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An Experimental and CFD Analysis on Helical Coil Heat Exchanger with Different Geometry

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Abstract –*An attempt is made here to investigate the effect of geometric features especially different geometric shape of coil on single phase flow and convective heat transfer characteristics by experimentally and using CFD technique. An experimentation done on helical, conical and spiral coil. Copper tube of internal diameter 9.5 mm , 1.5 mm thickness and 3000 mm long is used for experimentation. Readings recorded for different mass flow rate(15 LPH,20LPH, 25LPH). Comparative analysis shows that convective heat transfer rate of helical coil tube heat exchanger is 9.54% more than conical and spiral coil heat exchanger. Nusselt number increase as the mass flow rate increase. Helical coil heat exchanger is more efficient than conical and spiral coil heat exchanger. The Computational Fluid Dynamics (CFD) software has been used for simulation of heat exchanger. Experimentation conducted on new heat exchanger for particular mass flow rate and data is maintained as per various flow rate. The experimental results of water outlet temperature are validated with the results obtained by using computational fluid dynamics (CFD) tool and there is a good agreement in between them.*

Index terms: *Helical coil, Spiral coil, conical coil, heat exchanger, Computational Fluid Dynamics(CFD).*

I. INTRODUCTION

Heat exchanger is a device that continuously exchange heat from one medium to other medium in order to carry process energy. In heat exchangers design researches are continuously using new techniques to maximize the surface area of the wall between the two fluids flow through the exchanger in order to enhance heat transfer. There are active and passive techniques had used enhance heat transfer rate from straight tube *i.e.* use of tape or coil insert, use of electric field, surface vibration are active techniques and use of some additives in fluid, use of special surface geometry are passive techniques but this led to reduction in mass flow rate and required extra volume of material and entire effect is increases in overall cost of heat exchanger[1]. Now a day's research is going on fin and tube heat exchanger. Many researchers and academicians had been working on minimum pressure drop[2]. In order to improve heat transfer performance coiled tube have been used widely in heat exchanger. Temperature addition and curvature of coil considerably affect on flow behavior and heat transfer performance inside the tube [3]. The impact of stream wise forces inertia force is the major factor of heat transfer enhancement. Steam wise variation of circumferential distribution of heat transfer enhancement by rotation produces sensitivity to rotation speed, direction and curvature ratio[4]. Massimiliano Di Liberto studied turbulent heat transfer in curved pipes result exhibited that heat transfer rates were larger due to the curvature induced modification of mean flow temperature field[5]. Purandare deals with the parametric analysis of helical coil heat exchanger. This shows that in laminar region the secondaries developed in the fluid flow goes on increasing, as Re increases which increase the turbulence in the fluid flow[6]. J. S. Jayakumar et al. Carried out CFD simulation on vertically oriented helical coil by varying coil parameters such as pitch circle diameter, tube pitch, and pipe diameter and their effect on heat transfer has been studied. Also found a correlations to predict local value of nusselt number[7]. N. Ghorbani et al. Carried out experimentation of mixed convection heat transfer in vertical helically coiled tube heat exchanger .The results indicate that the equivalent diameter of shell is the best characteristic length[8]. Experimentation done on performance analysis of shell and tube heat exchanger using missible sysyter results found that increase in flow rate of cold fluid results in increase in the overall heat transfer coefficient [9]. Naphon et al studied different literature of flow and heat transfer characteristics in curved tubes helically coiled tube, spirally coiled tube, and other tubes are described[10]. A CFD package was used to numerical study of heat transfer characteristics of a double pipe helical heat exchanger for both parallel flow and counter flow. The result shows that an increasing overall heat transfer coefficients as the inner Dean number is increased. Thermal resistance were calculated for the annulus[11]. C. Biserni used inverted fins in coils this inverted fins may be regarded as negative fins. Different shapes of cavity used for improve the heat transfer performance[12]. The relationship based on the film temperature was used to determine the inner Nusselt number Nu_i.$Nu_i=0.021\ Re^{0.85}\ Pr^{0.4}\ (\delta)^{0.1}$ [13,14,15,16].

