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Experimental and CFD study of Helical Coil Heat Exchanger using CuO-Water Nano Fluid as Coolant

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Abstract—*The curved tubes are more advantageous than straight tubes because of its compact structure and have been practiced as an ace of passive heat transfer enhancement technique and are used in many heat transfer applications. Usually the coil will be wound inside the case of a helical coil heat exchanger but in our case 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 coil side is CuO-water nano fluid and tube side is water. The flow rate of both fluids is maintained below as laminar and the flow rate of coolant 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 and better than water as coolant.*

1. INTRODUCTION

Until now, it was known that, in forced convection [1, 2] as well as in mixed convection, using nano fluids could produce a considerable enhancement of the heat transfer coefficient that increased with increasing the nano particle volume fraction. One of the major reasons was that nano particles enhance heat transfer rate by increasing the thermal conductivity of the resulting nano fluid and incurring thermal dispersion in the flow [3, 4]. On the other hand, the experimental study by Putra et al. [5] for a natural convection case of copper and alumina-water nano fluids inside a horizontal differentially heated cylinder has shown an apparently paradoxical behaviour of significant heat transfer deterioration. Wen and Ding [6], using titanium dioxide nano particles, have also observed experimentally such deterioration in the natural convective heat transfer. Li and Xuan [7], Xuan and Li [8] and Pak and Cho [9] experimentally measured the convection heat transfer and pressure drop for nano fluid tube flows. Their results indicated that heat transfer coefficient was greatly enhanced and depends on the Reynolds number, the particle size and shape, and particle volume fraction. They also found that nano particles did not cause an extra pressure drop. Donsheng and Yulog [10] studied experimentally the convective heat transfer of nano fluid made of γ-Al2O3-water, flowing through a copper tube in the laminar flow regime. They showed a considerable enhancement of convective heat transfer using the nano fluids. The enhancement was particularly significant in the entrance region, and was much higher than that solely due to the enhancement on thermal conduction. Heat transfer in helical coil was successfully investigated for both laminar and turbulent flow regimes with constant wall flux BC [11]. The improvement techniques for helical coil heat exchanger were proposed by Janssen & Hoogendoorn [12]. The phenomenon of relamianrization was first studied by Sreenivasan and Strykowski [13]. The first review of heat transfer and flow through helical coils was done by Berger et al [14], followed by Shah and Joshi [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.

From the literature survey, it is inferred that many researchers performed various experiments for various Reynolds number and also by varying the diameter of coil or tube. In these cases the coil will be wound inside the tube with insulator over the tube. In our case the helix wound outside the tube is 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.

2. EXPERIMENTAL WORK

- **Preparation of nano fluid**

The CuO nano particles of average size 40nm were purchased and TEM analysis was done to confirm the particle size. The distilled water and sodium dodecyl sulphate (SDS) surfactant was obtained. The preparation of nano fluid is the first step for this experiment. The nano fluid was prepared by the two-step method in which the nano particles were dispersed in the base fluid. First of all calculation was made for the weight of CuO nano particles used for 50ml of the distilled water for 0.5vol %. It was 1.6gm of CuO nano particle for 0.5vol% of the nano fluid. The mass of the SDS surfactant used was 0.1gm for the 50ml distilled water. After the calculation of the mass of the CuO nano particle and the SDS surfactant, the required mass of the SDS was directly added to the distilled water and thoroughly stirred. Then required mass off the CuO was added to the surfactant dissolved distilled water and then stirred thoroughly. To increase the dispersion stability the sonication was done by the ultra-sonicator water bath for three hours. After the sonication the prepared nano fluids was used in experimental-setup for taking the readings.

