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An Experimental Study of Coil Side Heat Transfer Coefficient in Shell-and-Coil Exchanger

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ABSTRACT

In the present study, a heat transfer characteristic in shell and coil exchanger inside the helical tube was investigated. Two helical coils with different helix diameter were selected as test section for counter flow configuration. All require parameters like flow rate of fluid, temperatures etc were measured using suitable instrument. Experimental were performed by varying parameters such as flow rates in tube side and changing the helix diameter from which calculated heat transfer coefficient. The calculated tube side heat transfer coefficient was also compared with existing correlation and reasonable agreement was observed. Also, it observed that the higher heat transfer coefficient was found in small helix diameter coil compare to larger coil. This is because the high turbulence generate in small helix diameter. The Nusselt number increases by 38 % when the helix diameter decreases.

Keywords: Shell and coil exchanger, helical coil, Nusselt number, experimental

INTRODUCTION

There have been two techniques of heat transfer first Passive and second is active. The passive heat transfer enhancement techniques in helical coiled tubes are used in several industrial applications. In any chemical process industry there is applications heat exchanger. Due to the small area required, helical coiled tubes are used in heat exchangers, evaporators in the pharmaceutical, food, nuclear industries, heating ventilating and air conditioning (HVAC) engineering, petrochemical and chemical industries In coiled tubes centrifugal force make a pair of longitudinal vortices and these secondary flow increases the heat transfer coefficient. Dravid et al numerically investigated the effect of secondary flow on laminar flow heat transfer in helically coiled tubes in the fully developed and in the thermal entrance regions.

Nasser Ghorbani et al studied the mixed convection heat transfer in a coil-in-shell heat exchanger and reported for various Reynolds and Rayleigh numbers, different 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. They 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 shows that the ε−NTU relation of the mixed convection heat exchangers was the same as that of a pure counter-flow heat exchanger

M. Moawed experimentally studied the forced convection from outside surfaces of helical coiled tubes is studied experimentally with a constant wall heat flux. The experiments were performed in an open-circuit airflow wind tunnel system operated in suction mode. The experiments covered a range of Reynolds number (Re) of 660 to 2300. The experimental results indicated that key design parameters d_c/do and P/do have significant effects on the average heat transfer coefficient. The average Nusselt number increases with the increase ratio of coil diameter to tube diameter (d_c/d_o) at constant Reynolds number and pitch of coil to outer diameter of the coil tube (P/do). The average Nusselt numbers is correlated with Re, d_c/d_o and P/d_o. A general correlation of the average Nusselt number was obtained to describe the forced convection from the coiled tubes as the follows

$$Nu_c = 0.0345\,\mathrm{Re}_c^{\,0.48}(d_c/d_o)^{0.914}(p/d_o)^{0.281}$$
$$6.6\times10^2 \le \mathrm{Re} \le 2.3\times10^3,$$
$$7.086 \le (d_c/d_o) \le 16.142,$$
$$1.81 \le p/d_o \le 3.205$$

Genic et al studied shell-side heat transfer coefficient concerning three heat exchangers with helical coils. The experiment carried on shell-side heat transfer coefficient which is strongly influenced by geometric parameters such as winding angle, radial pitch, axial pitch, etc and proposed the correlation for calculating shell side Nusselt Number

$$Nu = 0.50\,\mathrm{Re}^{0.55}.\mathrm{Pr}^{0.33}.(\text{«} / \text{«}_{w})^{0.14}$$

Jayakumar et al. numerically and experimentally studied the coil side of shell and helically coiled tube heat exchangers and obsereved that the use of temperature dependent properties of working fluids results in prediction of more accurate heat transfer coefficients. They developed correlations to calculate the coil side heat transfer coefficient of the heat exchanger as follows

$$Nu_c = 0.025De^{0.9112}.\mathrm{Pr}^{0.4}$$

Alimoradi et al numerically and experimentally studied the heat transfer of shell and helically coiled tube heat exchangers. They investigate the effect of physical properties of fluid, operational parameters and geometrical parameters on Nusselt numbers of shell and tube sides. Results indicate that if the pitch size is doubled, the shell side Nusselt number increases by 10%, while the coil side Nusselt numbers increases by only 0.8%. Also it was found that an increase of 50% in the height and diameter of the shell causes a decrease of 34.1% and 28.3% in the Nusselt number of the shell side, respectively. Based on the results, two correlations were developed to predict Nusselt numbers of coil side and shell side for wide ranges of Reynolds and Prandtl numbers

$$Nu_c = \mathrm{Re}^{0.685}\left(\frac{d_c}{d_{t,i}}\right)^{-0.216}\left(\frac{d_v}{d_{t,i}}\right)^{0.024}\left(\frac{d_{sh}}{d_{t,i}}\right)^{-0.012}\left(\frac{H_c}{d_{t,i}}\right)^{-0.03}\left(\frac{H_{sh}}{d_{t,i}}\right)^{-0.045}\left(\frac{f}{d_{t,i}}\right)^{0.013}\left(\frac{p}{d_{t,i}}\right)^{0.011}.\mathrm{Pr}^{0.315}$$

