Experimental Research on Heat Transfer Characteristics of Helical Coil Heat Exchanger with Varying Pitch for laminar Fluid Flow

K S Madhu, Shankara Reddy R, S G Sanga Shetty

Abstract**: To Study on rate of heat transfer in heat exchanger using helical coils has been studied by many researchers. There is less published literature available on varying pitch helical coil heat exchanger and detail characteristics of helical coil varying pitch by keeping constant curvature ratio considering heat exchange between fluid to fluid heat exchanger for laminar flow condition not available in the present available literature. Hence in present study three different coils with varying pitches are used to investigate the heat transfer characteristics of a Helical Coil Heat Exchanger. Hence coil of 25mm, 30mm, 35mm are used by keeping constant curvature ratio (δ=0.0667), experiment is conducted to study the influence of varying pitch on effectiveness, heat transfer rate, over all heat transfer co-efficient and Nusselt Number. The experiments is conducted in horizontal counter steady flow condition and changing the flow rate of hot fluid, pitch of helical coil heat exchanger. The results show that the varying pitch of helical coil heat exchanger has influence on heat transfer characteristics. The effectiveness of the helical coil heat exchanger is decreases with increase in mass flow rate of the hot fluid inside helical tube for varying pitch considered for study. The heat transfer rate of the helical coil heat exchanger is increases with increase in Dean Number of the hot fluid inside helical tube for varying pitch considered for study. The overall heat transfer coefficient increases with increasing hot water mass flow rate. The Nussult Number at different dean number increases for increasing helical coil pitch however the trend of average heat transfer rate for increasing M Number for varying pitch observed similar. By increasing the coil pitch of helical coil heat exchanger decreases Nussult Number, inside overall heat transfer coefficient, heat transfer rate and effectiveness.

Keywords: Heat Exchanger, helical coil, varying pitch, Nusselt Number, effectiveness, Dean Number.

I. INTRODUCTION

Helical coil heat exchangers are one of the most generally use equipment found in numerous mechanical applications. Helical coil heat exchanger is one of the gadgets which are utilized for the recuperation framework. The helical coil heat exchangers can be made as a shell and tube heat exchangers and can be utilized for mechanical applications, for example, power plant, atomic industry, process plants, heat recuperation frameworks, refrigeration, sustenance industry and so forth. In the literature study shows that utilization of helical coil heat exchanger rather than straight tube builds effectiveness and heat transfer coefficients, Temperature ascent of the liquid was observed to be influenced by coil geometry and by the stream rate [1], the numerical examination of vertically coil tube heat exchanger has been conducted, the impact of coil tube and pitch diameter on the adequacy has been researched [2],S.S. pawer et al. exploratory examinations on unsteady state conditions were done in helical coils for Newtonian and non-Newtonian liquids, this tests performed for coil with varying curvature ratio in laminar and turbulent flow. it was seen from results that as helix distance across expands, generally speaking overall heat transfer coefficient and nussult quantities of hot liquids diminishes for the same flow [3], Jayakumar et al. Creators contrasted their trial results and the CFD results and they created above correlation to find out inward heat transfer coefficient in helical coil. They saw that the utilization of steady qualities for the thermal and transport properties of the heat transport medium outcomes in forecast of off base heat transfer coefficient [4], Jayakumar et al. the development of liquid particles in a helical pipe has been followed, CFD simulations are completed for vertically arranged helical coils by varying coil parameters such tube pitch, pipe width, pitch circle diameter and their impact on heat transfer has been contemplated [5]. Jayakumar et al. there do exist couple of trial results on hydrodynamics of air water move through helical pipes anyway numerical examination, which can give much knowledge into the material science of the issue. From this examination, it has been set up that relationships for heat transfer and weight drop will consider the pitch circle width, pipe diameter and portion at the inlet [6]. Jeschke He appeared just because the contrast between the heat transfer coefficient in coiled cylinders and straight cylinders is huge; the work was for a constrained scope of parameters [7], Seban and McLaughlin the liquid was warmed by electrical scattering through cylinder divider rather than steam. Their examinations demonstrated that the factor [1 + 3.5 (a/R)] isn't precise and significantly more noteworthy upgrade in the heat transfer coefficient is accomplished in helical coil over straight cylinder [8], Rogers and Mayhew It is like correlation created by [8].