- **Experimental Setup**

A schematic layout of helical coil heat exchanger is as shown in Fig. 1. The helical coil made of Copper is wound outside the shell made of Aluminium. The outer diameter of the shell is 51mm and the length is limited to 800mm. The hot water is entered from the tank to one side of the shell under gravity & exited from the other side of the shell. Similarly, coolant CuO-water nano fluid is entered into the coil from tank under gravity & exited from the bottom of the coil. The hot water tank is made of stainless steel properly insulated to reduce heat loss with a storage capacity of 25 liters & it consists of immersion type heater of capacity 1000W. The coolant tank is a plastic cylindrical container with a storage capacity of 40 liters. Suitable piping, tubing and fittings are used to circulate the hot fluid and coolant through the straight tube and helical coil tube respectively. The flow rates of both hot fluid and coolant are measured by using a beaker and a stop watch. Total four thermometers are used for measurement of the inlet & outlet temperatures of shell and coil sides. The tests were done at various mass flow rates of hot fluid at 0.022, 0.042, and 0.083 kg/s keeping the coolant mass flow rate constant at 0.008kg /s. Two different constant temperatures of 50 and 75^{o}C were considered for the mass flow rate of the shell and a constant temperature of 30^{o}C was considered for that of the coil. All the observations were taken under the steady state conditions. Table.1 gives the specifications of the helical coil heat exchanger.

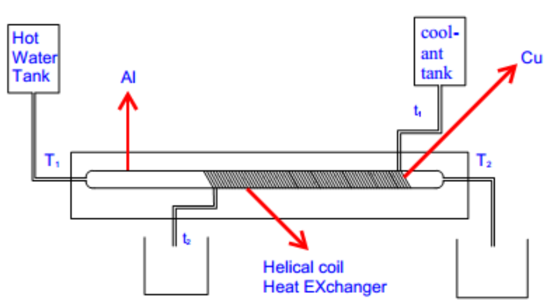

Fig. 1 Schematic Layout of helical coil Heat Exchanger

Table 1: Specifications 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 shell	1.2 mm
Tube length, L	800 mm
Inclination angle, ϕ	---
No. of turns	82
Pitch of the coil	8 mm
Fluids	CuO-water nano fluid, water

- **Computational Fluid Dynamics**

Basic Approach to using CFD

a) 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.

b) Solver:
- Indentify and apply conditions at the domain boundary.
- Solve the governing equations on the computational mesh using analysis software.

c) 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 of helical coil heat exchanger

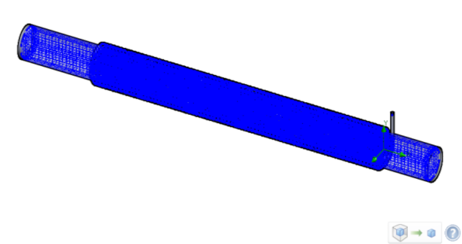

Fig. 3 (a) Fluid side meshing

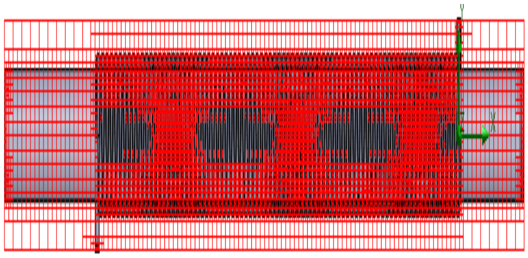

Fig. 3 (b) Solid side meshing

3. RESULTS AND DISCUSSIONS

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^{o}C.