Salimpour studied experimentally the heat transfer coefficients of horizontal shell and helically coiled tube heat exchangers. He chose as three heat exchangers with diverse coil pitches for counter-flow configurations. Two correlations were proposed for shell-side and tube-side of heat exchanger. He found in his studied that the larger pitch size the shell side heat transfer coefficient (HTC) increases.

$$Nu_c = 0.152De^{0.431}.\mathrm{Pr}^{1.06}.\text{¥}^{-0.277}$$

$$Nu_s = 19.64\,\mathrm{Re}^{0.513}.\mathrm{Pr}^{0.129}.\text{¥}^{0.938}$$

Kalb et. al., theoretically studied the fully developed heat transfer in curved tubes with circular cross section at steady state, under the thermal boundary condition of axially uniform wall heat flux with peripherally uniform wall temperature. They proposed the equation, for coil side Nusselt number

$$Nu_c = 0.913De^{0.476}.\mathrm{Pr}^{0.2}$$

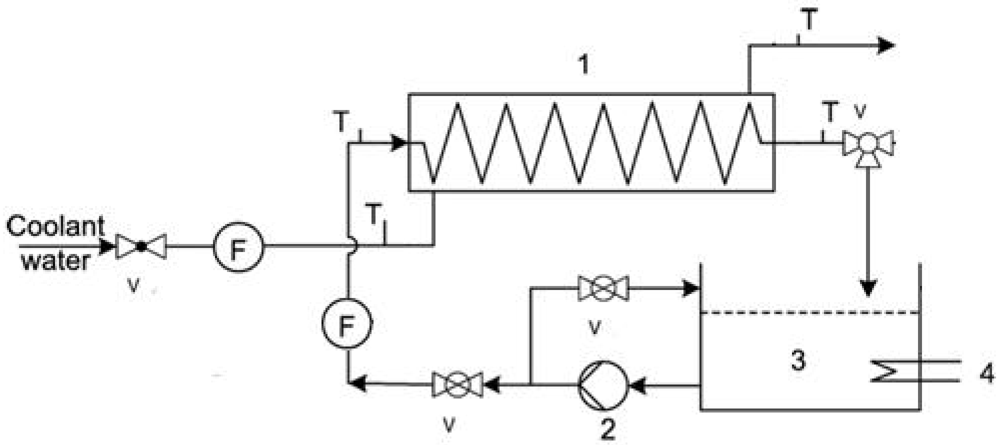
Beigzadeh et al. developed Artificial Neural Network models to predict the heat transfer and friction factor of the coil side, in helically coiled tubes. Studied effects of the Prandtl number and geometric parameters on the local and average convective heat transfer characteristics in helical pipes and suggested the equation for the coil side Nusselt number:

$$Nu_c = \left(2.153 + 0.318De^{0.643}\right)\mathrm{Pr}^{0.177}$$

EXPERIMENTAL APPARATUS

Test section

The test section comprising helically coiled heat exchanger is shown in Fig. 1. Copper helical tubes have 5 mm inner diameter and 7 mm outer diameter. The shell has 12 cm inner and 50 cm length. In this study, two helical diameter coils were considered with same inner tube diameter. The setup is a well instrumented heat exchanging system in which a hot water stream flowing inside the coiled tube is cooled by a cold stream flowing in the shell side. Two 2000 W electric heaters were placed in the hot water storage tank. The hot fluid (water) is then pumped using centrifugal pump to the helical tube which is placed in the shell side.



1 -	Shell and coil Exchanger	T -	Thermocouple
2 -	Centrifugal Pump	F -	Flow meter
3 -	Hot fluid storage Tank	v -	Valve
4 -	Electrical Heater		

Fig 1: Flow diagram of experiment setup

The volumetric flow rate is measured by two variable flow meters (i.e. rotameter) placed in between hot and cold waters stream. Recycling hot water for experimental as the hot water exits from coil, its temperature reduces so the hot flow returns back to the hot water storage tank to have the constant hot water temperature at the entry of helical tube. The cold water has the same closed cycle system. The inlet and outlet temperatures of hot and cold water stream were recorded using thermocouples inserted in the small holes made in the inlet and outlet tubes of each heat exchanger on digital temperature indicator. Experimental run were conducted with varying different parameters such as varying flow rates in tube side and find heat transfer coefficient for given duty and varying the helix diameter. For calculating the heat transfer coefficients in helical tube experimentally general heat transfer equation was used and for theoretical calculation considered different existing correlations.

