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HEAT TRANSFER ANALYSIS OF HELICAL COIL HEAT EXCHANGER WITH CIRCULAR AND SQUARE COILED PATTERN

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ABSTRACT

In present study, comparative analysis made on two different geometries of the helical coils for heat transfer analysis. Square and circular coiled patterned geometries were tested under counter flow configuration. The tube side and shell side flow rates were varied and both side input-output temperatures measured using suitable temperature sensors.The tube and shell side mass flow rates controlled by using flow meters and varied by using flow control valve.Overall heat transfer coefficients were calculated for both the coil. Inner heat transfer coefficients were calculated by using Wilson plot method. Tube side Nusselt number calculated for various mass flow rates. The new tube side Nusselt number correlations were developedfor both the coil geometries and compared with the available existing correlations.

Key words: Circular and square coiled pattern, Nusselt number, Heat Transfer.

1. INTRODUCTION

The helical coiled heat exchangers widely used as compact heat exchanger, power, chemical industries, condensers and evaporators in the food processing, and waste heat recovery application [1-5]. Recently, the helical coil heat exchangers are used to improve heat transfer performance. Helically coiled tubes have been introduced as one of the passive heat transfer enhancement techniques to enhance heat transfer coefficient in various application. The various analyses recorded that helically coiled tubes are superior to straight tubes [9]. The centrifugal force, due to curvature of tube results in secondary flow development (normal to the axial direction) which mixing the fluid particles to enhance heat transfer rate. Most of researcher has done numerical and experimental studies on helical coil heat exchanger in circular pattern with no pitch, varying curvature ratio and varying pitch [2-3].The double pipe helical heat exchangers studiednumerically and experimentally, in that neglected the effect of coiled tube pitch or zero pitch. Though the boundary condition of hiswork was different from the conventional boundary condition of constant wall temperature and constant heat flux, the comparative research made on straight tube heat exchanger and helical coil heat exchanger.

Nomenclature:

A_o	Outer surface area of coiled tube, (m^2)	n	Exponent,(-)
C	constant ,(-)	k	thermal conductivity, ($W/m^{2\,0}C$)
Pr	Prandtl number, = $\mu C_P/k$,(-)	Nu	Nusselt number,(-)
R	curvature radius,(mm)	Re	Reynolds number,(-)
ϕ	curvature ratio,(-)	U_0	overall heat transfer coefficient, ($W/m^{2\,0}C$)
d_i	Inner diameter of coiled tube,(mm)	v	fluid average velocity,(m/s)
d_0	Outer diameter of coiled tube,(mm)	h	averaged convective heat transfer coefficient, ($W/m^{2\,0}C$)
L	Stretch length of coiled tube,(mm)	d_h	shell-side hydraulic diameter, (m)
l	Length of straight tube between two bends,(m)	De	Dean number, = $Re(d/2R)^{0.5}$
FCV	Flow control valve,(-)	Q	Heat transfer,(watt)
m	Mass flow rate (kg/sec)	total	total
Cp	specific heat (kJ/kg ^0C)	ΔT1	temperature difference at outlet, (^0C)
T	Temperature, (^0C)	ΔT1	temperature difference at outlet, (^0C)
LM TD	Log mean temperature Difference,(^0c)		