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In any case, they warmed liquid streaming in helical cylinders by steam and liquid properties were evaluated dependent on mean mass temperature [9], Mori and Nakayama they found that the expansion in heat transfer rate isn't as huge as that under laminar stream condition.

They further expressed that there is no noteworthy contrast in heat transfer coefficient for steady divider temperature and consistent warmth motion limit condition [10], Mujawar and Rao They set up just because, the criteria for laminar stream in coiled tubes based on another dimensionless number 'M' reasoned from an information of the coil curvature ratio proportion on the stream bends. For Newtonian liquid, the basis for laminar stream in helical coil is given by above relationship [11], Pawar et al. No relationship was created by creators. Their outcomes for rectangular cross area demonstrated 24.8% normal upgrade in heat transfer coefficient over coil of circular cross section [12], Xin and Ebadian this connection depends on their exploratory outcomes for vertical direction of coil for water and air. They completed exploratory work for three distinct liquids air, water and ethylene glycol on five consistently warmed helical channels [13], N. jamshidi et al. trial examination is done investigation the heat transfer qualities in sell and helical coil cylinder heat exchanger utilizing Wilson plot and taguchi technique demonstrates that shell side stream rate, curl breadth, tube side stream rate and curl pitch are the most significant plan parameters in snaked heat exchanger[15] , Mahmoudi et al., researched the constrained convection heat transfer and weight drop in helically wound funnels utilizing TiO2/water nano fluid and revealed that for a given Reynolds number, senior member Number significantly affects heat transfer[16], Izadpanah et al., contemplated the characteristic convection heat transfer over the external surface of helically coil heat exchanger inside a water tank. The impact of coil breadth, pitch, turns and mass stream rate were considered and displayed a power law connection for the Nusselt number [17] , Shokouhmand et al. directed examinations on a helical curl heat exchanger with air and water as the heat transfer liquid and proposed a relationship for assessing the heat transfer coefficient [18], Conte et al., performed numerical examination to comprehend constrained laminar stream in rectangular wound funnels with round cross area. Tapered curls demonstrated better heat transfer performance [19], Chen et al. led numerical examinations on double cylinder heat exchanger in parallel and counter stream designs. Internal cylinder with oval cross area indicated better heat transfer characteristics [20] , Kharat et al. built up a connection for heat transfer coefficient for stream between concentric helical coils [21].

II. EXPERIMENTAL SETUP

A. *Layout of Experimental setup*

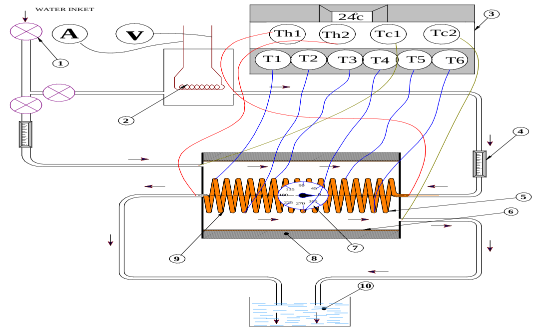

Figure 1 Schematic layout of Experimental setup

1.	Control valve	2.	Water heater
3.	Digital temperature indicator		
4.	Roto meter	5&9.	Helical coil tube
7.	Protractor	8.	Insulation (glass wool)
6.	Shell (shell inner diameter 320mm, outer shell 326mm, length is 500mm)Mild steel (powder coated)		
10.	Sump		
T_{h1}	Inlet temp. hot water in ^{O}C	T_{c1}	Inlet temp. Cold water ^{O}C
T_{h2}	Outlet temp. hot water ^{O}C	T_{c2}	Outlet temp. Cold water ^{O}C

