Heat Transfer Analysis of a Cone Shaped Helical Coil Heat Exchanger

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Abstract- In the present study an experimental investigation of heat transfer in cone shaped helical coil heat exchanger is reported for various Reynolds number. The purpose of this article is to compare the heat transfer in cone shaped helical coil and simple helical coil. The pitch, height and length of both the coils are kept same for comparative analysis. The calculations have been performed for the steady state condition and experiments were conducted for different flow rates in laminar and turbulent flow regime. The coil side flow rate is kept varying while the coil side flow rate is kept constant. It was observed that the effectiveness of the heat exchanger for the cone shaped helical coil is more than that for the simple helical coil. Results show that the heat transfer rates for the cone shaped helical coil are comparatively higher than that of the simple helical coil. It was found that the heat transfer rates are 1.18 to 1.38 times more for the cone shaped helical coil than that of simple helical coil.

Keywords – Heat Exchanger, Cone shaped helical coil, Simple helical coil, Heat transfer.

I. INTRODUCTION

Extensive research on numerical and experimental investigations in simple helical coils was carried out by different researchers in laminar and turbulent flow regime. However flow through the cone shaped helical coils is still under exploration. Helical coil heat exchangers are vastly used in process industries.

Ge Pei-qi *et al.,*[1] investigated the heat transfer characteristic of conical spiral tube bundle with numerical simulation method. He found that the cone angle & cross section have major effect on heat transfer through the conical coil and helical pitch has little influence on heat transfer enhancement. Heat transfer coefficient of circular section of conical tube is larger than the elliptical section in condition that the area of the cross section is kept constant. Salimpour M. R. [2] experimentally investigated the heat transfer coefficients of shell & helically coiled tube heat exchangers. He selected three heat exchangers with different coil pitches as test section for both parallel-flow and counter-flow configurations. He performed 75 test runs from which tube side & shell side heat transfer coefficients were calculated. He proposed empirical correlations for shell side & tube side. He found that the shell-side heat transfer coefficients of the coils with larger pitches are higher than those for smaller pitches. Naphon P. [3] studied the Thermal Performance and pressure drop of helical coil heat exchangers with and without helically crimped fins. He presented the new experimental data from the measurement of the average in-tube convective heat transfer characteristics and thermal performance of helical-coil heat exchanger. He concluded that the outlet cold water temperature increases with increasing hot water mass flow rate, an average heat transfer rate increases as hot and cold water mass flow rates increase, the friction factor decreases with increasing hot water mass flow rate. Prabhanjan D G. [4] studied the influence of coil characteristics on heat transfer to Newtonian fluids. He studied the relationship between tube geometry, operating parameters (temperature and flow rate), target fluid velocity and dimensionless numbers describing the flow field in the tube and heat transfer across the surface of the helical coil. He found that flow rate as low as 0.001 m/s in the water bath improved the outer and local heat transfer coefficients by 35 and 22% respectively. Ghorbani N. *et al.,* [5] experimentally investigated mixed convection heat transfer in a coil-in-shell heat exchanger for various Reynolds and Rayleigh numbers, various tube-to-coil diameter ratios and dimensionless coil pitch. The calculations have been performed for the steady-state and the experiments were conducted for both laminar and turbulent flow inside coil. He found that the mass flow rate of tube-side to shell-side ratio was effective on the axial temperature profiles of heat exchanger. The results also indicate that the ε–NTU relation of the mixed convection heat exchangers was the same as that of a pure counter-flow heat exchanger. Pawar S. S. *et al*, [6] has taken a critical review of heat transfer through helical coils of circular cross section. This review indicates that there is a need of analyzing dynamic similarities amongst the geometrical similarities on large scale models covering industrial applications. Further research is required to be conducted at large scale on considerable range of curvature ratio, low range Pr & Re number, temperature etc. to consider these parameters and geometry in order to address scalability issues, applicable to industries. It is proposed to develop correlation including Nu number in terms of M number to understand the type of flow pattern in helical coil. Kurnia C J. *et al*, [7] completed the Evaluation of the heat transfer performance of helical coils of non circular tubes. They have investigated the three configurations-conical, helical, and in-plane spiral and their performances are compared to the straight duct in terms of a figure of merit. It is found that even though coiled ducts give higher heat transfer rates, they also impose a higher pressure drop penalty. However, for an operation where space is limited and pumping power is not an issue, the coiled duct can be a desired choice. Flórez-Orrego D. *et al.,* [8] studied heat transfer in a cone shaped helical prototype with 15cm in maximum diameter, 7.5cm in minimum diameter, 3/8" pitch and 40cm in axial length. He developed An empirical correlation for the determination of average Nusselt number along the duct, with Reynolds ranging between 4300 and 18600. Numerical simulations were performed using ANSYS FLUENT 12.1 software, where the governing equations of mass, momentum and heat transport were solved simultaneously, using realizable k-e two equations turbulence model. Jaric M. S. *et al.,* [9] presented the results of experimental research on shell-side heat transfer coefficient concerning 3 heat exchangers with helical coils. Measurements were carried in laboratory and the following correlation was found to be adequate $Nu = 0.50.\ Re^{0.55}.Pr^{1/3}.(\eta/\eta_w)^{0.14}$ where Re and Nu are based on shellside hydraulic diameter. Attention was paid on shell-side heat transfer coefficient which is strongly influenced by geometric/construction parameters such as winding angle, radial pitch, axial pitch, etc. From the results of the study, it was found out that the shell-side heat transfer coefficients should be based on shellside hydraulic diameter, because this parameter includes the number of shell side construction parameters. Farhadi M. *et al.,* [10] presented the experimental analysis to enhance the heat transfer rate in shell and coiled tube heat exchangers. Hot water flows in helical tube and cold water flows in the shell side. Tube and shell side heat transfer coefficients are determined using Wilson plots. Experimental apparatus and Taguchi method are used to investigate the effect of fluid flow and geometrical parameters on heat transfer rate. Following conclusions were made after experimental analysis. By increasing the shell side flow rate, the Nusselt number increases. As inner tube Dean Number increases, tube side Nusselt number and overall heat transfer coefficient increase. However, the significance of increase in overall heat transfer coefficient is a function of shell side Reynolds number. As coil pitch increases, tube side Nusselt number decreases and tube side flow rate affects this variation. The highest tube side Nusselt number is gained by the lowest coil pitch and the highest tube side flow rate. By increasing coil pitch, shell side Nusselt number increases. Increasing coil pitch, increases overall heat transfer coefficient. In tube side, by increasing coil diameter, tube side Nusselt number and overall heat transfer coefficient increase and shell side Nusselt number decreases.

