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 relamianrization 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.

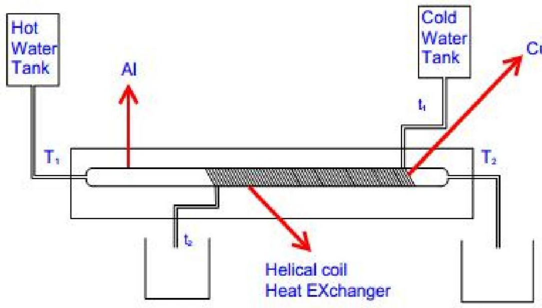

Fig. 1 Schematic Layout of helical coil Heat Exchanger

PARAMETERS	DIMENSIONS
Copper coil O.D.	6.5 mm
Copper coil I.D.	4.5 mm
Straight coil length	1675 mm
Aluminium tube O.D.	57.5 mm
Thickness of tube	1.2 mm
Tube length L	800 mm
Inclination angle, [illegible]	---
No. of turns	82
Pitch of the coil	8 mm
Fluid used	Water

Table1. Specifications of helical coil heat exchanger

PARAMETERS	PARAMETER RANGE
Coil side water flow rate	0.008 kg/s
Tube side water flow rate	0.022, 0.042, 0.083 kg/s
Coil inlet temperature	30 °C
Coil outlet temperature	30 - 45 °C
Tube inlet temperature	50, 65, 75 °C
Tube outlet temperature	45 - 75 °C

Table2. Operating range of heat exchanger

III. CFD ANALYSIS

The steps to be followed to use CFD are as follows:
Pre-processor: Establishing the model
* Identify the process or equipment to be evaluated.
* Represent the geometry of interest using CAD tools.
* Use the CAD representation to create a volume flow domain around the equipment containing the critical flow phenomena.
* Create a computational mesh in the flow domain.
Solver:
* Indentify and apply conditions at the domain boundary.
* Solve the governing equations on the computational mesh using analysis software.
Post processor: Interpreting the results
* Post-process the completed solutions to highlight findings
* Interpret the prediction to determine design iterations or possible solutions, if needed.

The CFD analysis was done in Solidworks Flow Simulation (Cosmos Express) software and various parameters were found out. Fig.2 and Fig.3 shows the model and meshing of helical coil heat exchanger using Solidworks Flow Simulation.

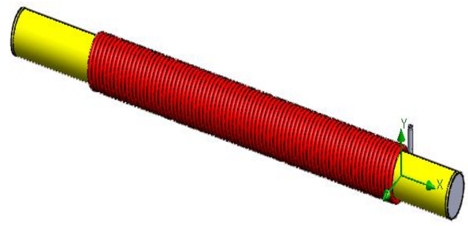

Fig.2 Model in Solidworks Flow Simulation

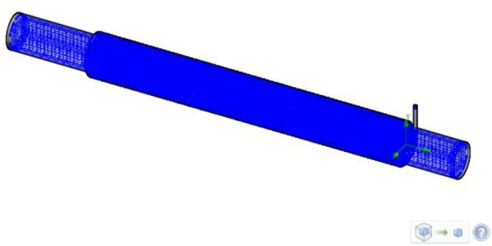

Fig.3 Meshing of heat exchanger

IV. RESULT AND DISCUSSION

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.