T_1, T_2, T_3, T_4, T_5, T_6 thermocouple readings connected at the six distinctive area on the outside of the helical coil

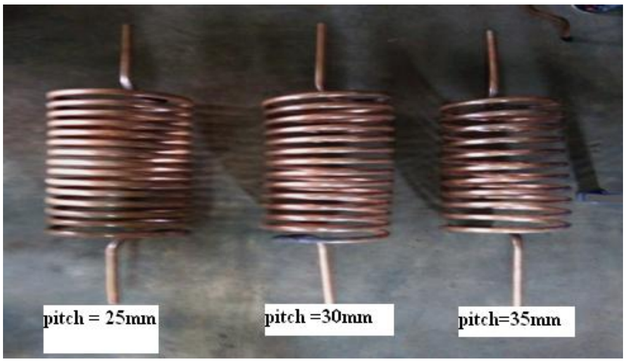

Fig 2 Helical coils

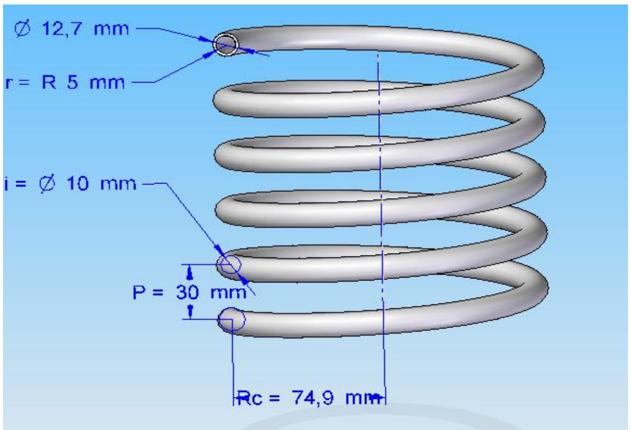

Fig 3 Basic geometry of a helical pipe

Table 1Physical Measurements of helical coils utilized

Helical Coils	Coil -1	Coil -2	Coil -3
P(mm)	25	30	35
Material Type	copper	copper	copper
k_c at 273K	386	386	386
N	15	13.5	11
Rc (mm)	74.9	74.9	74.9
R (mm)	5	5	5
δ	0.0667	0.0667	0.0667
do (mm)	12.7	12.7	12.7
di (mm)	10	10	10
L (m)	7409.1	6706.13	5531.01
$a_o(m^2)$	0.2956	0.2675	0.2206
a_i $(m^{2)}$	0.2327	0.2106	0.1737

B. Experimental Procedure

The proposed experimental setup consisting of helical coil heat exchanger is in the Fig. 2. The copper material helical tubes of having inner diameter10mm and outer diameter 12.7mm are used to obtained helical coil heat exchangers of different pitch are fabricated and used in the current investigation. The fluid used in the present experiment is water the hot fluid is flow through helical coil inside tube and placed concentrically inside the shell. The cold water flow through the shell observing heat from the hot fluid flowing in counter flow direction.The constant colds water (at 29 ± 2°C) the constant flow rate 1.6 LPM was supplied through the shell tube for all experimental tests consider for study.The constant Hot water (at 51 ± 1°C) the varying flow rates 0.6, 0.8, 1.0, 1.2, 1.4, 1.6 LPM was supplied through the helical coil tube for all experimental test consider for study. The flow rate measures both fluids by using two rotameters (capacity 0-5LPM).The inlet outlet temperatures of hot, coil fluid and helical coil outside surface where measure by K-Type thermocouples and where adjusted to meet furthest reaches of error ±0.1 °C. The test reading are taken at steady state condition and after that for each trial was rehashed for couple of readings to minimize the vulnerability in estimation of trial parameters. The reproducibility where observed to be inside ±1.5% for Temperatures, ±5.6% for stream rates of test fluids. The experiments were conducted by replacing helical coil inside the shell to vary pitch of the helical coil by keeping constant curvature ratio.

