An Experimentation of Helical Coil Tube Heat Exchanger with Different Curvature Ratio and Geometry

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Abstract

An attempt is made here to investigate effect of geometric feature specially curvature ratio and shape of coil by experimentally. The heat transfer analysis of straight helical coil and conical coil heat exchanger with various fluid flow rates and curvature ratio is presented in this paper. Six coils of different geometry and curvature ratio (0.064&0.054) were fabricated. Out of Six, three coils were manufactured by simple circular tube having outside diameter 9.5 mm and inside diameter 8 mm. Remaining three coils were manufactured with same dimensions only addition of notches (inverted fins).The experimentation is carried out for hot and cold water having hot water flow rate 15 Lph, 20 Lph, 25 Lph by keeping cold water flow rate 15 Lph throughout the reading. Temperature Difference was recorded for different mass flow rate across the heat exchanger. The comparative analysis shows that, Nusselt number increases as tube side flow rate increases. It is also reported that Nu Number increases by 5% in coil with notches because notches creates obstacle to fluid flow it creates more turbulence in the flow. Effectiveness of heat exchanger decreases with increase in dean number inside tube in all type of coils. The convective heat transfer coefficient is higher for helical coil than conical and spiral coil. Helical coil with notches having higher curvature ratio is more effective coil than conica coill.

Keywords: *helical coil, conical coil, notches and heat exchanger.*

1. 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]. The experimental study carried out for different fins found that wavy fins show larger heat transfer performance as indicated by higher Colburn factor (j). Pressure drop is also significant as compared to plain fin [2].Coiled/curved tube has been widely used in major industry especially in heat exchanger application. It offers higher transfer rate due to the presence of secondary flow induced by the coil curvature. As such, coiled tube has received considerable attention from researcher worldwide. A vast number of studies on coiled/curved tube have been carried out. Among the first studies on coiled/curved tubes was conducted by Dean who observed secondary flow development in a circular tube when the ratio of the viscous force acting on a fluid flowing in a curved pipe to the centrifugal force (defined as Dean number, De)[3].Zhongyuan Shi *et al.*Numerical simulation was carried out to analyze the heat transfer characteristics of flow through rotating helical pipes. The circumferential heat transfer is most significantly enhanced within the vicinity of the outermost point of the tube by rotation. This enhancement is more obvious when centrifugal force is comparably smaller to the stream wise inertia force for co-rotational cases whereas there versed flow and Dean vortex due to counter rotation of the helical pipe wall contribute considerably to the overall heat transfer enhancement [4].Turbulent heat transfer in curved pipes was studied by numerical simulation technique. Two pipe of curvatures 0.1 and 0.3 were considered; results were also obtained for a straight pipe (d = 0) for comparison purposes. A tract of pipe 5mm diameters in length were chosen as the computational domain and were discretized by finite volume multi block-structured grids of 5.3x10^6 hexahedral cells. Fully developed flow conditions were assumed; the friction velocity Reynolds number was 500, corresponding to bulk Reynolds numbers between 12 630 and 17 350 according to the curvature, while the Prandtl number was 0.86 (representative of saturated liquid water at 58 bar)[5].Pramod *et al.* had performed parametric analysis of helical coil tubes of dia. 8, 10 and 12 mm. Comparative analysis of the different correlations given by the different researchers for helical coil heat exchanger was made. Correlation compared was as below;