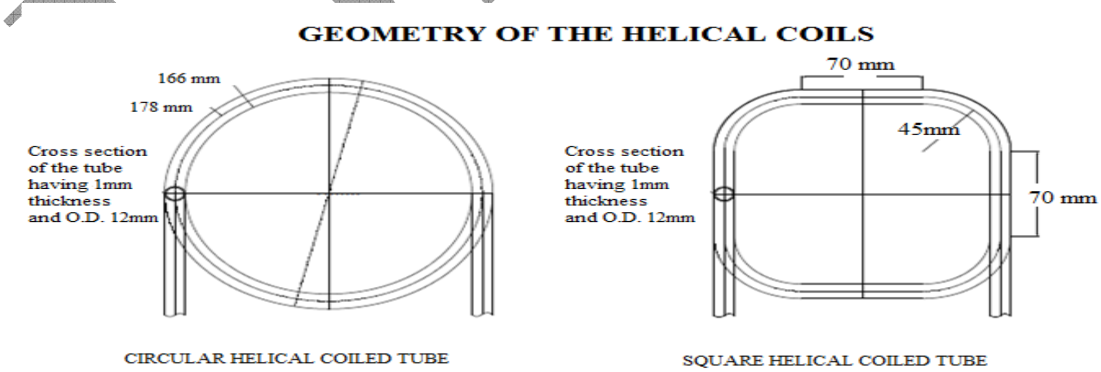
Subscripts

i	inside condition
o	outside condition

The experimentally investigated three heat exchangers with different coil pitches for circular geometries and found that the shell-side heat transfer coefficient of coils with larger pitches is higher than those with smaller pitches. Also, two correlations were developed to predict the inner heat transfer coefficients and the outer heat transfer coefficients of the coiled tube heat exchanger. He shows that heat transfer coefficient increases with both Reynolds number and curvature ratio growth. The inner Nusselt numbers of different shell and coiled tube heat exchangers are presented versus Dean Number. Also, found out that the shell-side heat transfer coefficients of the coils with larger pitches are more than the ones with smaller pitches. They observed that the overall heat transfer coefficients of counter-flow configuration are 40% more than parallel flow configuration [2-3].R. K. Patil described a method of calculating the shell side heat transfer coefficients for a shell and coiled tube heat exchanger; however, the calculations were based on empirical relations for flow over a bank of circular tubes which naturally cannot be relied on as a result of neglecting the effects of curvature [10].Kumar investigated a tube in tube helically coiled heat exchanger for turbulent flow region numerically and experimentally [7-8]. One of the most frequent uses of helically coiled tubes is in shell and coiled tube heat exchangers. Going through the existing literature, it was revealed that there are a few investigations on the heat transfer coefficients of circular coiland rectangular helical coil heat exchangers considering the geometrical effects instead of circular coil. In present study, presented comparative thermal analysis of circular coil and square coil at no pitch condition.

2. GEOMETRY OF SHELL AND COILED TUBE HEAT EXCHANGER

A geometry of coiled tube heat exchanger is shown in Figure.1 (a, b) in this figure, d_i is the diameter of coiled tube;R is the curvature radius of the coil. The curvature ratio, ϕ, is defined as the coil-to-tube diameter ratio, $d_i/2R$. The schematic diagram of experimental set-up is shown in Fig. 2. The setup is a well instrumented single-phase heat exchanging system in which a hot water flowinside the tube-side is cooled by a cold water flowing in the shell-side.



(a) (b)

Fig. 1 Geometry of the helical coiled tube (a) Circular coiled pattern (b) Square Coil pattern

Operating Parameter and Dimension

Table1:Characteristic dimensions of shell and coiled tube heat exchangers

Dimensional Parameters	Heat exchangers	
	Circular Coil	Square Coil
d_i, mm	10	10
d_o, mm	12	12
D, mm	178	Avg. 178
Curvature Radius, mm	89	NA
Corner Radius, mm	NA	45
Stretch Length, mm	3334	3334
Straight Tube length between two bends, mm	NA	70

Table 2: Range of parameters

Parameters	Range
Tube side water flow rate	0.003–0.024 kg/s
Shell side water flow rate	0.004–0.025 kg/s
Tube inlet temperature	55–59 °C
Tube outlet temperature	42–50 °C
Shell inlet temperature	35–37 °C
Shell outlet temperature	49–44 °C

2.1 Material and Method

The heat exchanger was constructed from copper tubing and standard brass connections. The copper tube having a 3.34m long, 10mm inner diameter and 1 mm wall thickness for both coils. The circular coil had a curvature radius 89 mm from tube center and square coil had a 45 mm corner radius and 75 mm straight tube. The both coil had six no. of active turn was made on wooden pattern. The dean number for square coil pattern calculated with average of diagonal distance and face to face distance. The six no. of active turns maintained for both geometries of coil, so that to keep same convective area. When the bending of copper tube very fine sand filled in tube to maintain smoothness on inner surface and this washed with compressed air. The care taken to preserve the circular cross-section of the coil during the bending process. The end connections soldered at copper tube ends and two ends drawn from coiled tube at one position.