Calculation of heat transfer coefficients inside coil tube

After a few minutes (12-20 min), temperatures will be fixed and the heat transfer rates of coil side and shell side will be steady. Once steady state is attained, values of two flow rates and four temperatures will be noted. By changing flow rates of coil sides, different test runs have been taken Range of the operational parameters is given in Table 2. To find the coil side Nusselt numbers following equations have been used:

$$Q_c = m_c Cp(T_{i,c} - T_{o,c})$$

$$h_c = \frac{q_c}{T_{c,mean} - T_{w,mean}}$$

$$Nu_c = \frac{h_c d_i}{k_c}$$

Table 1. Dimensions of the Shell and Coil Exchanger

HCT No.	D_c (mm)	di (mm)	do (mm)	Lc (mm)
1	70	5	7	2000
2	120	5	7	2000

Table 2. Range of fluids operating conditions

Parameters	Range
Flow rate of the coil side (lpm)	1-6
Flow rate of the shell side, (lpm)	2
HCT side inlet temperature, $T_{i,c}$ (ºC)	45.2-60.3
HCT side outlet temperature, $T_{o,c}$ (ºC)	42.3-52.4
Shell side inlet temperature, $T_{i,sh}$ (ºC)	30.5
Shell side outlet temperature, $T_{o,sh}$ (ºC)	36.3-41.9

Uncertainty in experimental data

In this experiment, the uncertainty of experimental data results from measuring errors of parameters such as volume flow rate and temperature. For the heat transfer experiment, heat transfer coefficient is calculated from readings of the volume flow meter and thermocouples reading. The precision of the thermocouples are 0.1 ºC. Precision of the volumetric flow meters are 0.5 LPM. Therefore, the uncertainty of Reynolds number and heat transfer experiment are less than 10 %.

RESULTS AND DISCUSSION

The experimental apparatus and procedure were validated by comparing the results of Nusselt number for hot water flowing through the helical tube with existing literature. Here, the present experimental data for tube side Nusselt number were validated with the experimental data obtained by Kalb C E et al, Salimpour M R, Jaykumar J S et al, Beigzadeh R et al, and Pawar S S et al. The results of these comparison are shown in figure 2 , it can be seen that the experimental results are admirable agreement with past studies.

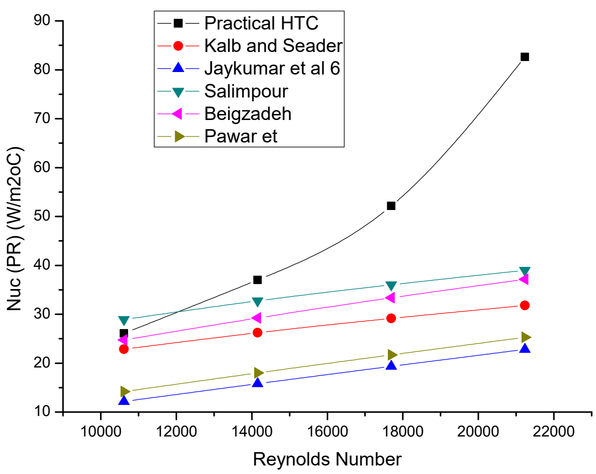


Fig. 2: Variation of Nusselt number with Reynolds number comparing with existing correlations

Here, studies the effect of Reynolds number on Nusselt number and also varying helix diameter observed the effect on heat transfer coefficient by studying the Nusselt Number. The operating conditions are hold constant in shell side at 2 lpm flow rate and inlet temperature 30.5 °C, while the helical tube operating conditions are varied as per mention in table 1. Figure 3 illustrates the effect of helix diameter on helical tube side Nusselt number versus tube side Reynolds number. From Fig 3 it is found that increasing the helix diameter increases the of tube side Nusselt number.

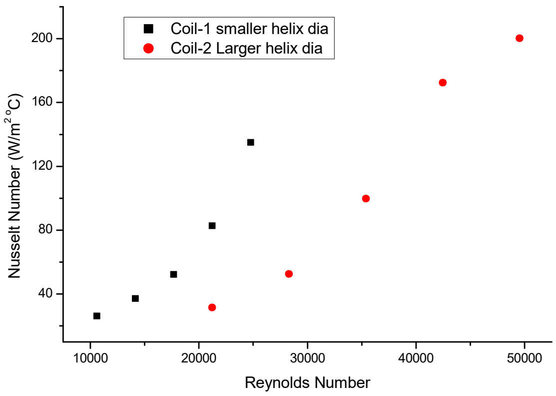


Fig. 3: Comparison Coil-1 and Coil-2 Nusselt number with Reynolds number

CONCLUSION

The present work was carried out to investigate the heat transfer characteristics in shell and coil exchanger inside the helical tube. The effects of helix diameter and Reynolds number were discussed. It is observed that with increasing the tube side Reynolds number increases the Nusselt number. If the helix diameter is increases, while inlet fluid flow rate and other geometrical parameter kept constant, the Nusselt numbers will increases in both coils with Reynolds Number. Also, it observed that the higher Nusselt number was found in small helix diameter coil compare to larger coil. This is because the high turbulence generate in small helix diameter. The Nusselt number increases by 38 % when the helix diameter decreases from 0.120 m to 0.07m

NOMENCLATURE

De	dean number, m
d	tube diameter , m
D	coil diameter, m
H	height, m
h	heat transfer coefficient, W/m^2 °C
k	thermal conductivity, W/m °C
L	coil length, m
Nu	Nusselt number
p	pitch, m
Pr	Prandtl number
Q	heat transfer rate, W

q heat flux, w/m^2
Re Reynolds number
T temperature , ºC

Subscripts

c coil
i inlet
o outlet
sh shell
t tube

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