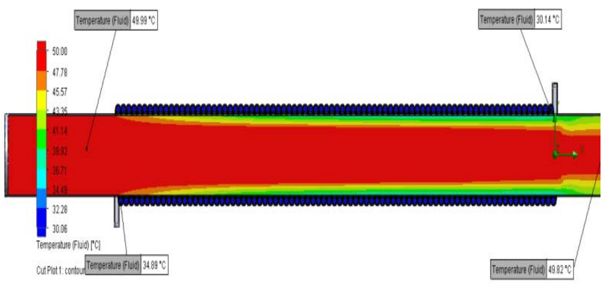

Fig. 4: Temperature Contour

Fig. 5: Velocity Contour

Fig. 6: Pressure Contour

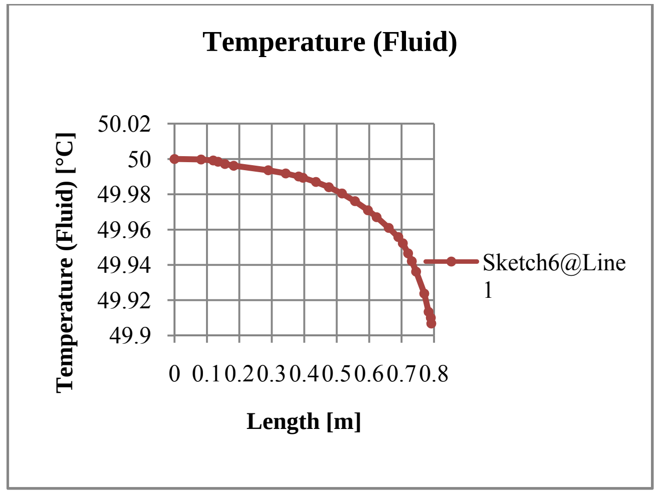

Fig. 7: Temperature along the length of tube

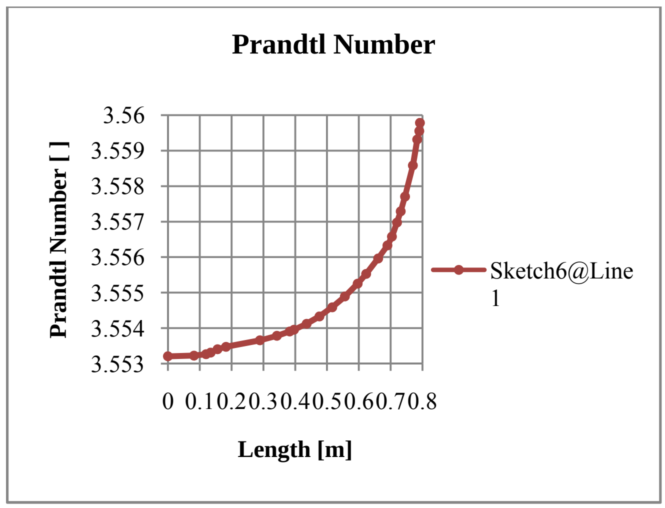

Fig. 8: Prandtl number along tube length

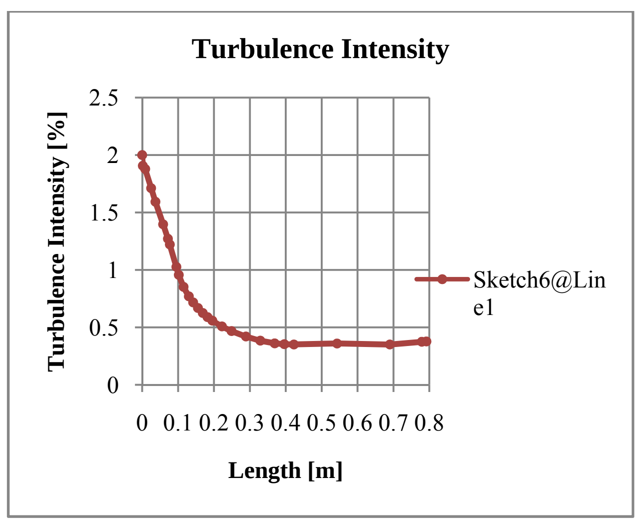

Fig. 9: Turbulence intensity along the tube length

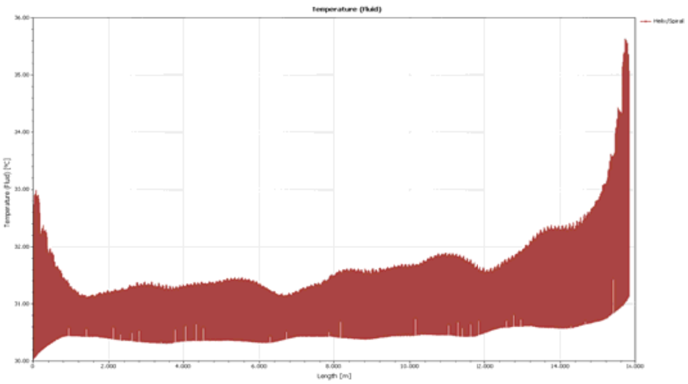

Fig. 10 : Temperature along coil length

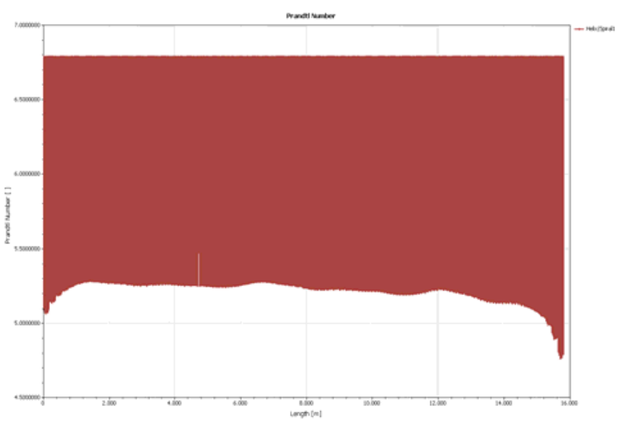

Fig. 11: Prandtl number along coil length

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.

