EXPERIMENTAL AND CFD STUDY OF A HELICAL COIL HEAT EXCHANGER USING WATER AS FLUID

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Abstract- As compared to straight tubes, curved tubes are more advantageous because of its compact structure and it has been practiced as ace of the passive heat transfer enhancement techniques and is being most widely practiced in several heat transfer applications. Usually the coil will be wound inside the case of a helical coil heat exchanger and in our field; the helix is wound outside the case. This offers the advantage of avoiding insulation outside the heat exchanger coils. This paper deals with experimental study and CFD simulation of helical coil heat exchanger using Solidworks Flow Simulation (Cosmos Express). The fluid used for both coil and tube side is water. The flow rate of both fluids is maintained below as laminar and the flow rate of cold fluid is kept constant while that of hot fluid is changed. The readings during experimental study are taken once steady state has reached. The performance parameters pertaining to heat exchanger such as effectiveness, overall heat transfer coefficient, velocity contours, temperature contours etc. have been reported. Based on the results, it is inferred that the heat transfer rates and other thermal properties of the helical coil heat exchanger are comparatively higher than that of a straight tube heat exchanger.

Keywords- Helical coil heat exchanger, experimental study, CFD, Solidworks Flow Simulation.

I. INTRODUCTION

Based on literature survey, the heat transfer in helical coils are comparatively higher than straight tubes. Because of its compact structure and high heat transfer rate, it is widely used in heat recovery systems, power generation, food industry, refrigeration, nuclear plants, etc. [1-5]. Heat transfer in helical coil was successfully investigated for both laminar and turbulent flow regimes with constant wall flux BC [6]. The improvement techniques for helical coil heat exchanger were proposed by Janssen & Hoogendoorn [7]. The pressure drop and void fraction measurement in helical coil for two phase counter current flow was conducted by Kasturi & Stepanek [8] & the flow pattern transition between stratified and annular flow was analyzed by Whalley [9]. The phenomenon of relaminarization was first studied by Sreenivasan and Strykowski [10]. The first review of heat transfer and flow through helical coils was done by Berger et al [11], followed by Shah and Joshi [12]. Awwad et al [13] has done an experiment on two phase flow in horizontal helicoidal pipes. Xin RC [14] carried out an experiment of two phase flow in vertical helicoidal pipes and measured pressure drop and void fraction. Experimental study for various process parameters of the residual heat removal system using a helically coiled tube was done by Jayakumar and Grover [15]. CFD analysis of helically double pipe heat exchangers for laminar flow were carried out and found the overall heat transfer coefficients for counter and parallel flows by Rennie and Raghavan [16, 17]. Pressure drop and heat transfer in tube-in-tube helical heat exchanger under turbulent condition was studied by Vimal Kumar et al. [18] using CFD package but could not give the correlation for estimation of Nu. The recent review of flow and heat transfer through helical pipes is given by Naphon & Wongwises [19].

So far in researches, they tried placing the helix inside the shell and varied the diameter of the coil. Various experiments were done for studying heat transfer coefficient and effectiveness for helical coil. In our work a simple construction of aluminium tube externally coiled with copper coil has been designed and fabricated. Further the parameters involved in helical coil heat exchanger have been studied for laminar flow conditions using Solidworks Flow Simulation (Cosmos Express) and by conducting experiments.

II. EXPERIMENT SETUP

The schematic layout of helical coil heat exchanger is as shown in Fig.1. The helix is made of Copper is wound outside the tube made of Aluminium. The hot water is entered from the tank to one side of the tube under gravity and exited from other side of the tube. Similarly, cold water is entered into the coil from tank under gravity and exited from bottom of the coil. The source of cold fluid is domestic water supply and reuse is avoided. The hot water tank is made of Stainless steel with 25 liters capacity and properly insulated to reduce heat loss and consists of immersion type heater of 1000W capacity. The cold water tank is plastic cylindrical container with 40 liters capacity. Suitable piping, tubing and fittings are used to circulate the hot fluid and cold fluid through the straight tube and helical coil tube respectively. The flow rates of both fluids were measured using beaker and stop watch.
Thermometers were used to measure the tube and coil side fluid temperature. The experiments are carried out once the steady state has reached. Table 1 shows the specification of helical coil heat exchanger and Table 2 shows the operating range of our heat exchanger.