II. GEOMETRY OF CONE SHAPED HELICAL COIL

Both helical coils are made from seamless copper tube of 9.53 mm outer diameter (O.D) & 8.41 mm inner diameter (I.D). The axial length of the copper tube for both helical coils is 20 ft. (6096 mm) each. Straight tube sections are provided at the inlet & outlet of the both coils. Simple helical coil have 7 turns whereas conical helical coil has 10 turns. Some flattening of the tube resulted during the formation of the helical coils. Experiments were performed with the axis of both coils in vertical direction. The hot water entered the coil at the bottom & exited from the top of the coil. The dimensions of both helical coils are given in table below.

Table No. 1: Specifications of coil.

Parameters	Dimensions	
	Cone shaped helical coil	Simple helical coil
Copper tube O.D.	9.53 mm	9.53 mm
Copper tube I.D.	8.41 mm	8.41 mm
Straight tube Length	6096 mm	6096 mm
Top coil diameter, DM	75 mm	210 mm
Bottom coil diameter, Dm	210 mm	210 mm
Coil Height, H	170 mm	170 mm
Inclination Angle, ø	65^0	----

No. of turns (approx)	10	7
Pitch of the coil	20 mm	20 mm

Table No. 2: Range of operating parameters.

Parameters	**Parameters Range**
Coil side water flow rate	60-280 LPH
Shell side water flow rate	60-280 LPH
Coil inlet temperature	50-55 ^{0}C
Coil outlet temperature	36-47 ^{0}C
Shell inlet temperature	25-27 ^{0}C
Shell outlet temperature	30-37 ^{0}C

III. EXPERIMENTAL APPARATUS

3.1. Experimental Set-up:

A schematic diagram of the experimental apparatus of cone shaped helical coil heat exchanger is shown in fig. 1. The test section is a cone shaped helical coil heat exchanger consisting of circular & cone shaped helical coils & shells. Both the coils are enclosed in a stainless steel vessel called shell. The shell having circular cross section with 250 mm diameter & the height of the shell is kept 250 mm. The shell side fluid is cold water & coil side fluid is hot water. The cold water is entered from the bottom of the shell & exited from the top of the shell. Similarly, hot water entered the coil from bottom & exited from the top of the coil.