M.R.Samilpour

$$Nu = 0.152 * Re^{0.431} * Pr^{1.06}{}_{\gamma}{-0.277} \qquad 1$$

B. Kalb

$$Nu = 0.836 * De^{0.5} Pr^{0.1} \qquad 2$$

Xin and Ebadian

$$Nu = [2.153 + 0.318 * De^{0.64}] * Pr^{0.177} \qquad 3$$

Roger

$$Nu = 0.023 * Re^{0.85} * Pr^{0.4}{}_{\gamma}0.1 \qquad 4$$

It was observed that Nusselt number and heat transfer coefficient increases with Re in laminar and turbulence region, The Nu obtained by Equation (2) is having lowest values when compared to the other two correlations given by Equation (3) and Equation (4), which may be due to the direct effect of dimensionless pitch considered. Equation (2 and Equation (4) shows the variation of about 15 to 20percent.The Nu and hi values for same Reynolds number. In turbulence region Equation (4) is applicable which has given higher values of Nusselt number and heat transfer rate for Reynolds number greater than 4500. The overall effect on Nusselt number and heat transfer coefficient shows that for low Reynolds number the slop of curve for Nu Vs Re and hi Vs Re were steeper than that at high Reynolds number which indicates that helical coils are efficient in low Reynolds number range. The analysis also shows that for constant coil diameter (D) curvature ratio increase with tube diameter (d), which increases the intensity of secondary's developed in fluid flow and indirectly increases Nusselt number. Hence, it is desirable to have higher curvature ratio helical coil heat exchanger to get advantage of secondary flow pattern[6]. Jayakumar *et al.*The experiment done at the cold and hot water mass flow rates ranging between 0.10 and 0.22 kg/s, and between 0.02 and 0.12 kg/s, respectively. The inlet temperatures of cold and hot water are between $5 - 25^0C$, and between $5 - 45^0C$, respectively. The effects of the inlet conditions of both working fluids flowing through the test section on the heat transfer characteristics discussed[7]. Ghorbani *et al.* was done an experimental investigation of the mixed convective heat transfer in a coil-in-shell heat exchanger for various values of Reynolds number and Rayleigh numbers. Helical coil tubes were made from 9.5mm and 12.5mm OD tube and pitch was 16.5 mm and 23.5mm.The purpose of this study was to check the influence of the tube diameter, coil pitch, shell-side and tube-side mass flow rate over the performance coefficient and modified effectiveness of vertical helical coiled tube heat exchangers. Experiments were conducted for both laminar flow and turbulent flow inside coil using water as working fluid and Nusselt number calculations were performed assuming the steady state condition at different characteristics length to find out best characteristics length. From experimental result it was observed that tube diameter had negligible influence on shell side heat transfer coefficient for same pitch on other hand heat transfer coefficient increase with increase in curvature ratio. It was also reported that overall heat transfer coefficient increases with pitch and Nusselt number increases with Reynolds number and Rayleigh number After validation against previous literature it was found that equivalent diameter of shell is best characteristics length to correlate Nusselt number with Rayleigh number and Reynolds number[8]. Jayakumar *et al.* was worked on CFD analysis of helical pipe by variation of local Nusselt number along the circumference and the length of tube. CFD simulations were carried out for vertically oriented helical coils tube by varying coil parameters such as tube dia. 20, 30 and 40mm, pitch of coils were 0,15,30,45 and 60 mm and for twelve different configurations. It had been found that local variation of heat transfer in outer side of tube is better as compare to inner side tube. After establishing influence of these parameters, correlation for prediction of Nusselt number was developed[9]. Paisarn ,Naphon*et al.* has studied the thermal performance and pressure drop of the helical-coil heat exchanger with and without helical crimped fins. The heat exchanger consists of a shell and helically coiled tube unit with two different coil diameters. Each coil is fabricated by bending a 9.50 mm diameter straight copper tube into a helical-coil tube of thirteen turns. Cold and hot water are used as working fluids in shell side and tube side, respectively [10].Timothy *et al.*was performed experimental and CFD study on double pipe heat exchanger of two sizes. In the analysis copper tubes of OD of outer tube 15.9 mm and OD of inner tubes of 9.6 and 6.4mm tested. Instead of constant wall temperature or constant heat flux, fluid-to-fluid heat exchanger condition was used[11].Biserni was work on inverted fins of different shape such as squre, triangular ,rectangular fins. where after his investigation found thar triangular fins were more efficient than others.[12]. D. G. Prabhanjan , G. S. V. Ragbavan And T. J. Kennic has explored experimental study for comparison of heat transfer rates between a straight tube heat exchanger and a helically coiled heat exchanger. Comparisons of heat transfer coefficient were made between a helically coiled heat exchanger and a straight tube heat exchanger the rise in temperature of the target was greater for the higher bath temperature for both the helical and the straight heat exchangers. The rise in the temperature of the target fluid was significantly affected by both the coil geometry and the flow rate , however, it was not significantly changed by the water bath temperature. The helical coil had a greater increase of temperature compared to the straight tube and the increase of flow rate resulted in a decrease of the temperature rise. The larger temperature rise in the helical coil compared to the straight tube would be due to the secondary flow developed in the coil[13,14].C. X. Lin And M. A. Ebadian have worked on developing turbulent convective heat transfer in helical pipes. Numerical study has been carried out to investigate three-dimensional turbulent developing convective heat transfer in helical pipes with finite pitches. k-Ɛ model were used to simulate turbulent flow. Experiment done with Reynolds number range of 2.5 x 10^{4} to 1.0 x 10^{5}, a pitch range of 0.0- 0.6 and a curvature ratio range of 0.025 - 0.050. It has been found that The Nusselt numbers for the helical pipes are oscillatory before the flow is fully developed, especially for the case of relatively large curvature ratio [16,17].Ali correlated the Nusselt number as a function of the Rayleigh number for each of the different heat fluxes used. It was found that the Nusselt number decreased with increasing Rayleigh numbers[15,18].