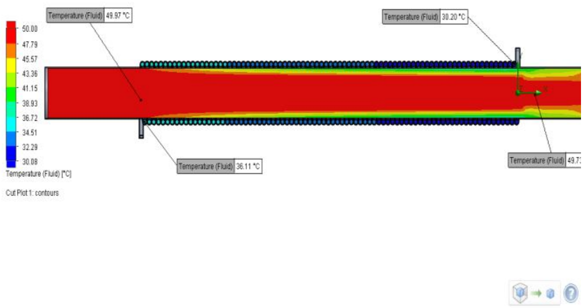

Fig.4 Temperature contour

Fig.5 Velocity contour

Fig.6 Pressure contour

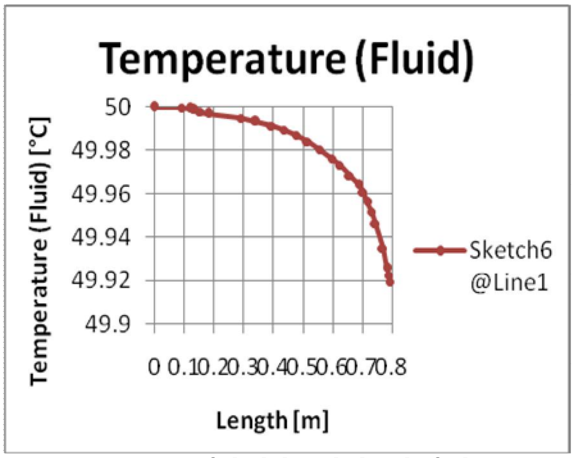

Fig.7 Temp of Fluid along the length of tube

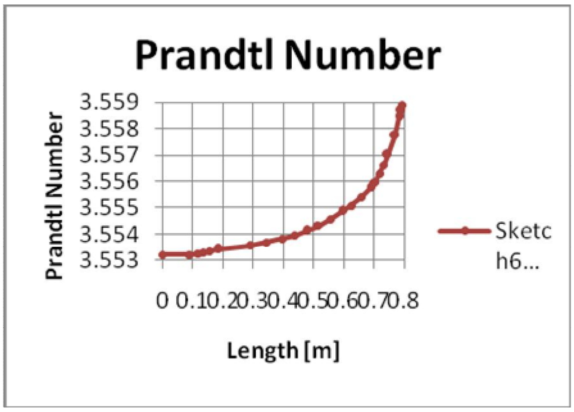

Fig.8 Prandtl number along the length of tube

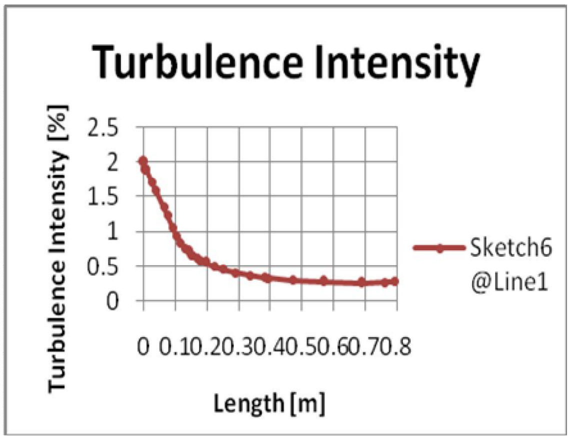

Fig.9 Turbulence intensity along length of tube

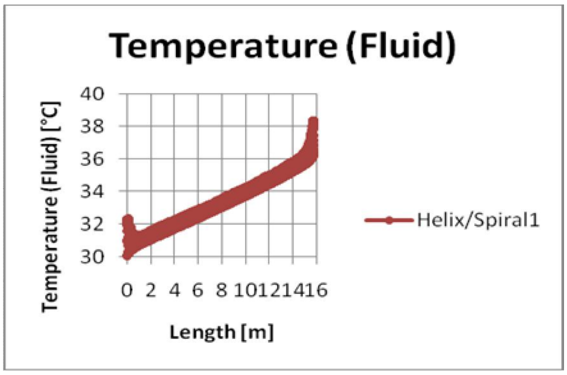

Fig.10 Temp of fluid along the coil length

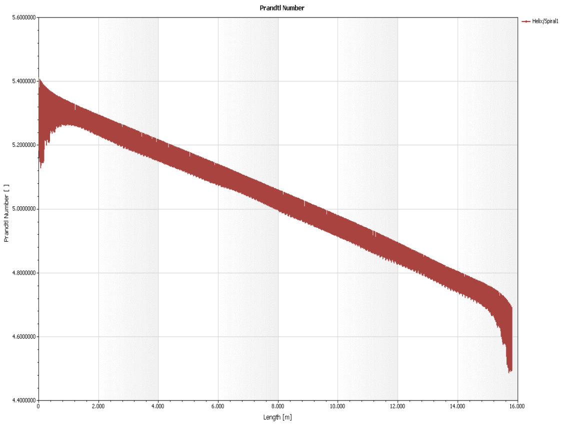

Fig.11 Prandtl number along the coil length

Fig.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.