The cold water flow to the shell is provided by the pumping of the cold water from the cold water tank. The centrifugal pump of ½ hp rate capacity is used to lift the water from the cold water tank. The cold water for the shell side is taken from the urban water supply. As the cold water passes through the shell, its temperature increases. So instead of supplying this cold water to the tank it is fed to the atmosphere so that the temperature of the cold water will not increase. The hot water flow is fed to the coil with ½ hp centrifugal pump from the hot water tank. Both the tanks have dimensions as 460mm X 410 mm X 410 mm. The hot water tank consists of two immersion type heaters having capacity 1500 watt each to heat the water in the tank.

The two Rota meters are connected in series with each of the two pumps to measure the mass flow rate of the cold & hot water respectively. Both the rotameters are calibrated & having the range of 60 to 600 LPH. The rotameters are mounted on a fabricated stand for the support. The connections of the water flow to both the shells & coils are made by using the T joints which are connected between rotameters and test sections. All these connections are made with PVC piping. Total 7 K-type thermocouples of 0.1^{0}c accuracy are used for measurement of the inlet & outlet temperatures of shell and tube side for both the coils. All the thermocouples are calibrated and connected to the 12 channel temperature indicator.

A U-tube manometer is connected across both the helical coils to measure the pressure drop. Mass flow rate on shell side is kept constant and the flow on tube side loop is varied by using the valve. Four different constant temperatures of 40, 50, 60 and 65^{0}c were considered for the mass flow rate of the coils. All the tests were performed under the steady state conditions. The inlet and outlet connections to the shells & coils are made with the flexible PVC piping. All the assembly of the cone shaped helical coil heat exchanger is placed on the mild steel fabricated structure.

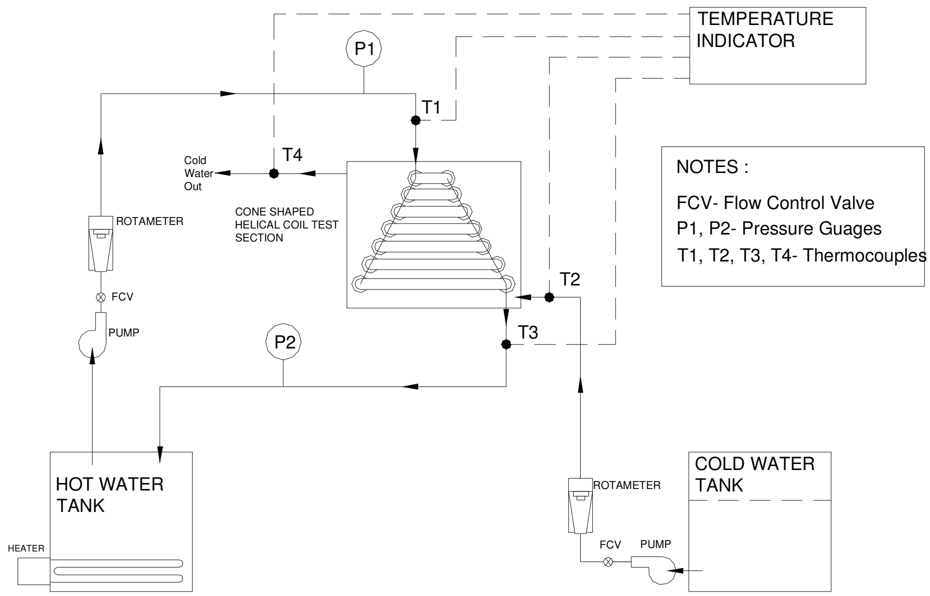


Fig. 1 Experimental set up of cone shaped helical coil heat exchanger

3.2. Materials & Methods:

Both helical coils of heat exchanger were constructed from copper tubing and standard brass connections. The copper tube having a 6096 mm long, 8.41 mm inner diameter & 0.56 mm wall thickness is used for both the coils. Circular helical coil have 7 number of turns & cone shaped helical coil have 10 number of turns with an inclination angle of 65^0. Both the coils made by winding a straight copper tube on wooden patterns. While bending of copper tube, very fine sand was filled in the tube to maintain smoothness on inner surface and after bending it was washed with the compressed air. The care was taken to preserve the circular cross section of the coil during the bending process & distortion was kept at minimum. The care was taken to maintain the constant pitch for both the coils while bending. The end connections soldered at copper tube ends & two ends each drawn from both the coils horizontally. Provisions were made for the straight entry & exit of hot water for both the coils. The two shells having circular cross section were made from Stainless Steel & insulated with insulation to prevent any heat loss from the shell side of the heat exchanger. The base structure for the experimental setup was fabricated from Mild Steel & powder coated.