2. Experimentation

An experimental set up was developed as shown in fig 1.The experimental set up consist of test section, hot water tank ,cold water supply, flow control valve, control panel ect. The section consists of heat exchanger with helical, conical, spiral coil. Coils manufactured by copper tube having outside diameter 9.5 mm and inside diameter 8 mm, pitch maintained 20 mm for every coil. The straight length of coil is 3 m. coils fabricated by bending operation while fine sand filled in to tube before bending to avoid pinching. It maintains its circularity. The shell is made for accommodate coils.

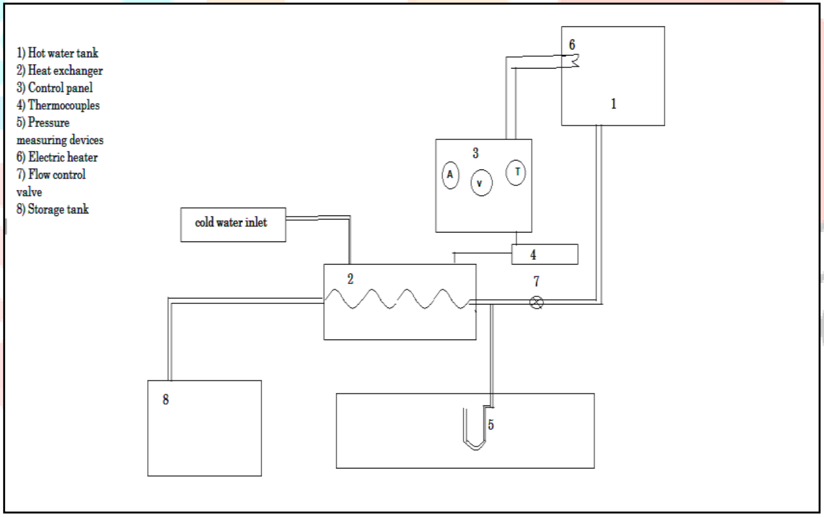

Figure 1. Experimental set up

The coil specification is as shown in table 1.total Six coils of different geometry and curvature ratio (0.064&0.054) were manufactured. Out of eight, four coils were manufactured by simple circular tube having outside diameter 9.5 mm and inside diameter 8 mm. Remaining four coils were manufactured with same dimensions only addition of notches (inverted fins). The notches is of square shape (4mmx4mm) as shown in fig 2

Table 1. Geometry parameters of coil

Parameters	**Dimensions**		
	Cone shaped helical coil	**Simple helical coil (curvature ratio=0.064)**	**Simple helical coil (curvature ratio=0.054)**
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(DM)	125 mm	125 mm	150 mm
Bottom Coil diameter(Dm)	250 mm	125 mm	150 mm
Coil Height,H	130	170	150
Inclination Angle,φ	90^0	0^0	0^0
No of turns(approx.)	5	7	6
Pitch of the coil	20mm	20mm	20mm
No of coil (circular tube)	1	1	1
No of coil(circular tube with notches)	1	1	1