II. EXPERIMENTATION

A. Design of coil

Design of helical coil tube for heat exchanger deals with deciding various geometric parametersand thermal parameters. There are two methods of tube design on is based on selecting Known length of tube and then from experimentation find out the outlet temperature of fluid inside tube using LMTD approach and another method is to decided outlet temperature of fluid as per application and then find out temperature of tube using LMTD and overall heat transfer coefficient approach. We have followed first method to design helical tube, in this a straight copper tube of 9.5 mm outside diameter and 3000 mm length has been selected for straight tube made first and then helical coil is generated from that straight tube and further analysis has been made. Similarly with the same dimensions generated conical coil as well as spiral coil from same copper tube The details regarding various geometric parameters of tubes are given in below table.

TABLE I
GEOMETRIC PARAMETERS OF COILS.

parameters	Dimensions		
	Cone shaped helical coil	Simple helical coil (curvature ratio=0.064)	Spiral shaped coil
Copper tube O.D.	9.5mm	9.5mm	9.5mm
Copper Tube I.D	8mm	8mm	8mm
Straight tube Length	3000mm	3000mm	3000mm
Top coil Diameter(D_M)	125 mm	125 mm	125 mm
Bottom Coil diameter(D_m)	250 mm	125 mm	290 mm
Coil Height,H	130	170	0
Inclination Angle,φ	90^0	0^0	180^0
No of turns(approx.)	5	7	4
Pitch of the coil	20mm	20mm	20mm
No of coil (circular tube)	1	1	1

B. Experimentation

Figure shows helical coil, conical coil and spiral coil which are used for experimentation.

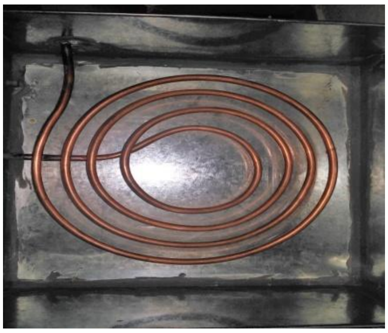

Figure 1: Test Section

TABLE II
OPERATING PARAMETERS OF COIL

Sr No	Parameter	Specification
1	Inlet temperature of hot water(T_1)	85^0c
2	Inlet temperature of cold water(T_3)	25^0c
3	Hot water flow rate(Kg/s)	15 lph,20 lph,25 lph
4	Cold water flow rate(Kg/s)	15 lph

Figure 2: Experimental set up

An experimentation consist of different shape coil first helical coil immersed it in cold water shell. Heat exchanger made crossflow, cold water inlet from top and hot water inlet from bottom of heat exchanger. Readings were recorded for different mass flow rate ie. at 15 Lph,20 Lph, 25 Lph.Note the temperature difference by digital temperature indicator. Record the temperature of cold water inside the shell from temperature indicator once again to ensure constant wall temperature boundary condition.

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C. Formula and correlations

Different correlations and formulae need for numerical calculations have been taken from heat transfer data book and some correlations taken from existing literature, all these used in calculation and analysis are given below

Reynolds number,

$$Re = \rho(V\ d)/\mu$$

Dean number,

$$De = (Re)*\sqrt{\delta}$$

Nusselt number,

$$N_{ui} = (0.021) * [Re^{0.85} Pr^{0.4}]\delta^{0.1}$$

Heat transfer coefficient

$$h = (N_{ui}*k)/D \quad W/m^2K$$

Heat flux

$$q = h(Th_m - Tw_m) \quad W/m^2$$

Calculation of coil side heat transfer coefficients:

Overall Heat transfer coefficient, Uo:

$$U_o = q / (A_o \Delta T_{LM})\ W/m^2K$$

Where, q is the heat transfer rate, Ao is the outer surface area of the coil, ΔT_{LM} is the Log Mean Temperature Difference. The overall heat transfer surface area was determined based on the tube diameter and developed area of tube diameter and it is given as $\pi L d_o$.

Hot water Heat Transfer Rate:

$$q_h = m_h.C_{ph}.(T_{in}-T_{out})_h$$

Cold water Heat Transfer Rate:

$$qc = m_c.C_{pc}\ (T_{out}-T_{in})_c$$

$$q = (q_h + q_c)/2 \quad J/s$$

The physical properties of water are taken at average temperature:

$$T_{mean} = (T_{in} + T_{out}) / 2$$

LMTD is the Log Mean Temperature Difference, based on the inlet temperature difference $\Delta T_1$and outlet temperature difference ΔT_2 given as follows:

$$\Delta T_{LM} = (\Delta T_1-\Delta T_2) / \ln(\Delta T_1/\Delta T_2)$$

Convective Heat Transfer Coefficient (h):

$$hi = Nui * k / di \quad W/m2K$$

Where Nu_i is the Inner Nusselt Number, k is the thermal conductivity of water and d_i is the inner diameter of the coil.

