertical helical coil of 60 mm and 188 mm coil diameter are fabricated from 6 mm ID copper tube with constant length. The horizontal spiral coil of different turns is fabricated from 9.1 mm OD copper tube with pitch spiral of ‘2d’. Different HST coils with inner coil diameter are as of 30 mm 40 mm and 50 mm respectively are fabricated and tube length is maintained. The pressure gauge is mounted at the inlet to measure inlet pressure same is maintained at 1 kg/cm² g. Pizometer (‘U’ tube manometer) mounted across the coil to measure the pressure drop, the flow rate through coil is controlled with bypass valve at inlet. The flow rate is measured with calibrated measuring cylinder and stopwatch. The reproducibility of data observed in the repetitive run. The schematic detail of experimental setup is as shown in Fig. 3. The geometric details of horizontal spirally coiled tube are indicated in Table 1. The both spiral coil tubes have inside spiral coil diameter 40 mm are studied.

![Fig. 3 Schematic details of Pressure drop measurement set up](image)

### RESULTS AND DISCUSSION

In case of vertical coil pressure drop in different coils is compared since it has different geometrical factor that is curvature ratio (\( d/dc \)). Hydrodynamic investigation of vertical coil of 60 mm and 188 mm coil diameter indicates that there is pressure drop variation with respect to Re and curvature ratio. Analysis indicates that ‘increase in coil diameter’ decreases the pressure drop per meter. The Figure 4 explains variation of pressure drop in vertical helical coil for fluid flow in laminar region (Re<2100)

![Figure 4 Variation of pressure drop for different coil diameter](image)

### Effect of inside coil diameter

In this experimentation the HSC tube of different innermost coil diameter coil of 30 mm 40 mm and 50 mm are investigated for its hydrodynamics. The numbers of turns are maintained around 4 to 5 to maintain tube length constant.

![Figure 5 Effect of Inside coil Diameter on HSC tube pressure drop](image)
It has been noted that inner coil diameter decides the pressure drop, figure 5 shows effect inside coil diameter variation on per meter pressure drop. Similarly vertical helical coils are compared with horizontal spiral coil for hydrodynamic behavior and same is shown in Figure 6, it indicates that the pressure drop in horizontal spiral coil is lower than vertical helical coil.

![Figure 6 Comparison of Vertical helical and horizontal spiral coil](image)

### HSC tube and CFD

The governing equations for three-dimensional laminar flow in the curved tube could be is express by navier stokes equation using k- ε model. Same is written in the master Cartesian coordinate system as indicated in continuity equation.

\[
\frac{\partial U_i}{\partial x_j} = 0.
\]

**Fig 7 Coordinate system for computation**

The geometry considered and the systems of coordinates used in the present study are shown in Figure 6. The circular pipe has a diameter of \(2a\) and is coiled at a radius of \(R_c\), while the distance between two turns (the pitch) is represented by \(H\). The Cartesian coordinate system is used in numerical simulation to represent a helical pipe.

- **Continuity equation:**
  The governing equations for or three dimensional laminar flow in the curved tube could be written in the master Cartesian coordinate system as

\[
\frac{\partial}{\partial x_j} \left[ \mu \left( \frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i} \right) - \rho u_j u_i - \delta_{ij} P \right] = 0.
\]

The horizontal helical coil geometry has been developed as hyper mesh with different inside coil diameter and five numbers of turns with coil pith of 2d and 3d.

### PRESSURE DROP ANALYSIS

The investigation for laminar fluid flow through tube coil (Re<2100) is investigated with CFD Fluent software by developing the hyper mesh for the configuration of 60 mm coil internal diameter and 20 mm ID tube. Five numbers of turns were considered and velocity varied from 0.01 to 0.1 m/s for CFD analysis. The higher inner coil diameter and higher tube diameter considered due to hyper mesh conversion problem for HSC tube configuration. Pressure drop estimated by CFD is compared with horizontal spiral coil tube fabricated fro experimentation, 8 mm internal diameter copper tube coil with five turns having ‘2d’ as pitch is fabricated. The figure 8 shows the comparison of pressure drop with respect to Reynolds number in laminar region.

![Figure 8 Comparison of CFD and Experimental pressure drop](image)

**CONCLUSION**

The secondary flow is higher due to higher curvature ratio d/dc in horizontal spiral coil tube. It has lower pressure drop lower as compared to vertical helical coil the pressure drop. This may be due to the number of turn’s are in different planes. As coil diameter reduces the curvature ratio increases and results in higher pressure drop. The experimentally measured pressure drop is higher as compared estimated pressure drop by CFD due to curvature ratio variation and entrance effect

**REFERENCE**