### Table 1: Specifications of helical coil heat exchanger

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>DIMENSIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper coil O.D.</td>
<td>6.5 mm</td>
</tr>
<tr>
<td>Copper coil I.D.</td>
<td>4.5 mm</td>
</tr>
<tr>
<td>Straight coil length</td>
<td>1675 mm</td>
</tr>
<tr>
<td>Aluminium tube O.D.</td>
<td>57.5 mm</td>
</tr>
<tr>
<td>Thickness of tube</td>
<td>1.2 mm</td>
</tr>
<tr>
<td>Tube length L</td>
<td>800 mm</td>
</tr>
<tr>
<td>Inclination angle</td>
<td>---</td>
</tr>
<tr>
<td>No. of turns</td>
<td>82</td>
</tr>
<tr>
<td>Pitch of the coil</td>
<td>8 mm</td>
</tr>
<tr>
<td>Fluid used</td>
<td>Water</td>
</tr>
</tbody>
</table>

### Table 2: Operating range of heat exchanger

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>PARAMETER RANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coil side water flow rate</td>
<td>0.008 kg/s</td>
</tr>
<tr>
<td>Tube side water flow rate</td>
<td>0.022, 0.042, 0.083 kg/s</td>
</tr>
<tr>
<td>Coil inlet temperature</td>
<td>30 °C</td>
</tr>
<tr>
<td>Coil outlet temperature</td>
<td>30 - 45 °C</td>
</tr>
<tr>
<td>Tube inlet temperature</td>
<td>50, 65, 75 °C</td>
</tr>
<tr>
<td>Tube outlet temperature</td>
<td>45 - 75 °C</td>
</tr>
</tbody>
</table>

### III. CFD ANALYSIS

The results obtained from CFD analysis have been plotted. Fig.4 shows temperature contours, Fig.5 shows velocity contours and Fig.6 shows pressure contours for mass flow rate of 0.022 kg/s with hot fluid temperature of 50°C.
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Fig. 5 Velocity contour

Fig. 6 Pressure contour

Fig. 7 Temp of Fluid along the length of tube

Fig. 8 Prandtl number along the length of tube

Fig. 9 Turbulence intensity along length of tube

Fig. 10 Temp of fluid along the coil length

Fig. 11 Prandtl number along the coil length

Fig. 12 Nu Vs De

Fig. 7, Fig. 8, Fig. 10 and Fig. 11 shows the Temperature of the fluid and Prandtl number along the length of tube and coil respectively. Fig. 9 shows Turbulence intensity along the length of tube obtained from CFD analysis. An investigation was carried out in helical coil heat exchanger experimentally and computationally. The results from computational analysis appear to be in good agreement with that of available experimental outcomes. The results obtained from both are compared below. The performance of the helical coil heat exchanger is assessed on basis of Dean number, Nusselt number, Overall heat transfer coefficient and effectiveness. Fig. 12 shows Nu Vs De for various mass flow rates of hot fluid and with temp of 50°C and 75°C. It is seen that with increase in mass flow rate, the De and Nu increases for a particular hot fluid inlet temperature.
Fig. 13 shows Dean number Vs Overall heat transfer coefficient. It is found that as the Dean number increases the U also increases. This is predominantly seen when the flow transmits from laminar to turbulent.

Fig. 14 shows Dean number Vs Heat removed. It is inferred that as the De increases the Q also increases. So, more amount of heat is exchanged between hot and cold fluid as the mass flow rate of hot fluid increases.

Fig. 15 shows mass flow rate of hot fluid Vs Effectiveness. It is seen that effectiveness of helical coil heat exchanger increases as the mass flow rate increases. So performance of this heat exchanger is comparatively higher than shell and tube heat exchanger.

Fig. 16 and Fig. 17 shows mass flow rate of hot fluid Vs Nu for temp of 50°C and 75°C respectively. In both cases as mass flow rate increases Nusselt number increases.

Fig. 18 and Fig. 19 shows mass flow rate of hot fluid Vs U for temp 50°C and 75°C respectively. It is inferred that as mass flow rate increases overall heat transfer also increases with temp.
CONCLUSION

In this study an experimental investigation and computational analysis of helical coil heat exchanger is carried out. From the above results the overall conclusion is when hot fluid mass flow rate increases, the Overall Heat Transfer Coefficient, Nusselt number, heat transfer coefficient of cold fluid and effectiveness also increases. This is due to helical nature of the coil and the better flow distribution of cold fluid. For the shell and tube configuration heat exchanger normally Nusselt number (Nu) is taken as a constant value of 3.66 and for this the heat transfer coefficient is low for cold fluid which in turn lowers the heat transfer rate under free convection mode. But in the above helical coil heat exchanger for the increasing hot fluid mass flow rate the Nusselt Number(Nu) for cold side, the effectiveness of this exchanger is also increasing than that of shell and tube heat exchanger conceptually.

REFERENCES