Effectiveness of Heat Exchanger (Ɛ):

If (mCp)c< (mCp)h, Ɛ= (Tco-Tci) / (Thi-Tci)

If (mCp)h< (mCp)c, Ɛ=(Thi-Tho) / (Thi-Tci)

III. Experimental Results And Discussion

The thermal performance of the helical coil, conical coil and spiral coil heat exchanger is investigated by studying the effect of different flow rate on inner tube Nu, convective heat transfer coefficient, overall heat transfer coefficient and effectiveness. Helical tube compare against conical coil and spiral coil and then different graph plotted as given below.

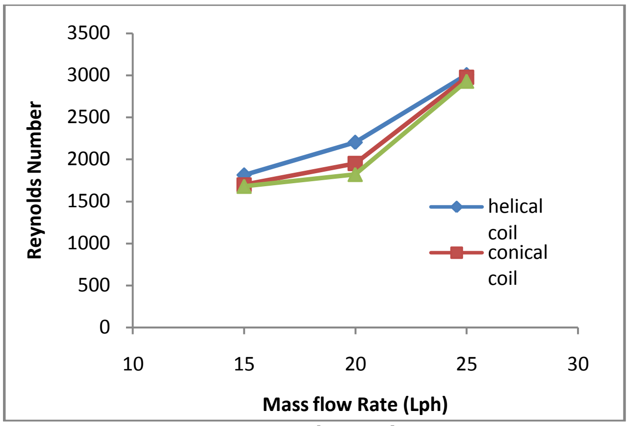

Figure 3: Re Number Vs Flow Rate

Experimentation is conducted by keeping wall temperature constant. Reynolds number increases as the mass flow rate of tube side increases. Reynolds Number goes on decreasing from helical to spiral coil.

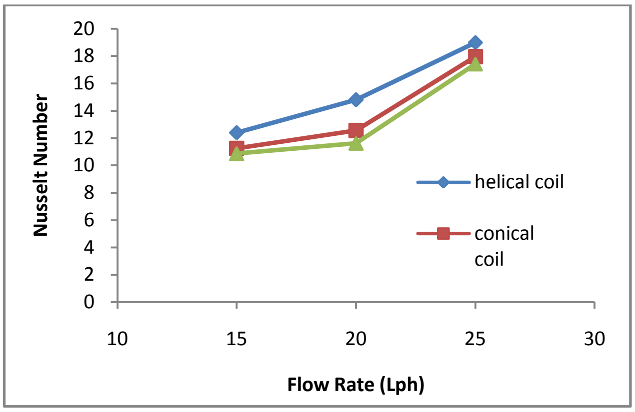

Figure 4: Ineer Nusselt Number Vs Flow Rate

Figure indicate that Nusselt number Vs mass flow rate plot for three different shape coil , it is found that Nusselt number increases with mass flow rate for all tubes but these increments are lesser at low mass flow rate and grater at higher mass flow rate. It is also found that Nusselt number of helical coil is highest as compared to other coils.

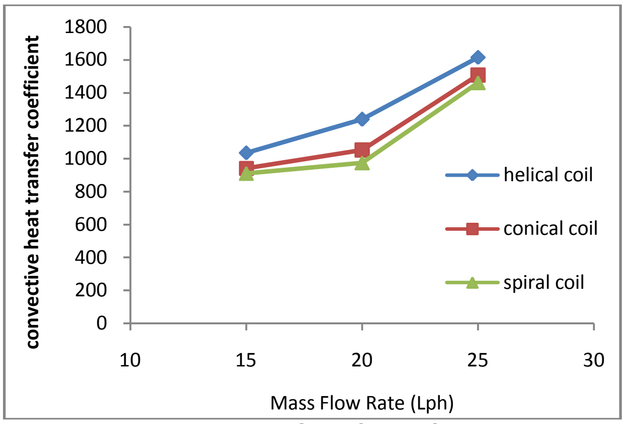

Figure 5: Ineer Nusselt Number Vs Flow Rate

It is observed that as mass flow rate increases convective heat transfer coefficient also increases. But increments in heat transfer coefficient are less at low mass

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flow rate and more at higher mass flow rate. Result shows that helical tube gives 9.81 percent higher value of heat transfer coefficient over conical tube and 13.66 percent higher than spiral coil. For the helical coil ,coil diameter is same for throughout length hence formation of secondary's flow are uniform this keeps uniform heat transfer per unit area while, in conical coil diameter goes on increasing hence formation of secondary's flow are ununiformed hence heat transfer coefficient lower than helical coil. Similarly overall intensity developed for spiral coil reduced having lowest heat transfer coefficient.