C. Data reduction

a. **L**, needed to make N turns:

$$L = (l + \left(N\sqrt{(2\pi R_c)^2 + P^2}\right)) \quad (1)$$

l = extended straight tube length both the sides=340mm

b. Log mean temperature difference,

$$\text{LMTD} = \Delta T_{lm} = \frac{(\Delta T_2 - \Delta T_1)}{(\frac{\Delta T_2}{\Delta T_1})} \quad (2)$$

c. The rate of heat transfer

$$Q_h = \dot{m}_h C_h (T_{h1} - T_{h2}) \quad (3)$$

$$Q_c = \dot{m}_c C_c (T_{c2} - T_{c1}) \quad (4)$$

$$Q_{actual} = \frac{Q_h + Q_c}{2} = U_o a_o \Delta T_{lm} = U_i a_i \Delta T_{lm} \quad (5)$$

$a_i = \pi d_i L$ and $a_o = \pi d_o L$ (6)

d. Determine the heat transfer coefficient by using relationship:

$$h_i \frac{Q}{a_i(T_{h(avg)} - T_{is})}, \quad (7)$$

$$h_o \frac{Q}{a_o(T_{os} - T_{c(avg)})}$$

$$T_{h(avg)} = \frac{T_{h1} + T_{h2}}{2} \quad (8)$$

$$T_{c(avg)} = \frac{T_{c1} + T_{c2}}{2} \quad (9)$$

T_{os} is the average outside coil surface temp.(a normal of six thermocouple readings connected at six unique areas on the outside of the surface of the coil), T_{is} is Average inside surface temperature of the coil can be calculated by using following relationship

$$Q = \frac{2\pi k_c L(T_{is} - T_{os})}{\ln(\frac{d_o/2}{d_i/2})} \quad (10)$$

e. **Nusselt Number** = $\frac{\text{Temperature Gradients by Conduction}}{\text{Convection at The Surface}}$

$$\text{Inside Nusselt number} = N_{ui} = \frac{h_i d_i}{k_i} \quad (11)$$

$$\text{Outside Nusselt Number} = N_{uo} = \frac{h_o d_o}{k_o} \quad (12)$$

f. NTU for counter flow heat exchanger

$$NTU = \frac{U_i a_i}{C_{min}} \quad (13)$$

g. **Effectiveness** (ε) = $\frac{\text{Actual Heat Transfer}}{\text{Maximum Possible Heat Transfer}}$

$$\varepsilon = \frac{Q_{actual}}{Q_{maxium}} = \frac{(C_h \times (T_{h1} - T_{h2})) \text{ or } (C_c \times (T_{c2} - T_{c1}))}{C_{min}(T_{h1} - T_{c1})}$$

$$= \frac{1 - \exp[-NTU \times (1 - C)]}{1 - C \times \exp[-NTU \times (1 - C)]} \quad \ldots(14)$$

h. The stream rate of a stream is equivalent to the stream (speed) increased by the cross-sectional region of the stream.

$$V_i = \frac{\dot{m}_h}{\rho \times A_i} \quad \ldots(15)$$

i. **Reynolds Number (R_e):** A dimensionless number utilized in liquid mechanics to show whether liquid stream past a body or in a pipe is unfaltering or fierce.

$$R_e = \frac{d_i V_i \rho}{\mu} \quad \ldots(16)$$

j. The Properties (ρ,μ,P_r, k_i, c_p) of saturated water at different temperature using journal of Chemicals and Physics reference [14] Data table A-9 Appendix1.

k. The **Dean number (De)**: A dimensionless gathering in liquid mechanics, which happens in the investigation of stream in bended pipes and channels.

