Study of Heat Transfer and Pressure Drop Inside Helical Cone Tube

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Abstract. The present work is devoted to numerically investigate the characteristics of the convective heat transfer and pressure drop of pure water in the helical cone tube with different taper angle inside cylindrical shell working as a shell and tube heat exchanger. This work is performed at different geometrical parameters of the HCTs and at different operating conditions for the tube side of the heat exchanger. Three helical cone tube (HCT) heat exchangers of counter-flow configurations are constructed with different torsions, and taper angles. Wilson plot method is used to investigate the thermal performance results in terms of tube average heat transfer coefficient, average Nusselt number and Fanning friction factor are presented. The results showed that the conical tube heat exchangers have lower heat transfer coefficient and lower friction factor compared with that in helical.

Nomenclature

\begin{tabular}{lll}
\textbf{Symbols} & \textbf{Definition} & \textbf{Letters} \\
\dot{m} & Mass Flow Rate, kg/s & \Delta \\
\mu_t & Dynamic Viscosity, kg/m.s & \theta \\
C_p & Specific heat, J/kg.°C & \mu \\
D_e & Dean Number & \rho \\
d & Diameter, m & \\
h & Convection Heat Transfer coefficient, W/m\textsuperscript{2}.°C & \\
c & Cross-sectional & \\
Nu & Nusselt Number & eq \\
P & Pressure, Pa & i \\
p & Pitch, m & L \\
m & Mean & \\
Re & Reynolds number & \\
S & Coil Spacing, m & \\
U & Overall heat transfer, W/m\textsuperscript{2}.°C & \\
\end{tabular}
1. INTRODUCTION

Heat exchangers are widely used in a lot of applications, like chemical processing, nuclear reactors, power plants, heat recovery systems, food industries and in refrigeration and air-conditioning systems. The improvement of heat transfer coefficient has two important outcomes in the heat exchangers. Firstly, it basically improves the performance and secondly reduces the size of the heat exchanger. In applications, many techniques are used to improve the heat transfer and are classified into two types as active and passive techniques. Coiled tube configuration in heat exchangers is the one of the most important passive heat transfer improvement techniques [1, 2], due to high heat transfer coefficient and compact structure.

Helical coiled configuration is very effective for some heat transfer equipments such as heat exchangers [3, 4] and reactors because in small space (volume) they accommodate a large heat transfer area. The curvature in tube induces secondary flow patterns [5] due to centrifugal force developed in the fluid when the fluid is flowing through the curved tube. For the same flow rate, these secondaries allow mixing of the fluid that enhances the heat transfer coefficient, whereas pressure drop across the coiled tube increases due to these secondaries. It was noted by Shah and Joshi [6], that the enhancement depends on the intensity of secondary developed in the coiled tube. In case of smaller coil diameter and tube diameters (D and d) the intensity of secondary flow developed is high. Eustice [7] was the first to observe the fluid motion in curved pipes. Since then many researchers presented their studies on the fluid flow that develop in curved pipes, including helical coils [2, 8]. They provided the flow fields and temperature field analysis experimentally and numerically. The major effects observed in the helical coil configuration were due to the flow pattern in the curved tube; hence it is very essential to understand the effect of the flow pattern in curved tubes.

Prabhanjan et al. [9] performed the comparative study of the heat transfer between straight tube and helical coil tube in liquid to liquid configuration and showed that the helical coil heat exchangers show higher heat transfer coefficient. Thermal performance of a helical heat exchanger was investigated by Jung-Yang Sen et al. [10]. The helical coil heat exchanger was considered for the analysis with rectangular cross section and cover plates with inside mixed flow and the flow was unmixed on outside the tube. The analysis was carried out to study the behavior of friction factor and heat transfer coefficient.

The analysis of water-water heat exchanger was carried out with numerical model by Fernandez-Seara et al. [11] with outer surface in natural convection. The analysis was validated with experimental data with two helical coil heat exchangers tested under same operating conditions and the analysis showed that the Nu increases with the increase in tube diameter. Lee et al. [12] also studied the buoyancy forces with constant heat flux on fully developed laminar flow effect in the flow field and Thermal field. The system for fully developed laminar flow was numerically analyzed with constant heat flux along the axis and constant wall temperature condition along periphery. They found that average Nu was affected by buoyancy. They also found that the rotation of the secondary flow patterns depends on the buoyancy forces. Padmanabhan [13] studied the entry flow into curved pipes for constant heat flux and for constant wall temperature condition axially. The secondary motion was affected by buoyancy.

The investigation on concentric helical coils heat exchangers were experimentally investigated by Gomaa et al. [14] for its thermodynamic and hydrodynamic characteristics. Various parameters were considered for study as coil curvature ratio, number of turns, flow configuration, and addition of surface. The results showed that the annulus Nu was affected by annulus curvature ratio, δ and number of turns in such way the Nu has direct relation with annulus curvature ratio, δ and inverse relation with number of turns. Similar relation was obtained with friction factor, and noted that it increases with curvature ratio, δ and decreases with number of turns. In the analysis of tube in tube helical coil heat exchanger Mandal and Nigam [15] studied the transfer and fluid flow under turbulent condition. For both side in the heat exchanger water was used as working fluid. The tube side operating condition of inside tube was as Re in the range of 14,000 to 86,000. The data was validated by CFD analysis. Salem et al.
[16-18] conduct a series of experimental investigations on a horizontal shell and coil heat exchanger. In [16], they investigated the effect of coil curvature on the thermal performance and developed correlations to predict the average Nusselt number in the tube and shell side in addition to the Fanning friction factor in the tube side.

