Experimental and CFD Analysis of Tube in Tube Helical Coil Heat Exchanger

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Abstract— **This Present work represents an Experimental studies and CFD investigation for a counter flow tube in tube helical coil heat exchanger where hot water flows through the inner tube and cold water flows through the outer tube. An experimental setup is used for the estimation of the heat transfer characteristics. A wire is wound over the inner tube to increase the turbulence in turn increases the heat transfer rate. The analysis deals with internal wound wire and its result on the heat transfer rate. From Experimental results, heat transfer rate, LMTD, overall heat transfer coefficient, efficiency and Reynolds number, Nusselt number, Friction factor are calculated. CFD analysis for helical coil tube in tube heat exchanger is carried out and the simulation results are used to predict the flow and thermal development in tube in tube helical coil heat exchanger. Experimental and CFD analysis of tube in tube helical coil heat exchanger and conventional heat exchangers are studied.**

Keywords— Tube-in-tube helical coil, Nusselt number, wire wound, Reynolds number, Dean Number, dead zone, efficiency.

I. INTRODUCTION

To transfer the heat between two fluids Heat exchanger is used which may be in direct contact or may flow separately in two tubes or channels. We find numerous applications of heat exchangers in day today life. For example condensers and evaporators used in refrigerators and air conditioners. In thermal power plant heat exchangers are used in boilers, condensers, air coolers and chilling towers etc. Similarly the heat exchangers used in automobile industries are in the form of radiators and oil coolers in engines. Heat exchangers are also used in large scale in chemical and process industries for transferring the heat between two fluids which are at a single or two states.

A. Helical Coil Heat Exchanger

Recent developments in design of heat exchangers to full fill the demand of industries has led to the evolution of helical coil heat exchanger as helical coil has many advantages over a straight tube.

B. Advantages

1. Heat transfer rate in helical coil are higher as compared to a straight tube heat exchanger.
2. Compact structure. It required small amount of floor area compared to other heat exchangers.
3. Larger heat transfer surface area.

C. Applications

1. Heat exchangers with helical coils are widely used in industries. The most common industries where heat exchangers are used a lot are power generation plants, nuclear plants, process plants, refrigeration, heat recovery systems, food processing industries, etc.

From the available literature I find that so much work had been done to find heat transfer characteristic of helical coil heat exchanger with constant wall temperature and constant heat flux conditions. Also by changing the working fluid heat transfer relation were found. But effect of pitch variation of the internal wounded wire and its result on the heat transfer rate is not explained properly. In the present work the performance of a Tube-in-tube helical coil heat exchanger for a water–water counter current flow system is going to study experimentally. The effect of the fluid flow rate on the heat transfer and hydrodynamics is going to study in the tube as well as in the annulus. In the present work four turns of coils is consider and also copper wire is to be introduce in the annulus area of the Tube-in-tube helical coil heat exchanger.

II. OBJECTIVES OF WORK

1.Experimental analysis of tube in tube helical coil heat exchanger and find out heat transfer rates, LMTD, overall heat transfer coefficient and Reynolds number, Nusselt number ,Dean number for counter flow arrangement.
2. CFD simulation for helical coil tube in tube heat exchanger will be carry out.
3. Comparison of Experimental and CFD results of tube in tube helical coil heat exchanger.

III. EXPERIMENTATION

A. Experimental Setup

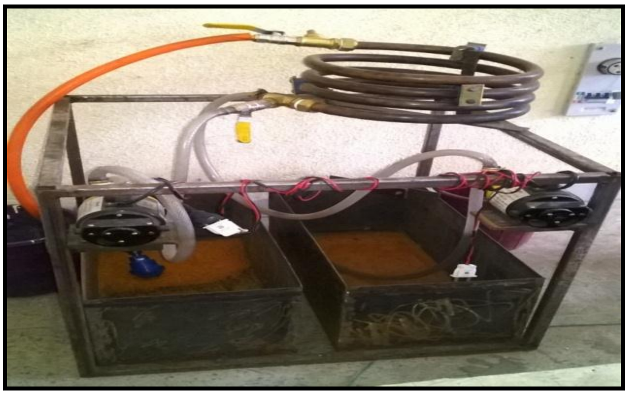


Fig.1 Experimental-Setup Tube-in-Tube Helical Coil Heat Exchanger

Experimental-Setup consists of following parts:-

1. Tube-In-Tube Helical Coil Heat Exchanger
2. Tank with thermostatic heater
3. Water Reservoir
4. Flow Control valve
5. Pressure Indicator
6. J-Type thermocouples