2.2 Experimental Apparatus

The performed was taken on the set-up show in Fig. 2. The hot water tank with 3000watt capacity thermostatic electric heater was used to supply constant hot water temperature on inner side of tube. The hot water pumped with 0.0125 kWthrough the suitable tubing. The cold water was used for fluid flowing in the annulus from large cold water reservoir. The two flow-meters used to measure tube side and annulus side mass flow rate trough flow metering valve. Flexible PVC tubing was used for all the connection. K type thermocouples were inserted into brass end connectors to measure inlet and outlet temperatures of both the fluids. Temperature data was recorded using data acquisition/switch unit.

2.3 Test Procedure

The set-up instrumented single phase heat exchanger system. The main components of the set-up were two coiled heat exchangers (Circular & Square helical Coil), Centrifugal pump, hot water tank, Cold water tank. From the hot water tank constant temperature 60^{0}C water supply in tube side, the mass flow rate varies from 0.003–0.024 kg/s. Cold water supply, in annulus side with mass flow rate 0.004–0.025 kg/s. Flow rate of hot water and cold water controlled by ball valve.After reach set temperature, pump was started and starts to circulate hot water from tube side. The temperature data recorded for every 5 min. this data was taken after temperature isstabilized.

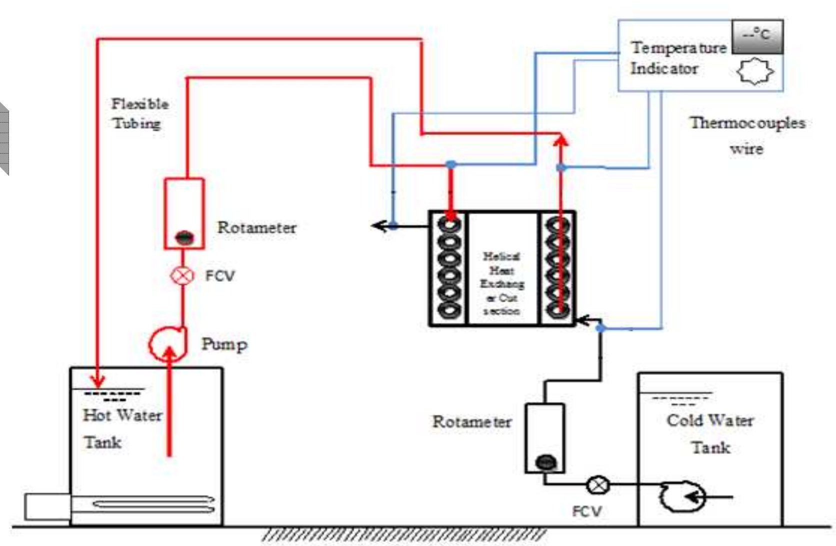


Fig. 2 Experimental Setup of Helical coil heat exchanger

The input –output temperature of flowing fluid measured with varying mass flow rate in tube and annulus side. From K-type thermocouples had limits of possible error of 1.2^{0}C. All the pipes, shells and pipe near end connection (came in contact with surrounding) insulated. The tube side pressure drop measured with appropriate pressure indictor. The dimensions of the heat exchangers are in Table 1.

2.4 Data Collection and analysis

In present investigation work the heat transfer coefficient and heat transfer rates were determined based on the measured temperature data. The heat flowing from tube side hot water to shell side cold water. The operating parameter range is given in table 2.

Tube Side Heat transfer

$$Q = m_t Cp_t (t_{in} - t_{out}) \quad \ldots(1)$$

Shell Side Heat Transfer

$$Q = m_s Cp_s (t_{in} - t_{out}) \quad \ldots(2)$$

The physical properties of taken on average temperature

$$T_m = (T_{in} + T_{out})/2 \quad \ldots (3)$$

The heat transfer coefficient was calculated with,

$$U_o = \frac{Q}{A_o \Delta T_{LMTD}} \quad \ldots (4)$$

The overall heat transfer surface area was determined based on the tube diameter and developed area of tube diameter. $A_{total} = \pi Ld$, The total convective area of the tube (πLd) keepconstant for two geometry of coiled heat exchanger.

$$A_{circular} = A_{Square} = \pi Ld = 3427 \text{ mm}^2$$

LMTD is the log mean temperature difference, based on the inlet temperature difference ΔT_1, and outlet temperature difference ΔT_2,

$$LMTD = \frac{(\Delta T_2 - \Delta T_1)}{In(\Delta T_2/\Delta T_1)} \quad \ldots(5)$$

The flow rate in shell side was varying with combination to tube side flow rate. The overall heat transfer coefficient can be related to the inner and outer heat transfer coefficient from following equation,

$$\frac{1}{U_0} = \frac{A_o}{A_i h_i} + \frac{A_0 In(d_o/d_i)}{2\pi KL} + \frac{1}{h_o} \ldots(6)$$

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 h_i and h_o convective heat transfer coefficient inner and outer side respectively, by keeping mass flow rate in annulus side is constant and tube side mass flow rate varying.

$$h_i = CV_i^n \qquad \ldots (7)$$

Where V_i are the tube side fluid velocity m/sec. Substituting Eq. (7) into Eq. (6), 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.