The present work is devoted to investigate numerically the characteristics of the convective heat transfer and pressure drop of helical cone heat exchangers of counter-flow configurations. This work is performed at different geometrical parameters of the HCT and at different operating conditions for the internal side of the heat exchanger.

A high-quality meshing is very important for more successful numerical simulations. The smaller the size of elements near the wall of the tube, the more detailed and also accurate flow structure will be captured. However, for 3-dimensional simulation, a small change in elements size leads to a substantial increase in number of elements, which leads to remarkable increase in the computational time. Therefore, for making a convenient balance between the accuracy of the simulations and solution time, an optimum size of mesh needs to be chosen.

A tetrahedral method is used for meshing the shell and tube domains with relevance center of medium type and fine smoothing. Skewness is one mesh metrics, available in ANSYS; the acceptable range for Skewness is between 0.8 and 0.95. This range is considered in the existing simulation study to get mesh with a high quality.

### Table 1: Characteristic dimensions of the used coils.

<table>
<thead>
<tr>
<th>N</th>
<th>d1 (mm)</th>
<th>d2 (mm)</th>
<th>Dexit (mm)</th>
<th>L (mm)</th>
<th>R (mm)</th>
<th>θ</th>
<th>χ</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.10</td>
<td>12.70</td>
<td>300</td>
<td>500</td>
<td>119.65</td>
<td>15</td>
<td>0°</td>
<td>14</td>
</tr>
<tr>
<td>2</td>
<td>10.92</td>
<td>12.70</td>
<td>300</td>
<td>500</td>
<td>119.65</td>
<td>22.5°</td>
<td>0.0041</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>11.82</td>
<td>12.70</td>
<td>300</td>
<td>500</td>
<td>119.65</td>
<td>45°</td>
<td>0.1206</td>
<td>8</td>
</tr>
</tbody>
</table>

### Table 2: Range of both fluids operating conditions.

<table>
<thead>
<tr>
<th>Parameters/operating conditions</th>
<th>Range or Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube-side</td>
<td></td>
</tr>
<tr>
<td>Water velocity, m/s</td>
<td>0.1, 0.2, 0.3, 0.4 &amp; 0.5</td>
</tr>
<tr>
<td>Inlet temperature, °C</td>
<td>10, 15, 20, 25</td>
</tr>
<tr>
<td>Shell-side</td>
<td></td>
</tr>
<tr>
<td>Air velocity, m/s</td>
<td>0.5</td>
</tr>
<tr>
<td>Inlet temperature, °C</td>
<td>50</td>
</tr>
</tbody>
</table>

**Results and discussion**

In the present work represents the effect of taper angle, water inlet boundary conditions
(temperature and velocity) on heat transfer rate. Fig. 2 shows the temperature contours for the tree coils with different taper angels 0, 22.5 and 45. From the fig it can be deduced that for air side as the taper angel increases the air temperature will decrease comparison with the helical one and for water side the outlet temperature will increase in comparison with the helical one due to vortices so increasing taper angel will increase the heat transfer rate but it was observe that the pressure drop will increase also along the coil Fig. 3 Comparison of pressure contours for different models with different taper angels and also Fig. 4 Comparison of velocity contours for different models with different taper angels.

**Effect of changing taper angel**

![Fig. 2 Comparison of temperature contours for different models with different taper angel](attachment:image1)

![Fig. 3 Comparison of pressure contours for different models with different taper angel](attachment:image2)
Effect of changing water inlet temperature

For the other side fig. 5 effect of changing inlet water temperature it was deduced that the by increasing the inlet water temperature the outlet temperature for air side will be decreased and for water side will be decreased so increasing water inlet temperature will decrease the rate.

Effect of changing water inlet Velocity

For fig. 6 Comparison of temperature contours for different models with different water inlet velocity as observed in the fig. by increasing the inlet water velocity the heat transfer rate will be increased in comparison with the helical one at the same condition.
4. Conclusions

Numerical CFD simulations with Realizable $k$–$\epsilon$ turbulence model are employed in the present work. The effect of changing in Reynolds number, flow rate, tapper angle and inlet temperature on the heat transfer and friction factor for fluid flow inside helical cone tube. The major conclusions drawn from this work can be summarized as following:

- Increasing tapper angle will increase heat transfer rate
- Increasing tapper angle will increase pressure drop
- Increasing inlet temperature will decrease the heat transfer rate.
- Increasing inlet velocity will increase the heat transfer rate.
- Increasing inlet velocity will increase the pressure drop.

REFERENCES