Cold tap water is use for the fluid flowing in the outer tube. The water in the outer tube will be circulated. The flow is control by a valve, allowing flows to be control and measure between 480 and 1200 LPH. Hot water for the inner tube is heated in a tank with the thermostatic heater set at 60^0C. This water is circulated via pump. The flow rate for the inner tube is control by flow metering valve as described for the outer tube flow. Flexible PVC tubing is use for all the connections. J-Type thermocouple is used to measure the inlet and outlet temperatures for both fluids.

B.Construction of Tube-in Tube Helical coil Heat Exchanger

During Construction of Tube-in Tube Helical coil Heat Exchanger following parameters are taken into considerations

- Effect of curvature ratio on heat transfer
- The Influence of pitch of coil on heat transfer
- Influence of the tube diameter change on heat transfer characteristics.

Actual Selected Dimensions from summary of tube-in-tube helical coil heat exchanger. To increase heat transfer rate, we have to increase the curvature ratio.

TABLE I

DIMENSIONAL PARAMETERS OF HEAT EXCHANGER

Dimensional parameters	Heat Exchanger
di,mm	10
do,mm	12
Di,mm	23
Do,mm	25
Curvature Radius,mm	125
Stretch Length,mm	3992
Wire diameter, mm	1.5
Curvature ratio	0.1
No. of Turns	4

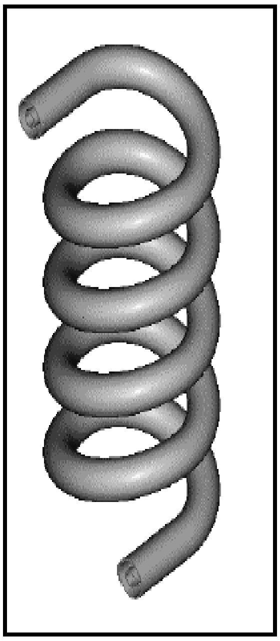


Fig.2 Tube-In-Tube Helical Coil Heat Exchanger

The tube of the heat exchanger is made up of copper for maximize the heat transfer, because copper has good thermal conductivity. Also the properties of the copper were also remains constant throughout the analysis.

TABLE II
PROPERTIES OF COPPER

Description	Value	Units
Density	8978	kg/m^3
Specific Heat Capacity	381	J/kg-K
Thermal Conductivity	387.6	W/m-K

IV. SIMULATION OF TUBE-IN TUBE HELICAL COIL HEAT EXCHANGER

A. *CFD Methodology*

For simulation of Tube-in Tube Helical coil Heat Exchanger, first we have to create a Heat Exchanger model using Solid Edge Software. After creating the geometry and doing the meshing in ANSYS 14 the problem is analysed in ANSYS 14. As this is counter flow of inner hot fluid flow and outer cold fluid flow so there is two inlet and outlet respectively. There is a pipe which separates the two flows which is made by copper. The detail about all boundary conditions are as follows. Inner fluid is taken as hot water and outer fluid is taken as cold water.

TABLE III
BOUNDARY CONDITIONS

S.N.	Parameters	Range
1.	Inner tube flow rate	120-480 LPH
2.	Outer tube flow rate	480-1200 LPH
3.	Inner tube inlet temperature (^{0}C)	58-62
4.	Inner tube outlet temperature (^{0}C)	35-46
5.	Outer tube inlet temperature (^{0}C)	28-30
6.	Outer tube outlet temperature (^{0}C)	30-40