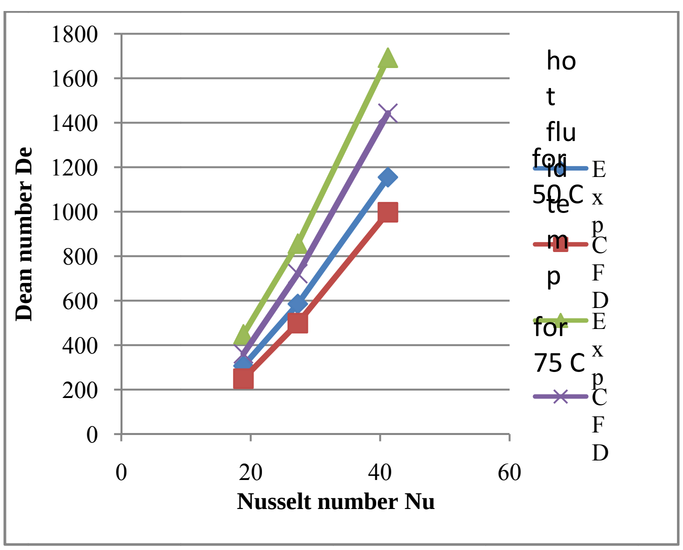

Fig. 12: Nu Vs De

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 for both experimental and computational results. 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. It is also seen that the overall heat transfer coefficient is higher for nano fluid as coolant than water.

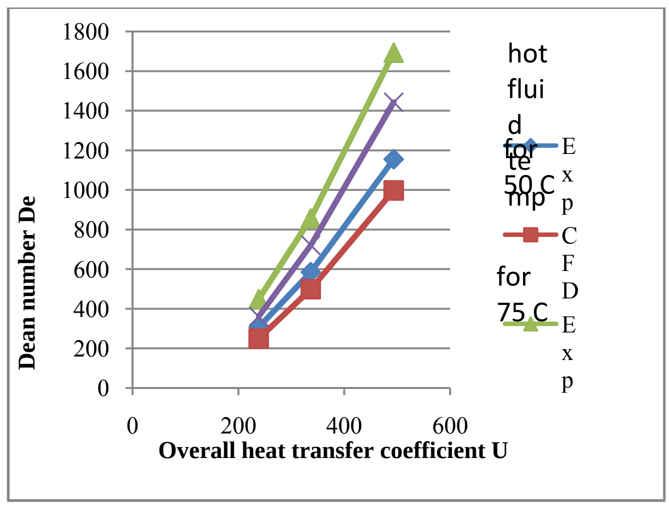

Fig. 13 U Vs De

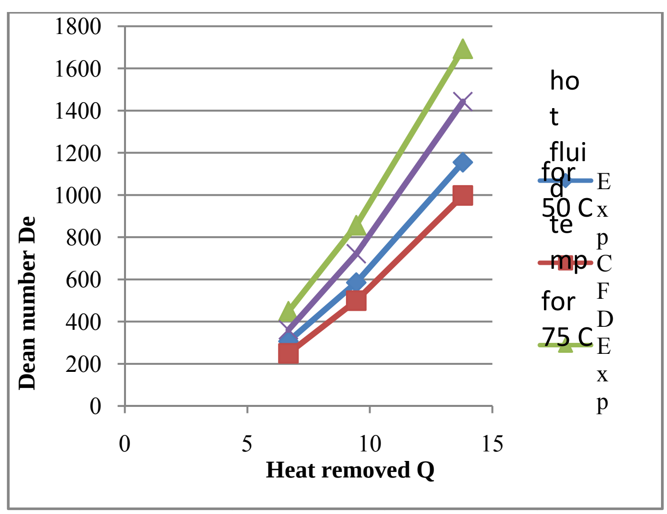

Fig. 14 Q Vs De

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. So, more amount of heat is exchanged between hot and cold fluid as the mass flow rate of hot fluid increases. The heat removed is high for nano fluid as coolant. This shows the heat exchanger is effective when nano fluid is used as coolant.