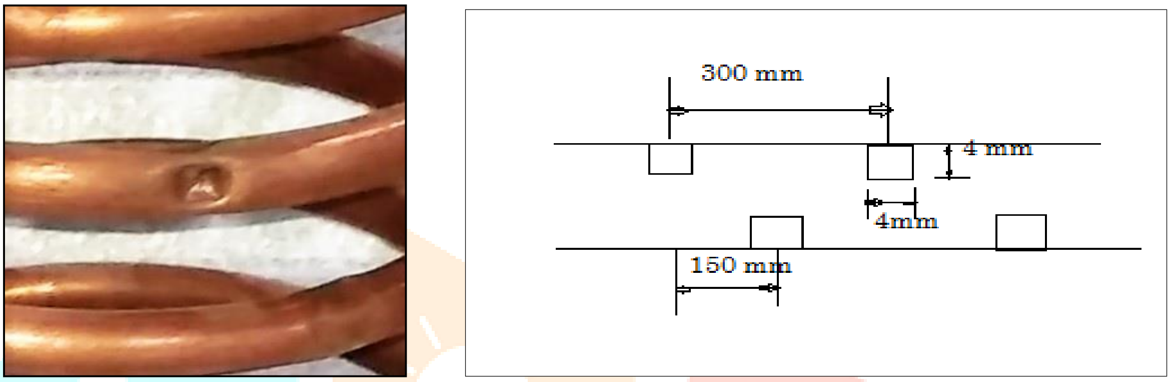

Figure 2: Dimensions for Notches

Heat exchanger is heart of overall setup. It consists of shell which is closed from all side and open at top for makeup cold water supply. While at the time of reading open part is covered to avoid heat losses. Coils which are made up from copper material have been completely immersed in GI sheet metal shell which contains cold water at constant temperature 25 ˚ C. Hot water enters at inlet flow through tubes from bottom of coil. First step of experimentation is select helical coil of desired curvature ratio and immersed it in cold water shell set the temperature at initial state. The next step is to record the mass flow rate of hot water ie. 15 Lph, 20Lph, 25 Lph. After that water heat up to 85 ˚ C by electric heater (1500 W). Open tap as temp reaches to 85 ˚ C and adjust it to desired mass flow rate. Record the outlet temperature of cold and hot water using digital temperature indicator having accuracy 0.1. Repeat this procedure for all coils one by one for all three mass flow rates.

Figure 3.Actual setup for experimentation

Parameters for experimentation:

Table 2.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

3. Experimental Analysis

The analysis is carried out for various hot water flow rate at tube side 15-25 lph interval of 5 lph and keep cold water flow rate 15 lph as constant.

All properties were recorded at mean bulk temperature.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 no

$$Re = \frac{\rho V d}{\mu} \qquad (1)$$

Dean number

$$De = (Re)*\sqrt{\delta} \qquad (2)$$

Nusselt number

$$N_{ui}= (0.021) * [Re^{0.85}Pr^{0.4}]\delta^{0.1} \qquad (3)$$

Heat transfer coefficient

$$h =\frac{Nui*k}{D} \quad W/m^2K \qquad (4)$$

Heat flux

$$q = h(Th_m - Tw_m) W/m^2 \qquad (5)$$

Calculation of coil side heat transfer coefficients:

Overall Heat transfer coefficient, Uo:

$$U_o = \frac{q}{(Ao\ \Delta TLM)} \quad W/m^2K \qquad (6)$$

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:

$$q_h = m_h.C_{ph}.(T_{in}-T_{out})_h \qquad (7)$$

Cold water Heat Transfer Rate:

$$q_c = m_c.C_{pc}\ (T_{out}-T_{in})_c \qquad (8)$$

$$q = \frac{(qh + qc)}{2} \quad J/s \qquad (9)$$

The physical properties of water are taken at average temperature:

$$T_{mean} = \frac{(Tin + Tout)}{2} \qquad (10)$$

LMTD is the Log Mean Temperature Difference, based on the inlet temperature difference ΔT_1 and outlet temperature difference ΔT_2 given as follows:

$$\Delta T_{LM} = \frac{(\Delta T1 - \Delta T2)}{\ln(\Delta T1/\Delta T2)} \qquad (11)$$

Convective Heat Transfer Coefficient (h):

$$hi = \frac{Nui * k}{di} \quad W/m^2K \qquad (12)$$

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, (13)

Ɛ= (Tco-Tci) / (Thi-Tci)

If (mCp)h< (mCp)c, (14)

Ɛ=(Thi-Tho)/(Thi-Tci)

4. Result and discussion

The thermal performance of the helical coil and conical coil heat exchanger is investigated by studying the effect of different flow rate on Nu, convective heat transfer coefficient, overall heat transfer coefficient and effectiveness. Helical tube compare against conical coil and spiral coil again comparison between smooth coils and coils with notches also effect of curvature ratio of tube has been analyzed using mass flow rate.