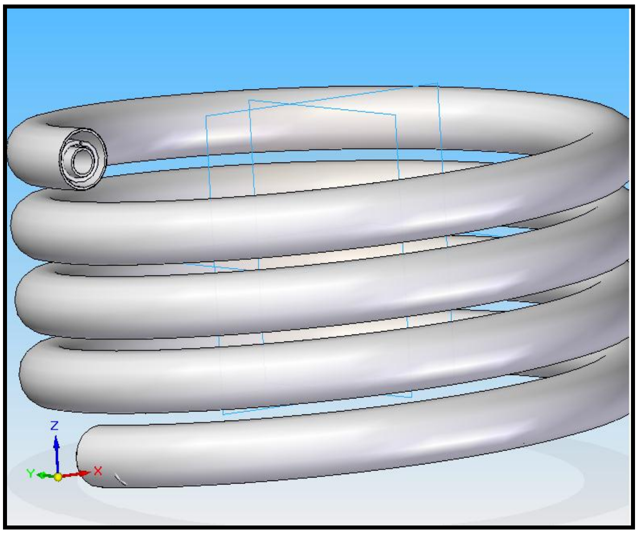


Fig.3Solid Edge Model of Tube-In-Tube Helical Coil Heat Exchanger

V. RESULTS &DISCUSSION

A. Experimental Results

TABLE IV
FOR COLD WATER FLOW RATE =720LPH

Cold water flow rate =720LPH								
S.N	Flow rate	Cold water temp.		Hot water temp.		Δt_1	Δt_2	LMTD
		T_{in}	T_{out}	T_{in}	T_{out}			
1	120	30	36.2	60	41.4	23.8	11.4	16.85
2	240	30	37.4	60	42.4	22.6	12.4	17
3	360	30	39	60	43.5	21	13.5	17
4	480	30	40	60	44.5	20	14.5	17.10

In present investigation work the heat transfer coefficient and heat transfer rates were determined based on the measured temperature data. The heat is flowing from inner tube side hot water to outer tube side cold water.

Mass flow rate of hot water (Kg/sec):

$$m_H = Q_{HOT}(LPH) \times \rho(Kg/m^3)$$

Mass flow rate of cold water (Kg/sec)

$$m_C = Q_{COLD}(LPH) \times \rho(Kg/m^3)$$

Velocity of hot fluid (m/sec)

$$V_H = Q_{HOT}/(1000\times Area)$$

Heat transfer rate of hot water (J/sec)

$$q_H = m_H\times C_P\times \Delta t_{HOT}\times 1000$$

Heat transfer rate of cold water (J/sec)

$$q_C = m_C\times C_P\times t_{COLD}\times 1000$$

Average heat transfer rate [7]

$$Q_{avg} = (q_H + q_C)/2$$

The heat transfer coefficient was calculated with [2],

$$U_o = q/(A\times LMTD)$$

The overall heat transfer surface area was determined based on the tube diameter and developed area of heat transfer which is A= 0.22272m^2, The total convective area of the tube keep constant for two geometry of coiled heat exchanger. LMTD is the log mean temperature difference, based on the inlet temperature difference ΔT1, and outlet temperature difference ΔT2,

$$LMTD=(\Delta T_1-\Delta T_2)/(\ln(\Delta T_1/\Delta T_2))$$

The overall heat transfer coefficient can be related to the inner and outer heat transfer coefficients by the following equation [7],

$$1/U_0= (A_0/A_i h_i)+(A_0\times \ln(d_o/d_i)/2\pi KL)+(1/h_o)$$

Where d_i and d_o are inner and outer diameters of the tube respectively. k is thermal conductivity of wall material and L, length of tube(stretch length) of heat exchanger. After calculating overall heat transfer coefficient, only unknown variables are hi and ho convectiveheat transfer coefficient inner and outer side respectively, by keeping mass flow rate in annulus side is constant and tube side mass flow rate varying[5],

$$h_i= CV_i^n$$

Where V_i are the tube side fluid velocity m/sec., the values for the constant, C, and the exponent, n, were determined through curve fitting. The inner heat transfer could be calculated for both circular and square coil by using Wilson plot method. This procedure is repeated for tube side and annulus side for each mass flow rate on both helical coils [7].