3. RESULT AND DISCUSSION

Fig.3 represents the performance of two helical coils of tube side Nusselt number versus Inner side Dean Number with different coil geometries. The experimental Nusselt number compared with the empirical correlations available in the literature data [11, p. 139-141], also this experimental Nusselt number compared with straight tube correlations. The predicted Nusselt number was well matches with existing correlations. The tube side hot water flowing with various mass flow rates trough controlling devices.

The various empirical Nusselt number correlation of circular pattern helical coil compared with the square pattern helical coil. With keeping same operating parameters the comparative analysis made on both coils in Fig. 3 & Fig. 4. Square coiled heat exchanger gets more convective heat transfer coefficient than circular and straight tube heat exchanger. Fig. 5 presents the inner side Nusselt number versus tube side mass flow rate.

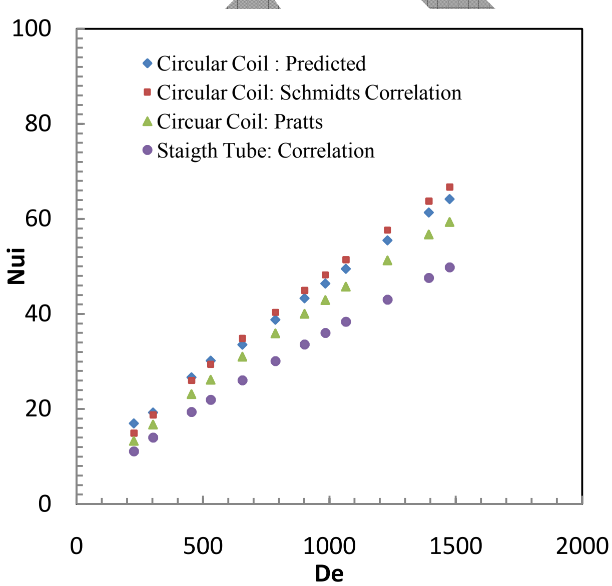


Fig. 3 Variation of inner Nusselt Number with Dean Number for available Correlation of circular coil

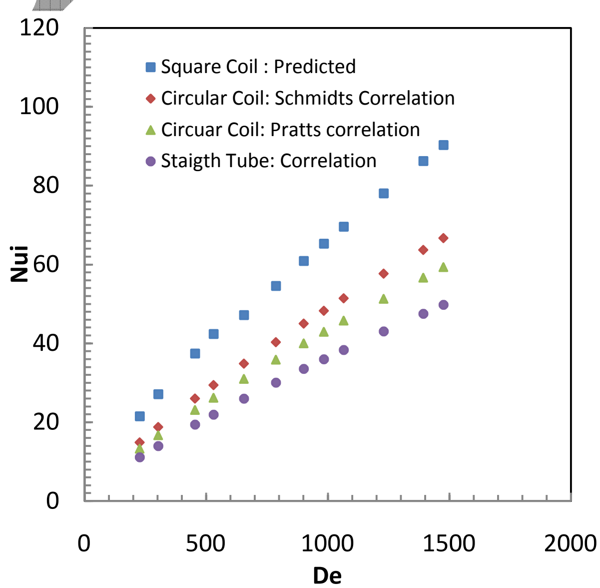


Fig. 4 Variation of inner Nusselt Number with Dean Number for available Correlation of Circular coil and Predicted Correlation Square

Fig. 4 represents the variation of tube side Nusselt number of square pattern helical coil versus Dean Number. The available correlations were compared with predicted correlation and these are well fitted with present study as shown in Fig. 3.