Fig.4 indicate Nusselt number Vs mass flow rate plot for eight different tube, 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 increases with increase in curvature ratio of helical tube. It is found from the graph Nusselt number of helical coil with notches of curvature ratio 0.064 is highest as compared to other coils.

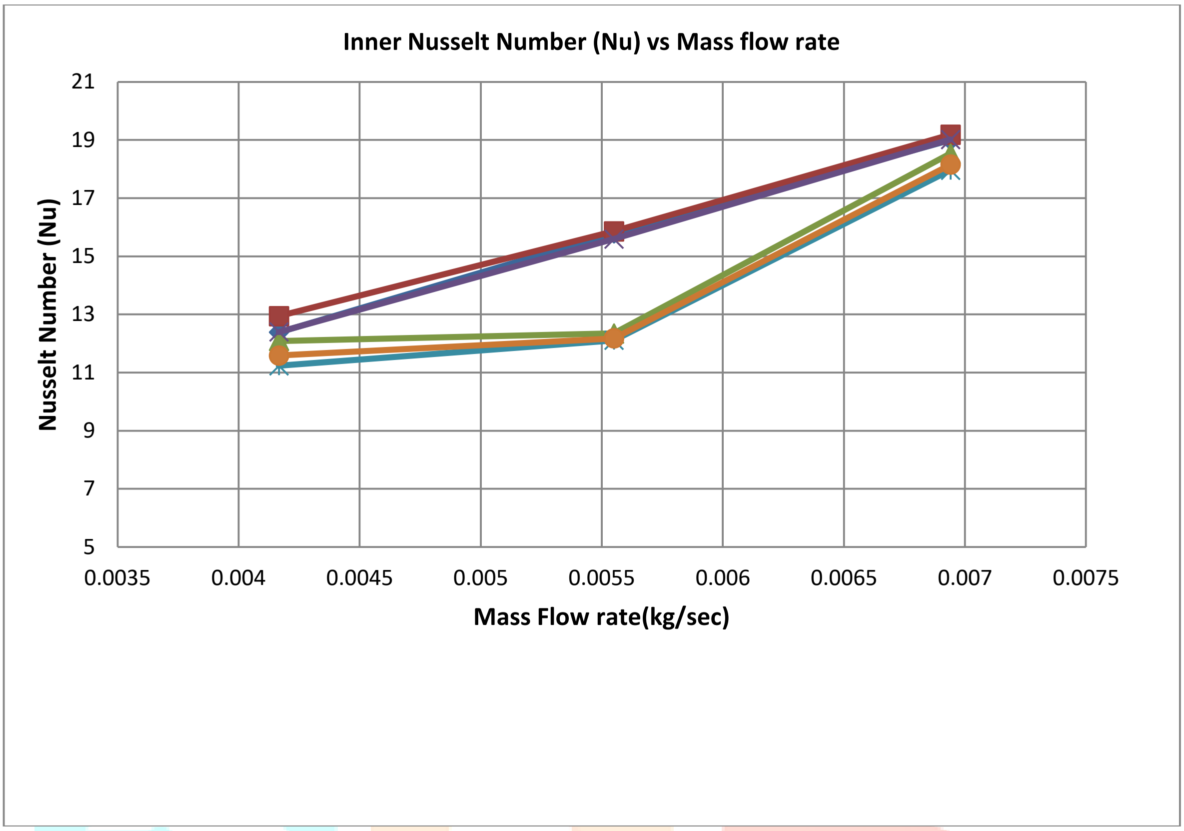

Figure 4. Nusselt Number Vs Flow Rate

It is also reported that nusselt number increases by 5% in coil with notches at same mass flow rate 15 Lph and same curvature ratio 0.064 as smooth coil. It is observed that Nusselt number increases by 3% percent when curvature ratio changes from 0.054 to 0.064 at 0.004 kg/s mass flow rate. Nu is highest for the helical coil with notches having curvature ratio 0.064 and lowest for the smooth conical coil for all mass flow rate.