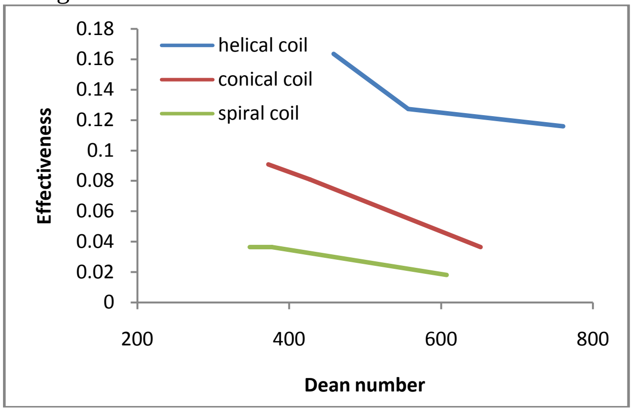

Figure 6: Dean Number Vs Effectiveness

The heat exchanger effectiveness is used to predict the outlet temperatures of tube-side and shell-side fluids. The variation of effectiveness with Dean number inside tube at different coil geometry is as shown in Chart 4 .at the same geometry and mass flow rate effectiveness of heat exchanger decreases with increase in Dean number inside tube in all type of coils.From the graph it is also reported that at the low mass flow rate effectiveness is sufficiently high .But as the the flow rate increases effectiveness decreases.

IV. CFD Results And Discussion

The 3D model for helical coil is created using CAD Package. It is imported in ANSYS fluent workbench with .igs/step file saved in CATIA. The geometrical specification of helical coil is as per design. Inlet & outlet outside tube diameter is 9.5 mm and thickness 1.5 mm is selected. The model of helical coil heat exchanger is shown in figure.

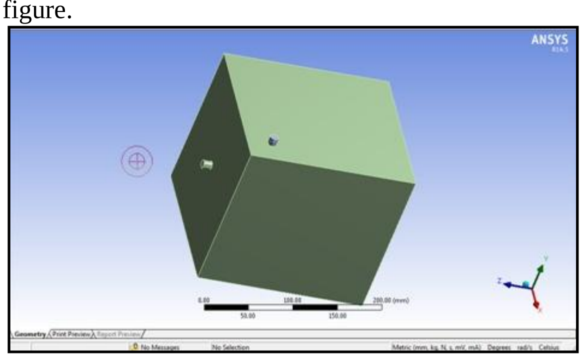

Figure 7: model of heat exchanger

Then all the parts are defined i.e. inlet is defined as Inflow, outlets as Outflow and wall.

A. Grid Generation for the helical coil with Solid-Fluid Interface

Creation of an accurate computational mesh for the domain under investigation is a paramount importance in CFD simulations. The shape of control volumes should satisfy certain geometry requirements in order to eliminate irregularities in computational results. The accuracy of numerical results in CFD modelling was mesh dependent. The finer mesh generally provides better results at the increased computational time. Therefore the size of the mesh in the domain should be gradually increased to such level that the further raise in the number of control volumes does not result in considerable changes in experimental results produced.

The pre-processor software provided an option to check the quality of the computational mesh created in order to avoid the use of control volumes with high skewness which would very much affect the accuracy of the CFD solution and the optimal mesh used in these investigations passed such check as the levels of skewness were low in the range of 0.2-0.3. The ANSYS ICEM-CFD is used for discretization of domain. Initially a relatively coarser mesh is generated. This mesh contains tetrahedral cells having triangular faces at the boundaries. Care is taken to use tetrahedral cells as much as possible. It is meant to reduce numerical diffusion as much as possible by structuring the mesh in a well manner, particularly near the wall region. Later on, a fine mesh is generated for this fine mesh, the edges and regions of high temperature and pressure gradients are finely meshed which is solid fluid interface. Details of mesh are given below in table 3.