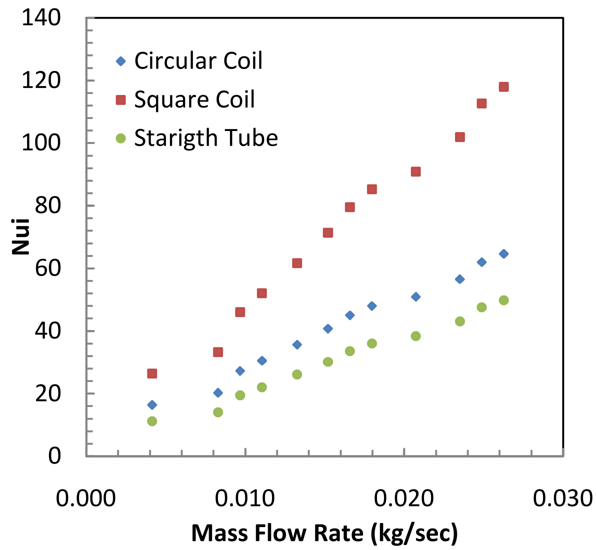


Fig. 5 Variation of inner Nusselt Number with various mass flow rate into various coil geometry

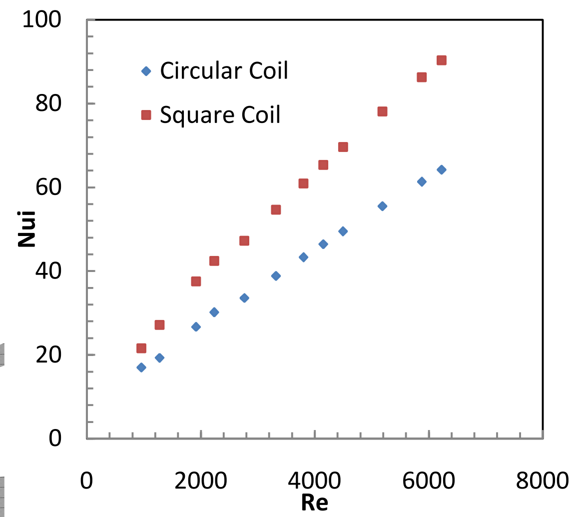


Fig. 6 Variation of inner Nusselt Number with Reynolds number forcircular and square helical coil geometry

The three geometries of the heat exchanger were compared with varying mass flow rate. The performance of the square coiled pattern was better than circular and straight heat exchangers. Fig. 6 shows comparison of the Nusselt number variation with Reynolds number for circular helical and square helical coiled pattern.

4. PROPOSED CORRELATIONS TO PREDICT TUBE SIDE NUSSELT NUMBER FOR CIRCULAR COIL AND SQUARE COIL

The existing correlations available in the literature are for helical circular and rectangular coil. The various correlations cover the with-without coil pitch, curvature ratio and different tube helix and tube diameter. As per discussion the new correlation developed to predict inner tube side Nusselt number for both coil geometries.

$$Nu_i = C_1 De^{n_1} Pr^{n_2} \phi^{n_3} \ldots (8)$$

The correlation between the Nusselt number and dean number, prandtl number and curvature ratio.Where ϕ=r/R, is the correction factor considered to take into account the effect of variable properties of the fluid. Using curve fitting, the following correlations was found to predict the tube side heat transfer coefficient for both geometries.

$Nu_i = 0.23De^{0.735}Pr^{0.22}\phi^{0.01}$ For circular coil geometries … (9)

$Nu_i = 0.27De^{0.77}Pr^{0.2}\phi^{0.014}$ For square coil geometries… (10)

The range of validity of this equation is $220<De<1500$, $0.34<\phi<0.60$.

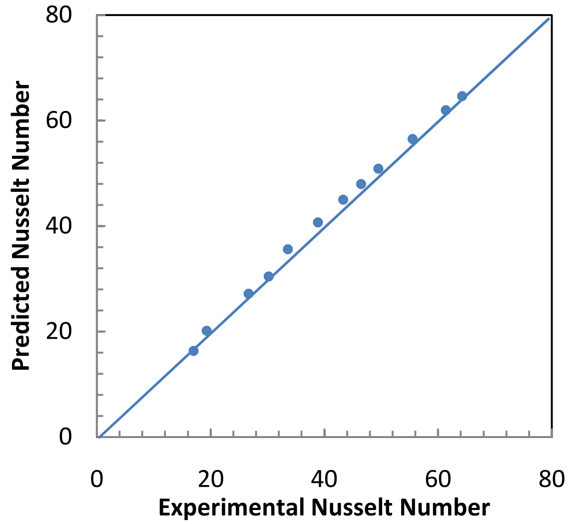


Fig.7 Comparison of predicted tube side Nusselt number by eq. 9 and experimental Nusselt Number for circular coiled tube