3.3. Test Procedure:

Experiments were performed for various inlet temperatures and flow rates of hot water entering the test section. The hot water flows though the test coil and cold water flows through the shell with constant flow rate. The inlet hot water temperatures were adjusted at desired level by using electric heaters controlled by temperature controllers. The system was allowed to reach steady state before any data was recorded. Te flow rates were controlled by adjusting the valve and measured by the two calibrated thermocouples having range 60 to 600 LPH.

Experimental procedure is as follows:

a) First fill the water in both tanks and switch on the electric supply to the heater of hot water tank.

b) After reaching the desired temperature of hot water, start the centrifugal pump of hot water side and circulate the hot water through the test coil. The mass flow rate of hot water is controlled by FCV and measured by the rotameter.

c) At the same time circulate the cold water through the shell by starting the centrifugal pump. The flow rate of cold water is controlled by FCV kept in cold water line and measured by the rotameter.

d) The test was conducted for counter flow configuration.

e) Water inlet and outlet temperatures of coil side and shell side are measured by the temperature indicator after the steady state is reached.

f) Record the temperature readings for different mass flow rates of hot water while keeping the shell side flow rate constant.

g) Repeat the procedure for simple helical coil.

3.4. Calculation of heat transfer coefficients:

In this experimental work heat transfer coefficients and heat transfer rates were based on the measured temperature data. The overall heat transfer coefficient, Uo and heat transfer rate, q is calculated from equations as below. The operating parameter range is given in table 2.

Calculation of coil side heat transfer coefficients:

Overall Heat transfer coefficient, Uo:

$Uo = q / (Ao\ \Delta T_{LM})$ W/m^{2}K (1)

Where, q is the eat 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 πLdo.

Hot water Heat Transfer Rate:

$q_h = m_h.Cp_{,h}.(Tin\text{-}Tout)_h$

Cold water Heat Transfer Rate:

$q_c = m_c.Cp_{,c}\ (Tout\text{-}Tin)_c$

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

The physical properties of water are taken at average temperature:

Tmean = (Tin + Tout) / 2 (3)

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

$\Delta T_{LM} = (\Delta T_1 - \Delta T_2) / \ln(\Delta T_1/\Delta T_2)$ (4)

Convective Heat Transfer Coefficient (h):

$h_i = Nu_i * k / d_i$ W/m^{2}K (5)

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

Effectiveness of Heat Exchanger (ε):

If (mCp)c < (mCp)h,

ε = (Tco-Tci) / (Thi-Tci) (6)

If (mCp)h < (mCp)c,

ε = (Thi-Tho) / (Thi-Tci) (7)

IV. RESULTS AND DISCUSSIONS

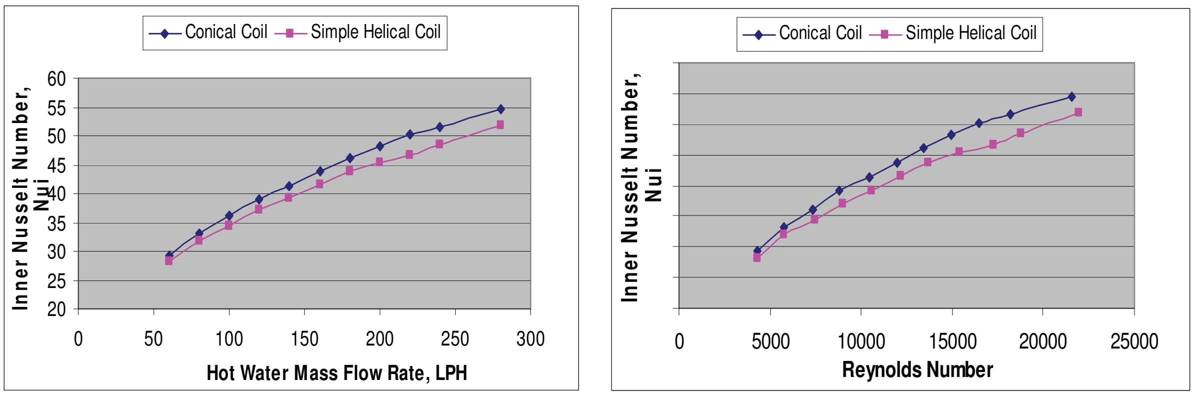
The results obtained from the experimental investigation of cone shaped helical coil heat exchanger operated at various operating conditions are studied in detail and presented.

4.1Thermal Performance:

The thermal performance of cone shaped helical coil heat exchanger is evaluated on the basis of heat transfer rates, overall heat transfer coefficients and Nusselt numbers. The coil side flow rate is varying between 60 LPH to 280 LPH and at the same time flow rate through the shell side is maintained constant. The tests are conducted only for counter flow configuration.