The Reynolds number

$$R_e= (\rho\times V\times D)/\mu$$

Dean number,

$$D_e= ((\rho\times V\times D)/\ )\ x\ (D/2R)^{1/2}$$

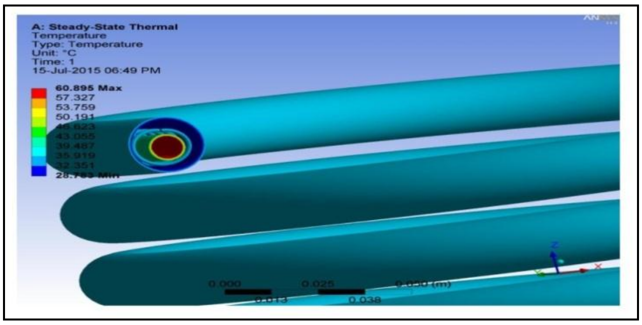
TABLE V
RESULT TABLE FOR COLD WATER FLOW RATE =720LPH

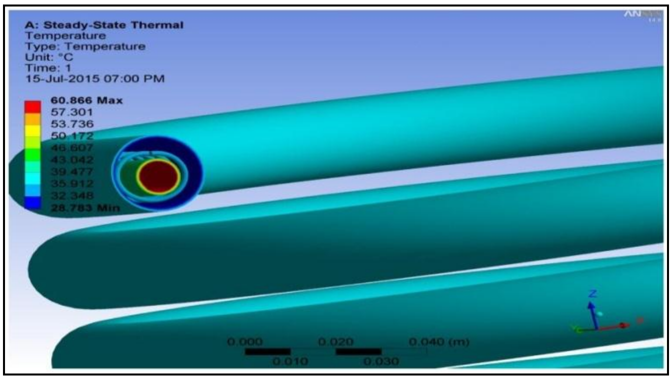
Parameters	120 LPH	240 LPH	360 LPH	480 LPH
For Inner Side of Inner Tube				
LMTD(^{0}c)	16.85	17	17	17.10
M_H(Kg/sec)	0.0327	0.0655	0.0983	0.131
M_c(Kg/sec)	0.2	0.2	0.2	0.2
V_H(m/sec)	0.4246	0.8492	1.2738	1.6985
q_H(J/sec)	2546.01	4825.62	6789.48	8499.67
q_c(J/sec)	5190.64	6195.28	7534.8	8372
Q_{avg}(J/sec)	3868.325	5510.45	7162.14	8435.84

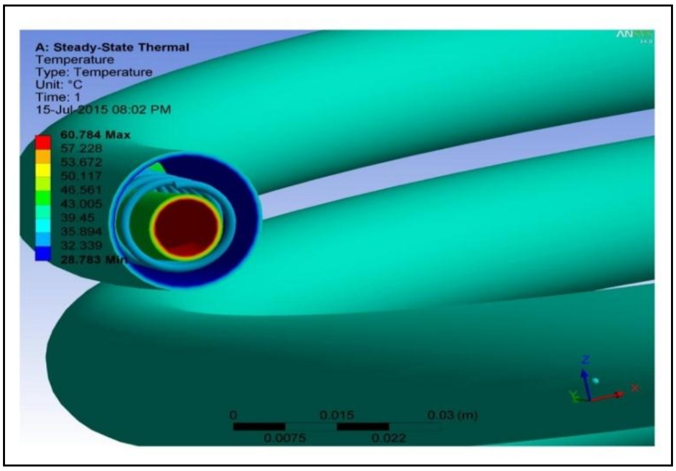
U_o(W/m^{2}k)	1961.99	2321.068	2822.92	3118.236
R_e	5230.34	10460.69	15691.04	20922.02
D_e	1689.89	3307.96	4961.94	6616.11
N_u	7.92	13.06	17.56	22.13
For Outer Side Of Inner Tube				
N_u	29.65	33.82	36.02	45.44
V_c(m/sec)	0.66159	0.66159	0.66159	0.66159
R_e	16581.20	16581.20	16581.20	16581.20
D_e	5243.43	5243.43	5243.43	5243.43

B. CFD Results

For CFD analysis, we were taken Constant Cold water Flow Rate =720LPH and different Hot water flow rate i.e. 120LPH, 240LPH, 360LPH, 480LPH for Validation of above experimental results.