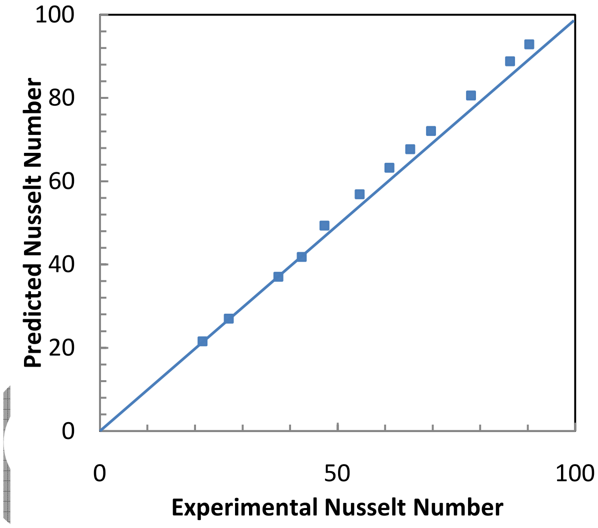


Fig.8 Comparison of predicted tube side Nusselt number by eq. 10 and experimental Nusselt Number for square coiled tube

In the literature, there was no correlation available of tube side Nusselt for square pattern coiled heat exchanger. Fig. 8 & Fig. 9 present the proposed correlations are in good agreement with experimental data.Fig. 8 presents the experimental tube side Nusselt number with the predicted Nusselt number. The experimental data compared with the predicted Nusselt number correlation eq. (9). Fig. 9 shows Comparison of predicted tube side Nusselt number by eq. 10 and experimental Nusselt Number for square coiled tube.

5. CONCLUSION

An experimental study of helical pipe heat exchanger was performed by using two differently shaped heat exchanger. The heat transfer rate in the square coil heat exchanger was much higher than circular coiled pattern, due curvature effect at corner radius. It was revealed that the empirical correlations for circular and square pattern helical coiled heat exchanger are quite in agreement with the present experimental data. Fig. 10 Presents comparison of tube side overall heat transfer coefficient of circular and square coiled heatexchanger. For better understanding the effect of geometries on heat transfer coefficient. Above figure represents the square pattern

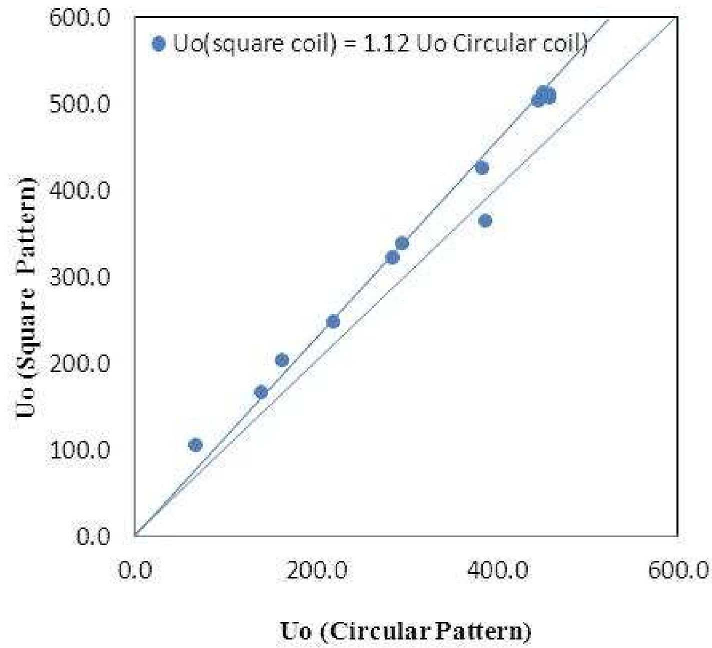


Fig. 10 Comparison of tube side overall heat transfer coefficient of circular and square coiled heat exchanger

helical coil heat exchanger is 12% more than that of circular pattern helical coil for counter flow configuration.

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