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.

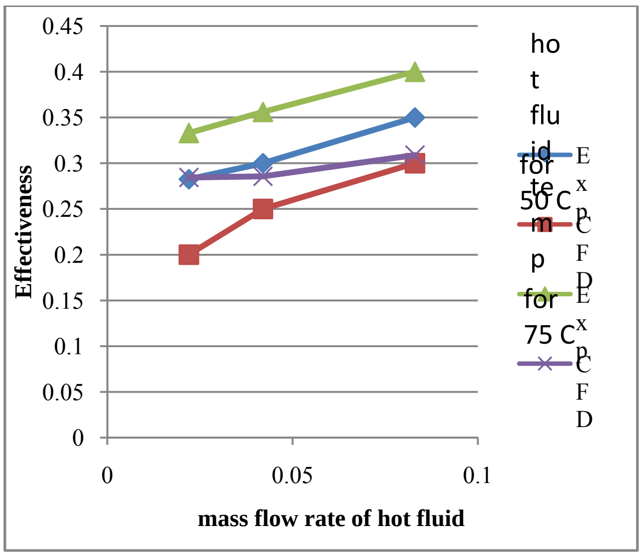

Fig. 15: mass flow rate Vs Effectiveness

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

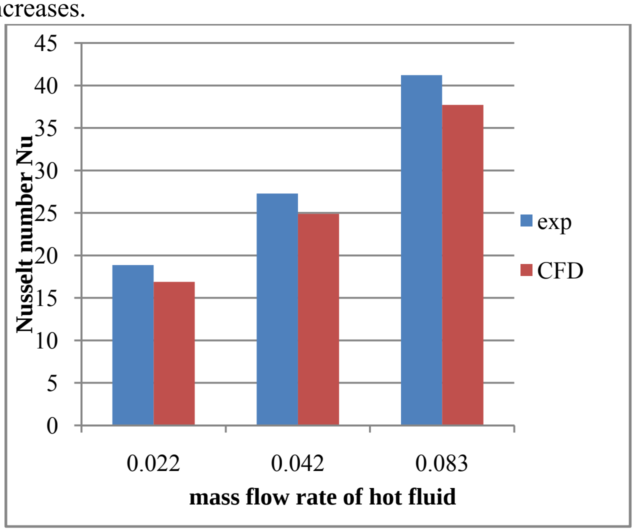

Fig. 16: mass flow rate Vs Nu for 50°C

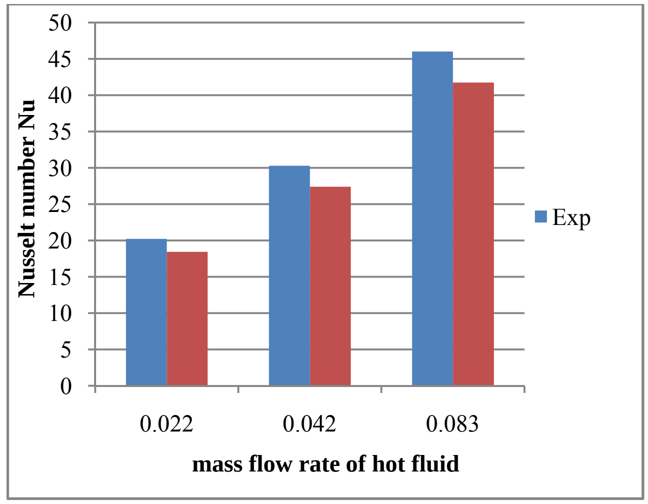

Fig. 17: mass flow rate Vs Nu for 75oC

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.