TABLE 3
MESH DETAILS

Sr. No.	Parameter	ANSYS Fluent
1	Global Mesh Size	7.7 mm
2	Surface Mesh Size	7.7 mm
3	Curve Mesh Size	7.7 mm
4	Mesh Type	Tetrahedral
5	Mesh Quality	fine

Mesh is checked first for duplicate elements, unconnected vertices and then mesh is smoothened by smoothing tool. Then file is exported to FLUENT file, which is imported in ANSYS-FLUENT. The Mesh domain of helical coil heat exchanger are as shown in figure 8.

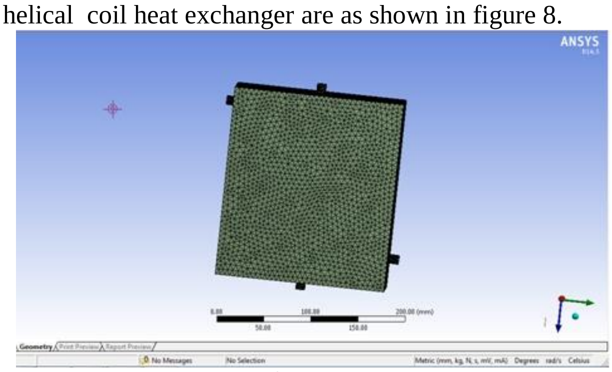

Figure 8: Mesh Domail of Helical Coil Heat Exchanger

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B. Boundary Conditions

Boundary conditions are used according to the need of the model. Boundary conditions used at inlets are velocity and temperature of water and at outlet at static pressure is applied. Domain surface is used as a wall with 'No Slip Condition'.

C. Solver Parameters

The high resolution scheme is used and Auto-timescale is used for convergence control. The convergence criteria are RMS residual type and convergence rate 1e-03 is used for mass and momentum etc. The general simulation parameters of heat exchanger with solid fluid assembly is summarized as given in table 4:

TABLE IV
DETAILS OF SIMULATION

Sr. No.	Parameter	Ansys Fluent
1	Domain of simulation	Heat exchanger with solid liquid
2	Laminar model	Viscous
3	Heat Transfer model	Thermal Energy
4	Fluid	Water
5	Solid	Copper
6	Reference Pressure	1 atm.
7	Inlet	velocity and Temperature of Fluid
8	Outlet	Static pressure
9	Discretization	High Resolution
10	Residual Type	RMS
11	Residual Target	1e-03

D. Steady State Analysis

This section presents the numerical results obtained from CFD modelling of a simplified model of a helical heat exchanger.ANSYS-FLUENT Results obtained using appropriate boundary conditions at inlet and outlets of helical heat exchanger are as shown in figure 9.