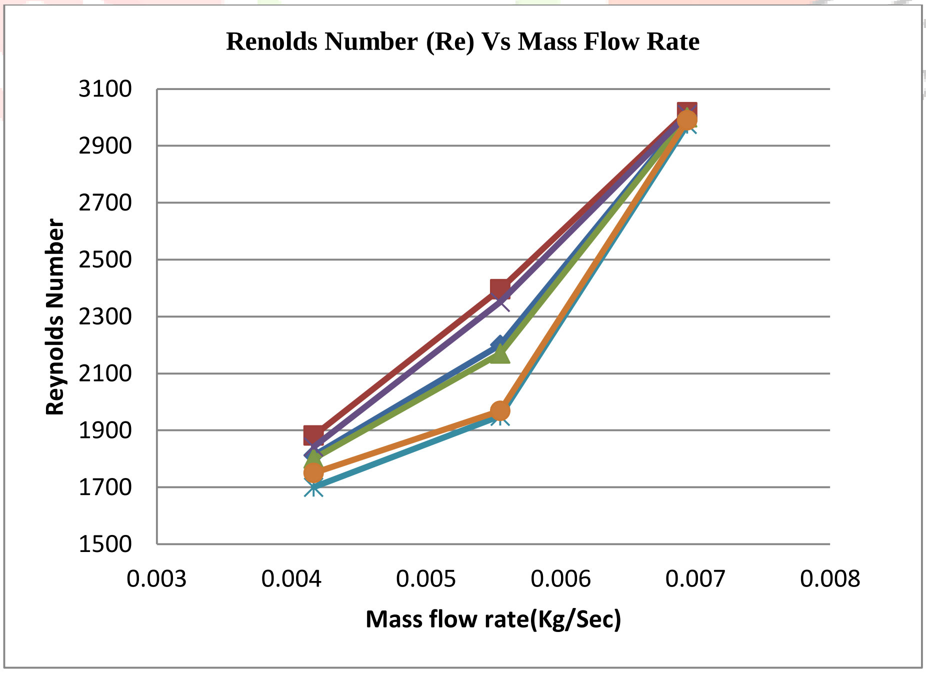

Figure 5.Variation of Reynolds Number Vs Mass Flow Rate.

Fig.5 indicate Reynolds number Vs mass flow rate plot for different coils, it is found that Reynolds number increases with mass flow rate for all tubes but these increments are lesser at low mass flow rate and greater at higher mass flow rate. It is also found that Reynolds number increases with increase in curvature ratio of helical tube. Reynolds Number goes on decreasing from helical to spiral coil. The analysis of fig 5 represent that coil with notches having higher Re Number than smooth coil due to notches creates obstacle in flow path causes increase in turbulence in inside tube. As turbulence increases with mass flow rate Reynolds number increases.