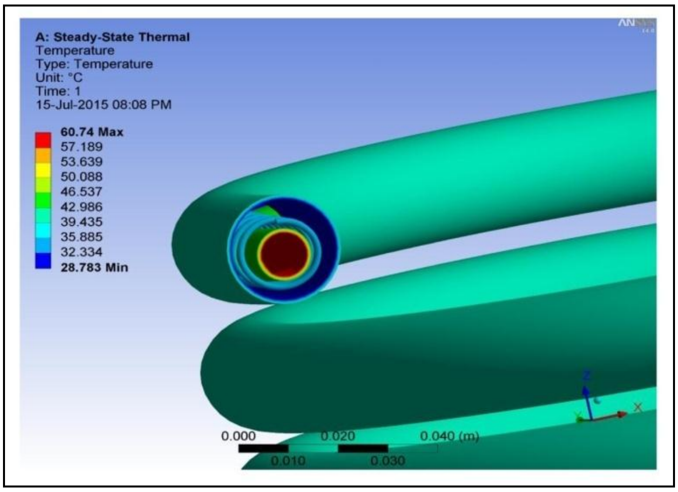


Fig.4 CFD Analysis of Tube in Tube Helical Coil Heat Exchanger with copper wire wounded over inner tube with 6 mm pitch for constant cold water flow rate =720LPH with different hot water flow rate a) 120 LPH b)240 LPH c) 360 LPH d)480 LPH.

From above CFD results, we were obtained the outlet temperature of Hot and Cold Fluid. From temperature data, we find Nusselt number, Reynolds number, Dean Number, overall heat transfer coefficient. After Calculation, We observed that overall heat transfer coefficient is increases with increasing inner tube flow rate, for constant Cold Water Flow Rate =720LPH.

VI. COMPARISON OF EXPERIMENTAL & CFD RESULTS OF TUBE IN TUBE HELICAL COIL HEAT EXCHANGER

TABLE VI

RESULT TABLE FOR CONSTANT COLD WATER FLOW RATE =720LPH WITH DIFFERENT HOT WATER FLOW RATE (120,240,360,480LPH)

N	Nusselt no.(Nu)		Reynolds no.(Re)		LMTD		(Uo) (W/m^{2}K)	
	Expt	CFD	Expt.	CFD	Expt.	CFD	Expt.	CFD
	7.92	8	5230	5530	16.85	17	1961	2000
	13.06	13	10460	11460	17	17.25	2321	2400
	17.56	18	15691	16691	17	17.25	2822	2900
	22.13	23	20922	21922	17.1	17.5	3118	3195

From above Experimental and CFD (FLUENT) Results, we obtained the graphs for Constant Cold water Flow Rate =720LPH and different Hot water flow rate i.e 120LPH, 240LPH, 360LPH, 480LPH.

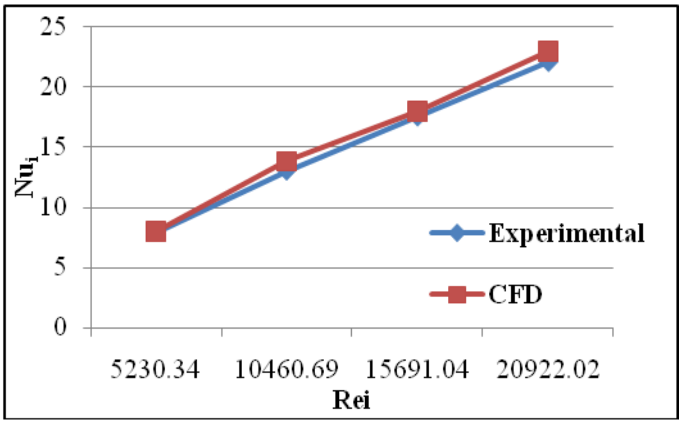


Fig.5 Inner Tube Nusselt Number(Nu$_i$) Vs Inner Tube Reynolds Number(Re$_i$)