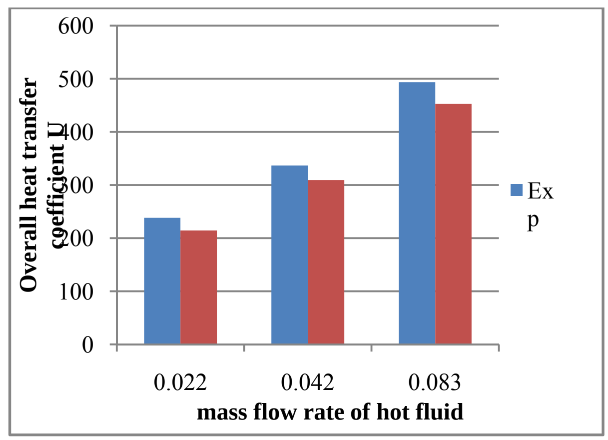

Fig. 18: mass flow rate Vs U for 50°C

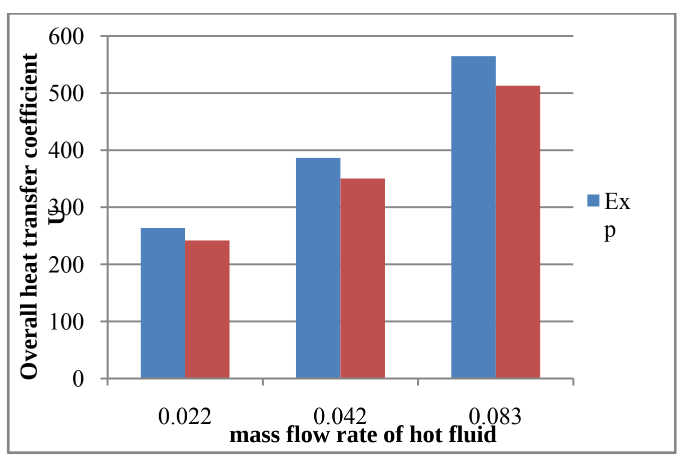

Fig. 19: mass flow rate Vs U for 75°C

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.

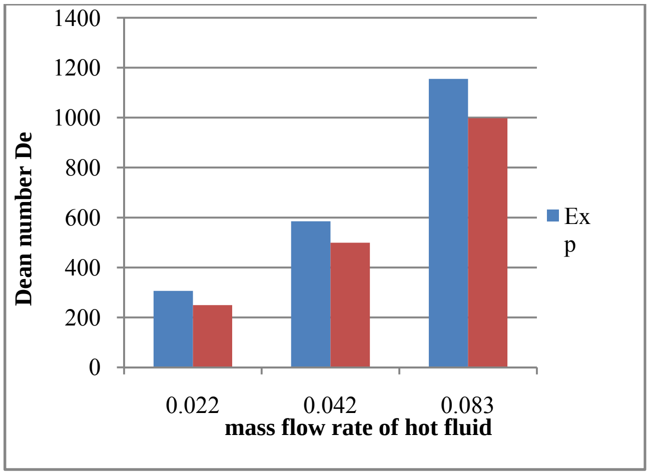

Fig. 20: mass flow rate Vs De for 50°C

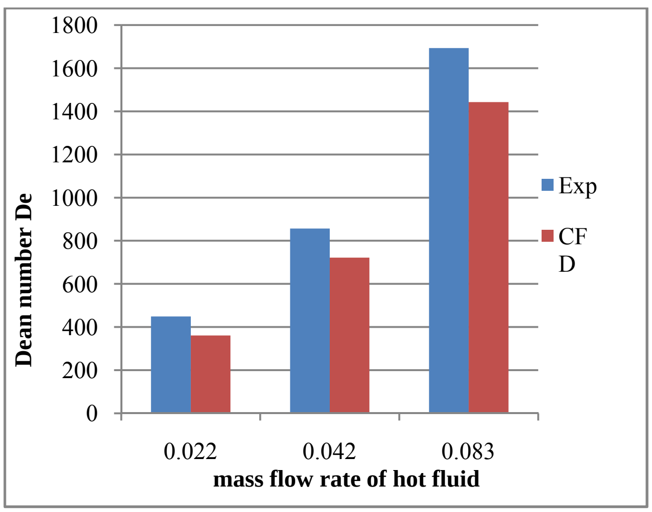

Fig. 21: mass flow rate Vs De for 75°C

It is inferred that the computational results and experimental results are in agreement with each other.

4. 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. The overall heat transfer coefficient, heat removed and in all the performance of helical coil heat exchanger is better when nano fluid coolant is used instead of water. The performance can be still increased by increasing the volume fraction of nano particle while preparing the nano fluid.

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