Dean number is used to characters of the flow in a helical coil pipe.

$$De = Re\sqrt{r/R_c} \qquad (17)$$

l. To proposed correlation for finding out the new dimensionless number M available in the literature [2], M number is observed to be noteworthy to portray the hydrod ynamics of stream in helical coil for any curl ebb and flow proportions and heat transfer variables.

$$M = \frac{Re^{0.64}}{0.26 \times (\frac{r}{R_c})^{0.18}} \qquad (18)$$

III. RESULTS AND DISCUSSION

Experimental investigation have been carried out to study the effect of effectiveness, Dean number, mass flow rate and Nusselt Number on the heat transfer in a helical coil heat exchanger. The flows in both inner helical coil tube and shell (annulus) are lamina flow and the flow configuration is counter flow. In this experimental study pitch is varied 25mm, 30mm and 35mm maintaining the same curvature ratio and mass flow rate.

A. Influence of mass flow rate of hot fluid on the effectiveness of heat exchanger for varying pitch

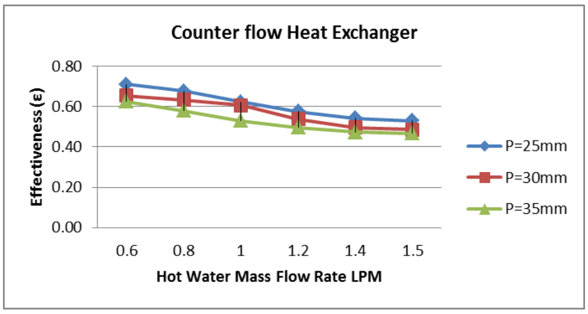

Figure 4 Influence of mass flow rate of hot fluid on the effectiveness of heat exchanger for varying pitch

Effectiveness of heat exchanger consisting of helical coil of varying pitch 25mm, 30mm and 35mm under steady state laminar flow conditions is represented in the fig. 4. It is observed that as mass flow rate of inside hot fluid increases, effectiveness of heat exchanger decreases for all pitches consider for study. Effectiveness found maximum for helical coil of pitch 25mm and it is minimum for helical coil of pitch 35mm for fixed mass flow rate inside hot fluid. There is a increasing heat transfer rate is observed for lower helical coil pitch this is because of increasing surface area of coil which is contact between hot and cold fluid for the inside surface area of helical coil of Pitch 25mm is 0.23276m^2, coil of Pitch 30 mm inside surface area is 0.21068 m^{2}and coil of Pitch 35mm inside surface area is 0.17376 m^2. For increasing helical coil pitch surface area decreases leading to decreasing helical coil effectiveness. Also, it is observed from results that, for helical coil of pitch 25mm an average value of effectiveness is found to be 6.6 % higher than the helical coil of pitch 30mm and13.17 % higher than the helical coil of pitch 35mm under steady state laminar flow conditions. The effectiveness of the helical coil heat exchanger is decreases with increase in mass flow rate of the hot fluid inside helical tube for varying pitch considered for study.