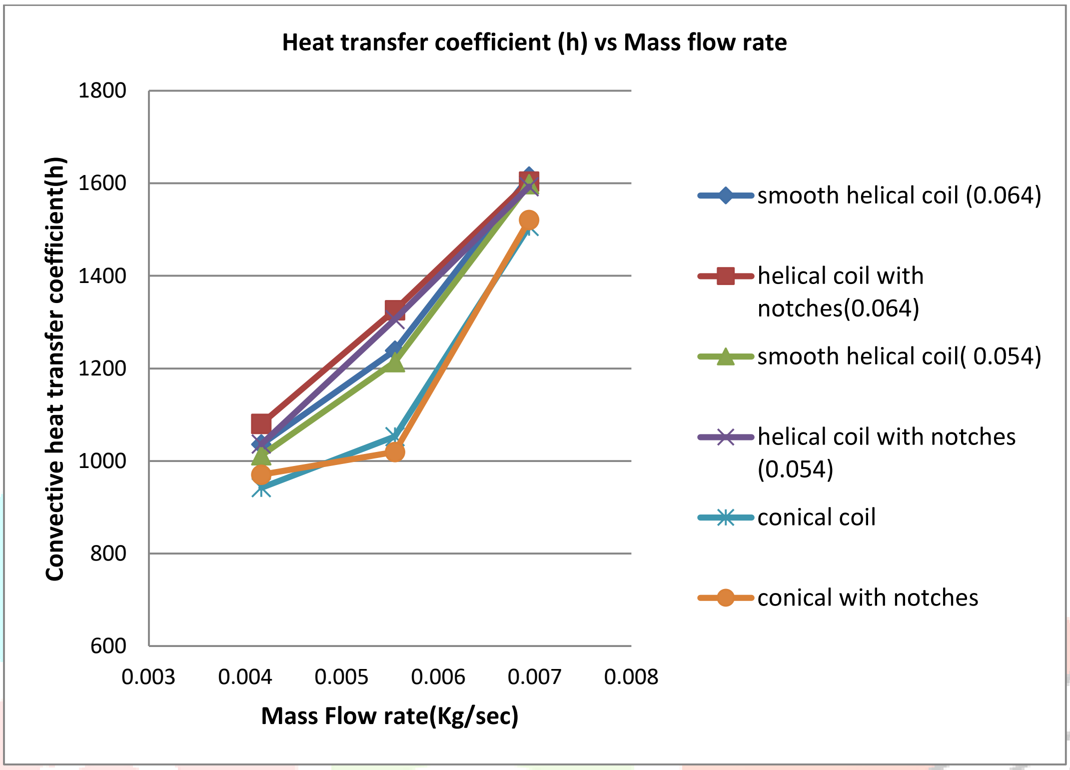

Figure 6. Convective Heat Transfer Coefficient Vs Mass Flow Rate

It is observed that as mass flow rate increases convective heat transfer coefficient increases. But increments in heat transfer coefficient are less at 15 Lph mass flow rate and more at 25Lph mass flow rate. It is also noted that heat transfer coefficient increases with increase in curvature ratio of helical tubes *i.e.* heat transfer coefficient increases by 4.45 percent on increasing curvature ratio from 0.054 to 0.064. 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. It is also reported that helical coil with notches having curvature ratio 0.064 produces higher heat transfer coefficient than other coils. For the helical coil ,coil diameter is same for throughout length hence formation of secondary's are uniform this keeps uniform heat transfer per unit area while, in conical coil diameter goes on increasing hence formation of secondary's are ununiformed hence heat transfer coefficient lower than helical coil.

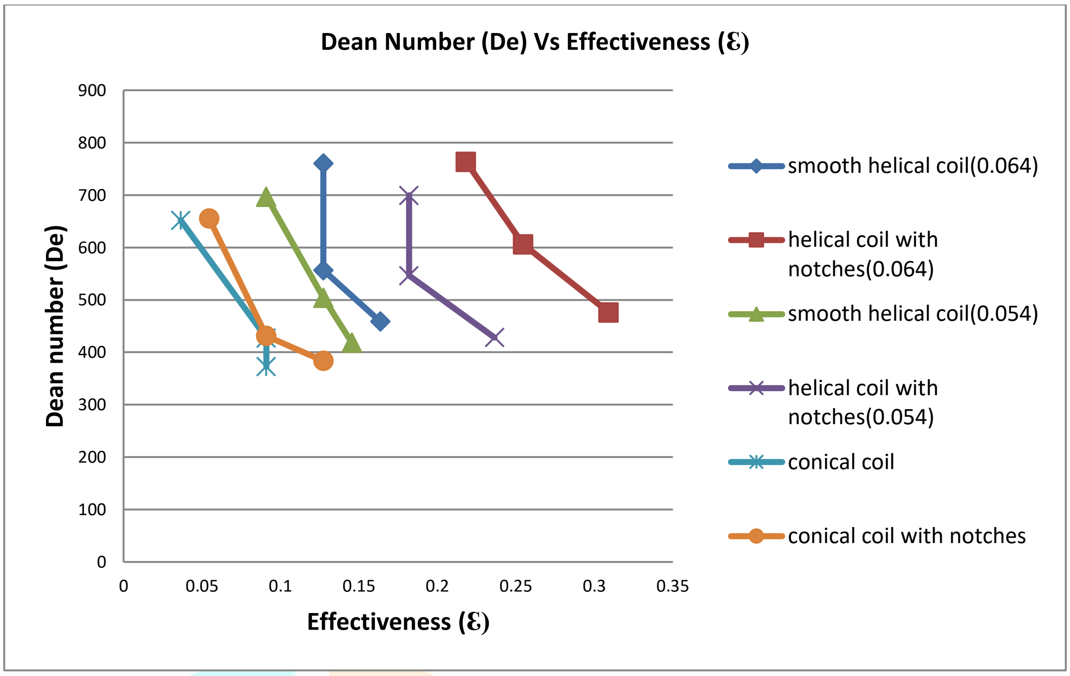

Figure 7. Dean Number Vs Effectiveness

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 fig 7.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 flow rate increases effectiveness decreases.