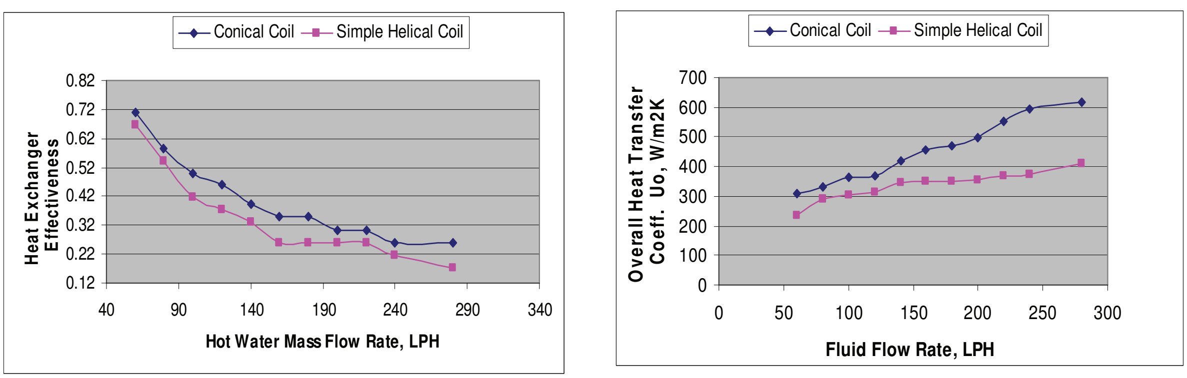
Fig. 4.1 (a) shows the variation of inner Nusselt number, Nui with hot water mass flow rate. It is seen that the values for Nusselt number for cone shaped coil are on higher side as compared with the simple helical coil. Fig. 4.1 (b) indicates the variation of inner Nusselt number, Nui with Reynolds number. The values for the cone shaped helical coil are higher as compared with the simple helical coil. The difference between the values of inner Nusselt number increases as the Reynolds number increases. The critical Reynolds number, Re_{cr} for laminar to turbulent flow transition is found as 8222 for cone shaped helical coil and 7268 for simple helical coil. It is calculated from the equation [6] considering curvature ratio, δ for the coil given as;

$$Recrit = 2100(1 + 12\,\delta^{0.5})$$



(a) (b)

Figure 4.1 (a) Variation of inner Nusselt number with hot water mass flow rate (b) Variation of inner Nusselt number with Reynolds number



(a) (b)

Figure 4.2 (a) Variation of heat exchanger effectiveness with hot water mass flow rate

(b) Variation of overall heat transfer coefficient with fluid flow rate.

Fig. 4.2 (a) indicates the variation of heat exchanger effectiveness with hot water mass flow rate. The heat exchanger effectiveness decreases from 0.72 to 0.20 as hot water mass flow rate increases from 60 LPH to 280 LPH. It is clearly found that the heat exchanger effectiveness for cone shaped helical coil is higher than that of the simple helical coil. Fig. 4.2 (b) gives the variation of overall heat transfer coefficient, Uo with the fluid flow rate. The overall heat transfer coefficient increases with fluid flow rate. The values for the same are on higher side for cone shaped helical coil as compared with that of simple helical coil.

Experimental analysis shows, in the heat transfer analysis the performance of conical coil is higher than that of the simple helical coil. The Reynolds Number ranges from 4000 to 21000 for different observations. The inner Nusselt number, Nui for the cone shaped helical coil is also on higher side as compared with the simple helical coil. Results show that the heat transfer rates for the cone shaped helical coil are comparatively higher than that of the simple helical coil. It was found that the heat transfer rates are 1.18 to 1.38 times more for the cone shaped helical coil than that of simple helical coil.

V.CONCLUSION

In this work, the experimental evaluation of cone shaped helical coil heat exchanger is carried out. The overall conclusions related to the comparative analysis between the cone shaped coil & simple helical coil are presented. It is found that the inner Nusselt number, Convective heat transfer coefficient and overall heat transfer coefficient increases when the coil side fluid flow rate increases. From comparative experimental analysis for the conical coil & simple helical coil it is found that the inner Nusselt number, convective heat transfer coefficient & overall heat transfer coefficient are higher in case of conical coil than that of simple helical coil. From comparative experimental analysis, it is found that the effectiveness of heat exchanger is on higher side in conical coil than that of simple helical coil. It was found that the heat transfer rates are 1.18 to 1.38 times more for the cone shaped helical coil than that of simple helical coil.

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