B. Effect of Dean Number on heat transfer.

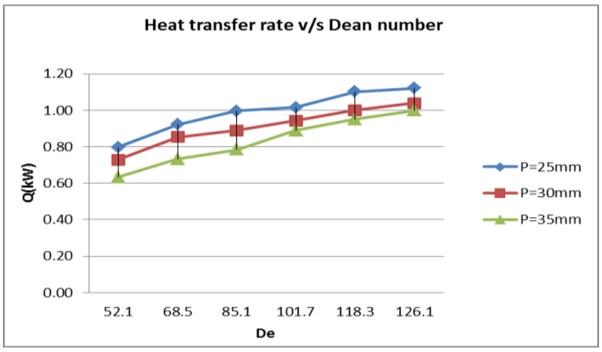

Figure 5 Comparison of heat transfer rate vs. Dean Number for different pitch

Heat transfer rate of heat exchanger consisting of helical coil of varying pitch 25mm, 30mm and 35mm under steady state laminar flow conditions is represented in the fig. 5. It is observed that as Dean Number of inside hot fluid increases, heat transfer rate of heat exchanger increases for all pitches consider for study. Heat transfer rate found maximum for helical coil of pitch 25mm and it is minimum for helical coil of pitch 35mm for fixed Dean Number of inside hot fluid. Since Dean number directly proportional to Reynolds Number of the fluid, as a Reynolds number increase heat transfer rate between the hot and cold fluid increases. The kinetic energy of the hot fluid particles observe more heat Also, it is observed from results that, for helical coil of pitch 25mm an average value of heat transfer rate is found to be 6.76 % higher than the helical coil of pitch 30mm and 14.93 % higher than the helical coil of pitch 35mm under steady state laminar flow conditions. The heat transfer rate of the helical coil heat exchanger is increases with increase in Dean Number of the hot fluid inside helical tube for varying pitch considered for study.

C. Effect of overall heat transfer coefficient.

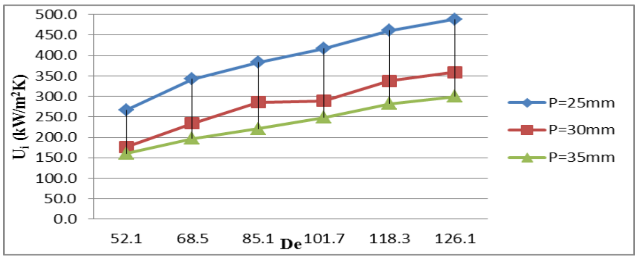

Figure 6 Comparison of inside overall heat transfer coefficient vs. Dean Number for different pitch.

The overall heat transfer coefficient of heat exchanger consisting of helical coil of varying pitch 25mm, 30mm and 35mm under steady state laminar flow conditions is represented in the figer. 6. It is observed that as overall heat transfer coefficient increases and dean number increases for different varying pitch consider for study. The hot water inside overall heat transfer coefficient directly proportional to heat transfer rate and inversely proportional to inside surface area of coil, a_i and ΔT_{lm}. However there is increase in heat transfer rate as coil length increases

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but this is dominated by larger inside surface area of coil which decreases value of U_i for higher pitch. For coil 25mm Pitch inside surface area is 0.23276m^2, coil 30 mm Pitch inside surface area is 0.21068 m^2 and coil Pitch 35mm inside surface area is 0.17376 m^2. Value of ΔT_{lm} also increases as helical pitch increases. Value of inside heat transfer coefficient is inversely proportional to the length of the coil. also, secondary motion becomes weaker for increase pitch (which decreases value of inner transfer coefficient) due to decrease in centrifugal forced acting on moving fluid element inside the coil. Due to all these reasons, overall heat transfer coefficient decreases as a pitch increases. Also, it is observed from results that, for coil 25mm pitch an average value of U_i is found to be 9.43 % higher than 30mm pitch and 24.1% for 35mm under steady state condition and laminar flow.

D. Effect of compare of heat transfer correlation.

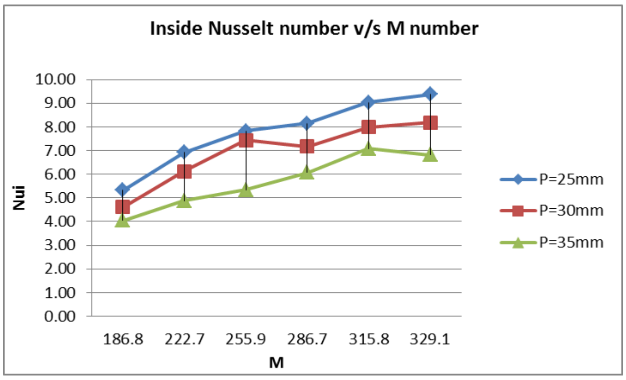

Figure 7Comparison of Nusselt Number vs. M Number for different pitch

Nusselt Number of heat exchanger consisting of helical coil of varying pitch 25mm, 30mm and 35mm under steady state laminar flow conditions is represented in the fig. 7. It is observed that as M Number of inside hot fluid increases, Nusselt Number of heat exchanger increases for all pitches consider for study. From this study it's observed that M Number significantly influences the heat transfer enhancement. For the range of the M Number of hot fluid in the experiments lies between 186.8 to 329.1.the average inside Nusselt Number observed minimum for pitch 35mm and it increases as the M number increases. The same trend of results is also observed for the helical coils of pitch 25mm and 30mm. the average Nusselt Number observed maximum for helical coil pitch 25mm and Dean Number 329.1.the Nusselt Number at different dean number increases for increasing helical coil pitch however the trend of average heat transfer rate for increasing M Number for varying pitch observed similar.