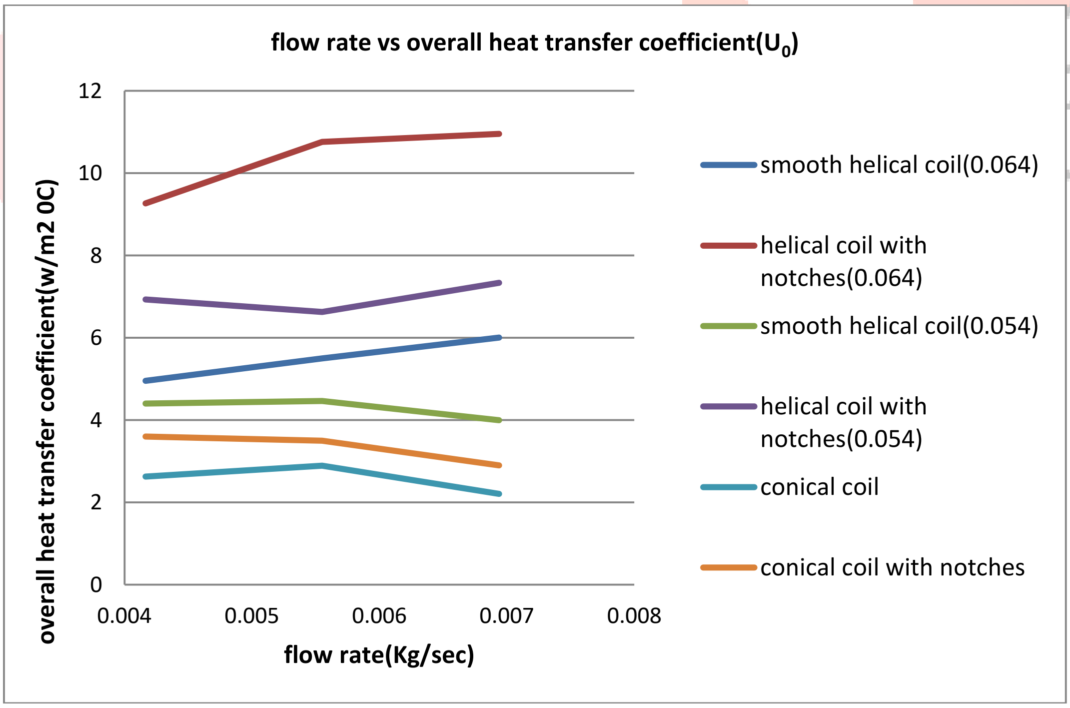

Figure 8. Flow Rate Vs Overall Heat Transfer Coefficient

Overall heat transfer coefficient increase with mass flow rate in helical coil but decreases in conical. At the lower mass flow rate increment in overall heat transfer coefficient is more but at the higher rate increment is less. Helical coil is more efficient than conical. As the curvature ratio increases from0.054 to 0.064 overall heat transfer coefficient increases. Overall heat transfer coefficient is highest for helical coil with notches and lowest for conical coil.

6. Conclusion

In this work different coil model have been design and manufactured in order to investigate the effect of curvature ratio and geometry on convective fluid flow and heat transfer characteristics. Using mass flow rate as variable different parameter have been analyzed experimentally. After result analysis several conclusions have been arises as below.

- After experimental investigation found that increment in various parameter ie. inside Nu , heat transfer coefficient , Dean number when curvature ratio increased from 0.054 to 0.064.
- In an experimental comparison of coils with circular diameter coil against coil with notches it was also noted that inside Nu , heat transfer coefficient ,Dean number these parameters increases by 3.75% and hence here prove that coil with notches are superior than simple circular tube coils.
- Nu increases as Re number increases inside the tube for constant cold water flow rate.
- Nu is highest for helical coil and lowest for conical coil.
- Effectiveness of heat exchanger decreases with increase in dean number. Helical coil with notches of curvature ratio 0.064 is the most efficient coil among all six coils.

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