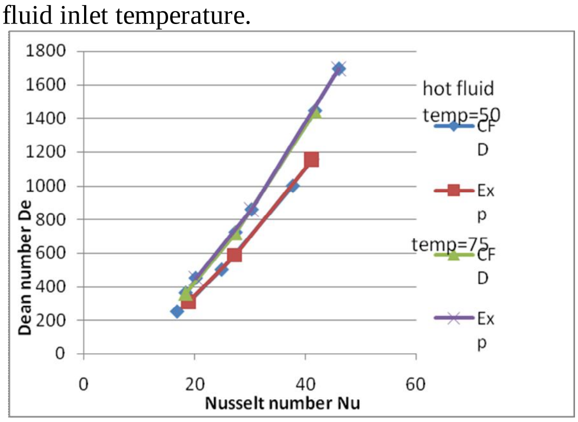

Fig.12 Nu Vs De

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.

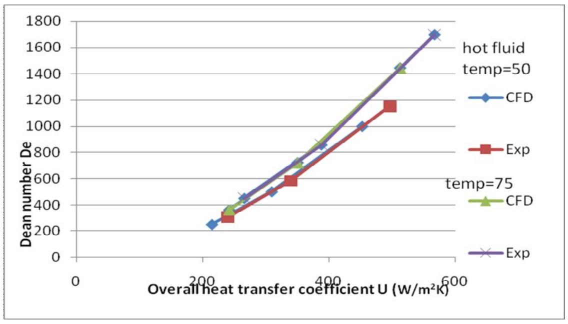

Fig.13 U Vs De

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.

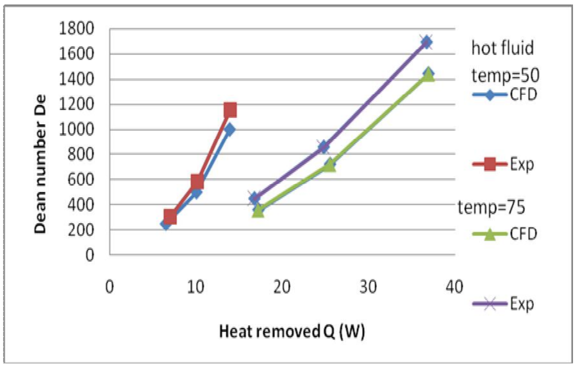

Fig.14 Q Vs De

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.