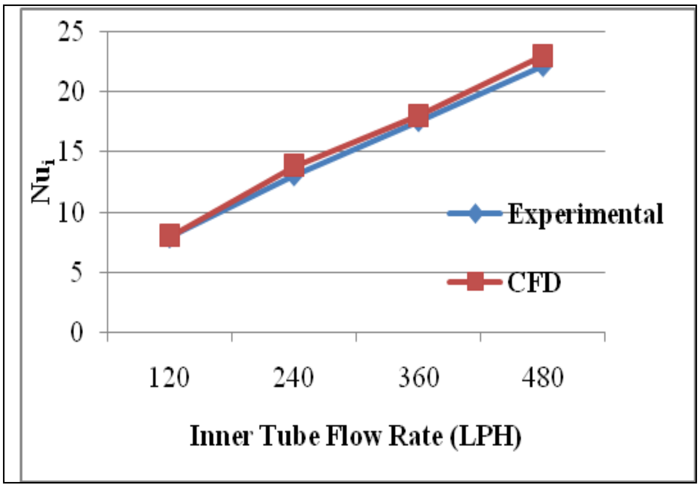


Fig.6 Inner TubeNusselt Number(Nu$_i$) Vs Inner Tube Flow Rate (LPH)

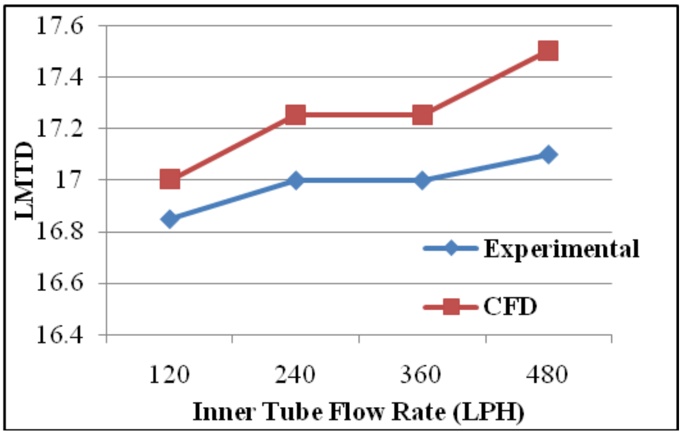


Fig.7 LMTD Vs Inner Tube Flow Rate (LPH)

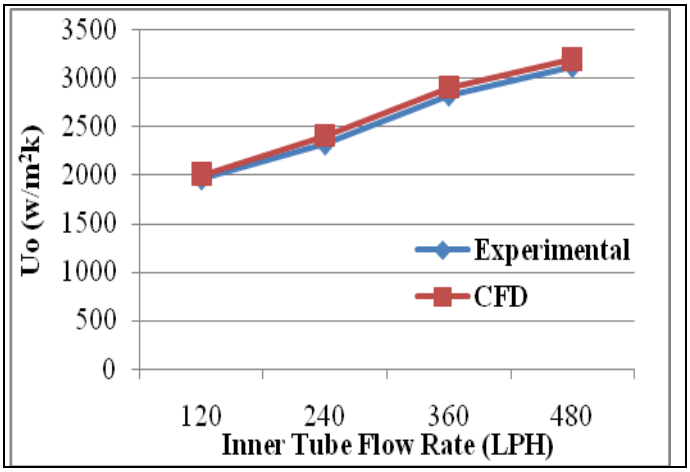


Fig.8 overall heat transfer coefficient (U$_o$) Vs Inner Tube Flow Rate (LPH)

VII.CONCLUSION

1. By comparing these Experimental and CFD results of wire wounded Tube in Tube Helical Coil Heat Exchanger, we observed that as the inner tube flow rate (LPH) increases, inner heat transfer coefficient (h_i) is also increases. As we know that Nusselt Number is directly proportional to inner heat transfer coefficient (h_i) ,So that Nusselt Number is increases with increasing inner tube flow rate, for constant Cold Water Flow Rate.
2. We found that as the inner tube flow rate (LPH) increases, Velocity of hot fluid (V_H) (m/sec) is also increases, So that Reynolds Number, Dean Number is increases with increasing inner tube flow rate, for constant Cold Water Flow Rate.
3. We observed that as the inner tube flow rate (LPH) increases, Temperature difference (Δt_1-Δt_2) also increases, So Log mean temperature difference (LMTD) is increases with increasing inner tube flow rate, for constant Cold Water Flow Rate.
4. We found that as the inner tube flow rate (LPH) increases, the heat gain by cold water(J/sec) is also increases, So that overall heat transfer coefficient is increases with increasing inner tube flow rate, for constant Cold Water Flow Rate.

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