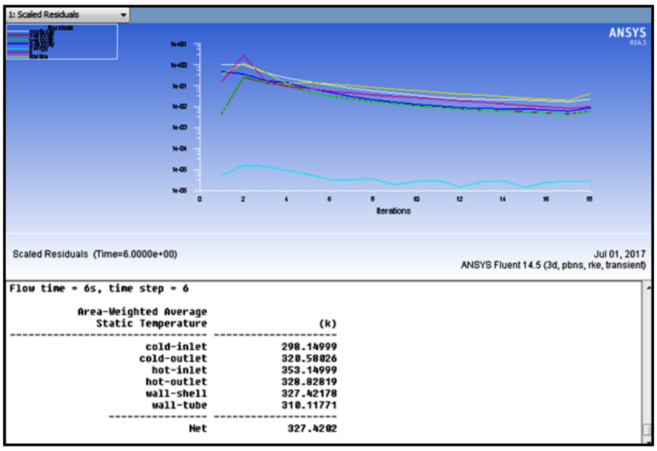


Figure 9: Temperature Result Of Helical Coil Heat Exchanger

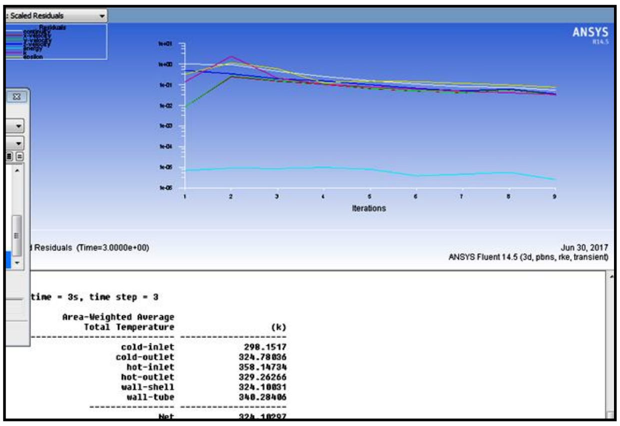


Figure 9: Temperature Result Conical Coil Heat Exchanger

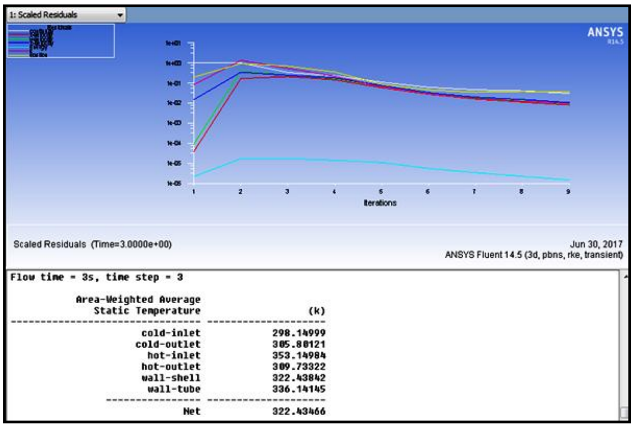
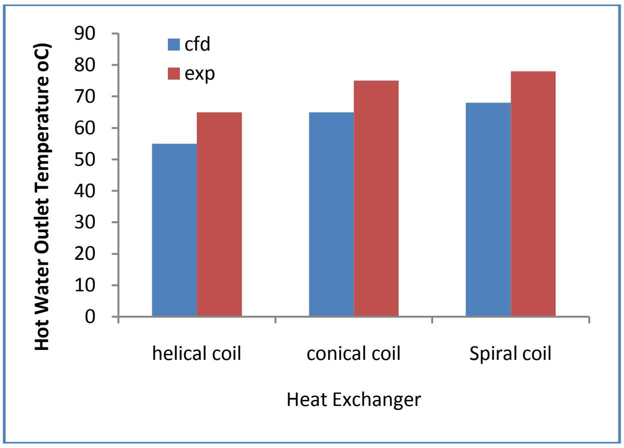


Figure 10: Temperature Result Of Spiral Coil Heat Exchanger



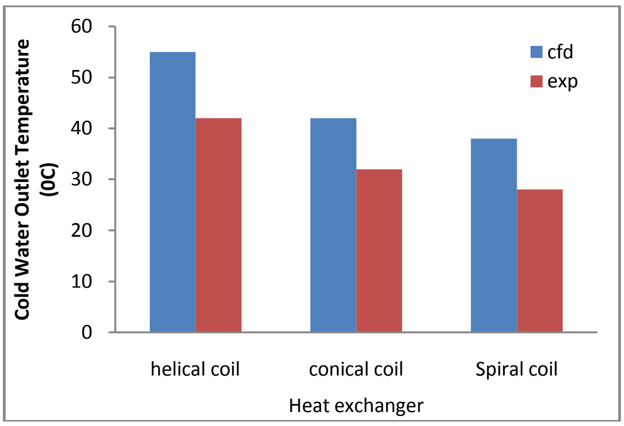


Figure 11: Comparison Between Experimental Results And CFD Results

Figure Shows that Hot water outlet temperature of heat exchanger are range from 55 to 78 and for cold water outlet temperature range from 48 to 28 degree celcius for hot water less that 10-12°c than experimental results.

And cold water outlet temperature is more than 10-12°c than Experimental results its due to different atmospheric conditions while taking readings. This shows that good agrement with CFD results.

V. CONCLUSIONS

The following conclusions may be drawn from the present study that new heat exchanger is successfully designed through Experimental analysis and validated using CFD simulation. Nu increases as Re number increases inside the tube for constant cold water flow rate.

- Nu is highest for helical coil and lowest for spiral coil and in between for conical coil.
- Effectiveness of heat exchanger decreases with increase in dean number. Helical coil is the most efficient coil among all three coils.
- It has been observed that outlet temperature of water in simulation greater than experimental results.
- CFD Result shows good agreement with experimental results

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