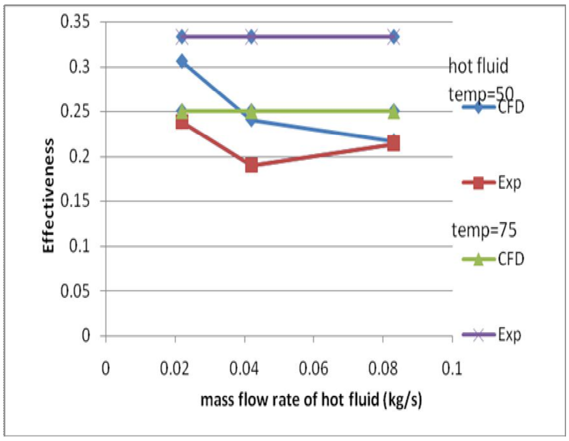

Fig.15 mass flow rate of hot fluid Vs Effectiveness

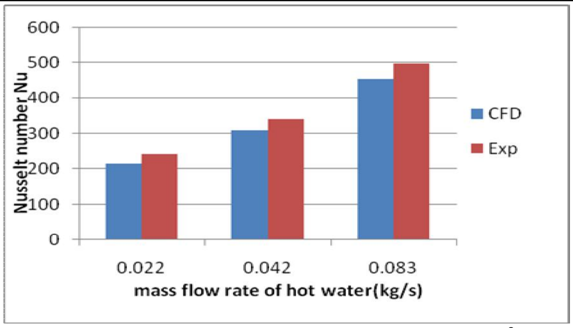

Fig.16 mass flow rate of hot fluid Vs Nu for temp 50°C

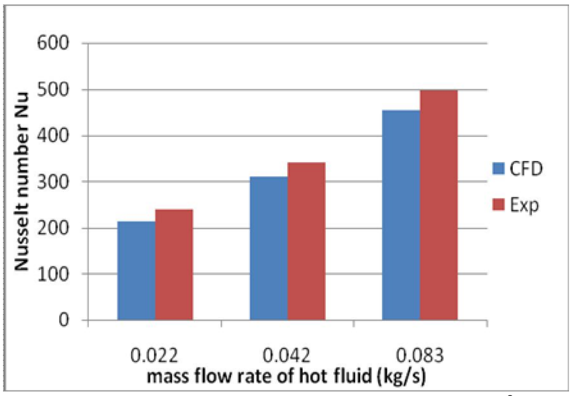

Fig.17 mass flow rate of hot fluid Vs Nu for temp 75°C

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.

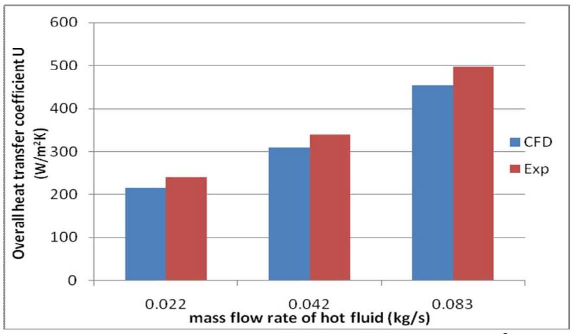

Fig.18 mass flow rate of hot fluid Vs U for temp 50°C

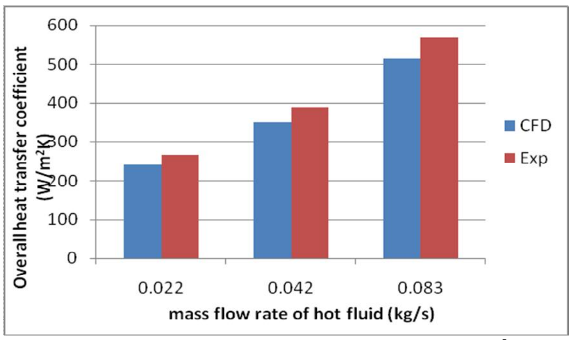

Fig.19 mass flow rate of hot fluid Vs U for temp 75°C

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

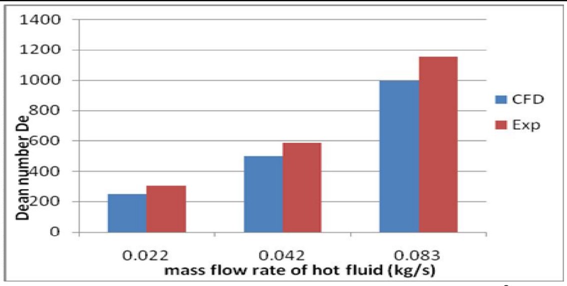

Fig.20 mass flow rate of hot fluid Vs De for temp 50°C

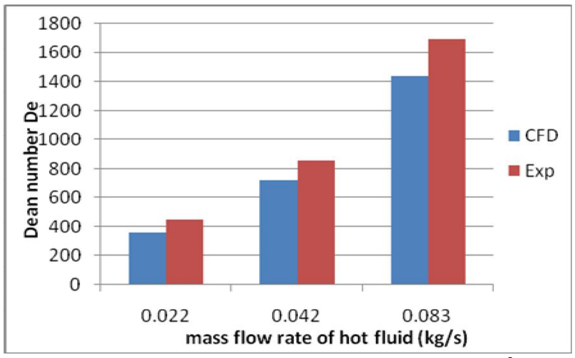

Fig.21 mass flow rate of hot fluid Vs De for temp 75°C

Fig.20 and Fig.21 shows mass flow rate of hot fluid Vs De. It shows increase in mass flow rate increases the Dean number with temperature increase. It is inferred that the computational results and experimental results are in agreement with each other.

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.

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