IV. CONCLUSION

In the present research work, an experimental investigation is carried out to study effectiveness of heat exchanger, heat transfer rate, inside overall heat transfer coefficient and inside average Nussult Number for Varying different Pitch of 25mm, 30mm and 35mm is carried out. From the obtained results it's from the obtained results it's concluded that:

a. The effectiveness of the helical coil heat exchanger is decre ases with increase in mass flow rate of the hot fluid inside helical tube for varying pitch considered for study.

b. The heat transfer rate of the helical coil heat exchanger is increases with increasevin Dean Number of the hot fluid in side helical tube for varying pitch considered for study.

c. The overall heat transfer coefficient increases with increasing hot water mass flow rate. It is observed from results that, for coil 25mm pitch an average value of U_i is found to be 9.43 % higher than 30mm pitch and 24.1% for 35mm under steady state condition and laminar flow.

d. the Nussult Number at different dean number increases for increasing helical coil pitch however the trend of average heat transfer rate for increasing M Number for varying pitch observed similar.

e. By increasing the coil pitch of helical coil heat exchanger decreases overallvheat transfer coefficient, heat transfer rate, Nussult Number and effectiveness.

APPENDIX

Nomenclature

P	Pitch
k_c	Helical coil thermal conductivity in W/m K.
k_i	Cold fluid thermal conductivity in W/m K.
k_o	Hot fluid thermal conductivity in W/m K.
N	Helical coil no. of turns
R_c	Mean helical coil radius in mm
r	The helical coil tube inner radius of in mm
d_o	The helical coil tube outside diameter in mm
d_i	The helical coil tube inside diameter in mm
a_o	The helical coil tube outside surface area in m^2
a_i	The helical coil tube inside surface area in m^2
L	The helical coil tube m^2Overall length in mm
Q	Discharge rate in m^3/sec
A_i	The helical coil tube cross sectional area in m^2
V_i	The Velocity of inside helical coil in m/sec.
D_e	Dean number
R_e	Reynolds Number
ΔT_{lm}	LMTD or Log Mean Temperature Difference in ^oC
$\dot{m}_h$	Mass stream rate of hot fluid in kg /sec
$\dot{m}_c$	Mass stream rate of hot fluid in kg /sec
c_{ph}	Hot water specific heat at constant pressure in kJ/kg K
c_{pc}	Coldwater specific heat at constant pressure in kJ/kg K
C_h	$\dot{m}_h c_{ph}$ = capacity rate of hot fluid in kW /K
C_c	$\dot{m}_c c_{pc}$ = capacity rate of cold fluid in kW /K
C	Capacity ratio
U_o	Outside coil tube Overall heat transfer coefficient in W/m^2°C
U_i	Inside coil tube Overall heat transfer coefficient in W/m^2°C
h_o	Outside coil tube heat transfer coefficient in W/m^2°C
h_i	Inside coil tube heat transfer coefficient in W/m^2°C
NTU	Number of Transfer units
M	New Dimensionless Number

Greek letters

δ	Curvature ratio
ρ	Water density kg/m^3
μ	Fluid Dynamic viscosity in N-sec/ m^2

ε	Effectiveness

Subscripts

h_1	Inlet Hot fluid
h_2	Outlet Hot fluid
c_1	Inlet Cold fluid
c_2	Outlet Cold fluid
i	Inlet
o	Outlet
temp.	Temperature

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