Experimental and CFD Analysis of Helical Coiled Tube Heat Exchanger

#1M.S.MULE , #2DR.J.A.HOLE

#1P.G. Student, Department of Mechaniacal Engineering,S.P.University,Pune,R.S.C.O.E Pune,Maharashtra,India-411033
#2Department of Mechaniacal Engineering, S.P.University,Pune,R.S.C.O.E Pune,Maharashtra,India-411033

ABSTRACT— Nowadays the importance of heat exchangers is increasing in many areas. Heat exchangers are the important equipments with a variety of industrial applications including power plants, chemical, refrigeration and air conditioning industries. Especially helically coiled heat exchangers are used in order to obtain a large heat transfer area per unit volume. In this study the heat transfer coefficients of shell and helically coiled tube heat exchangers are investigated experimentally. Three heat exchangers with different coil pitches are selected as test section for counter-flow configurations. All the required parameters like inlet and outlet temperatures of tube-side and shell-side fluids, flow rate of fluids, etc. is to be measured using appropriate instruments.

Keywords— Heat exchanger, helical coil, Nussult number, Reynolds number, Overall heat transfer coefficient.

I. INTRODUCTION

Heat recovery is the capture of energy contained in fluids otherwise that would be lost from a facility. Heat sources may include heat pumps, chillers, steam condensate lines, hot flue gases from boiler, hot air associated with kitchen and laundry facilities, exhaust gases of the engines, power-generation equipment. Helical coil Heat exchanger is one of the devices which are used for the heat recovery system. A heat exchanger is a device used to transfer heat between two or more fluids with different temperatures for various application including power plants, nuclear reactors, refrigeration & air condition system, automotive industries, heat recovery system, chemical processing and food industries.

Several studies have indicated that helically coiled tubes are superior to straight tubes when employed in heat transfer applications. The centrifugal force due to the curvature of the tube results in the secondary flow development which enhances the heat transfer rate. This phenomenon can be beneficial especially in laminar flow regime. Helical coils are used for various processes such as heat exchangers because they can accommodate a large heat transfer area in a small space, with high heat transfer coefficient. In the coiled tube, the flow modification is due to centrifugal forces. The centrifugal forces are acting on the moving fluid due to the curvature of the tube results in the development of secondary flow which enhances the heat transfer rate.

[1] Presented a detailed investigation on heat transfer from exhaust particulate air of detergent spray drying tower to water by helical coiled heat exchanger. From the results he found that the tube-side heat transfer coefficients of the coils with smaller pitches are higher than those of larger pitches but the pitches of coiled tubes slightly affect the shell-side heat transfer coefficients The exchanger duty, overall heat transfer coefficient are investigated as function of the tube surface geometry, the flow pattern (parallel and counter) and tube Reynolds number. The result shows that the increasing of the coiled tube pitch decreases the inside Nussult number.

[2]Investigated three heat exchangers with different coil pitches and found that the shell-side heat transfer coefficient of coils with larger pitches is higher than those with smaller pitches for the counter-flow configuration. Also, two correlations were developed to predict the inner heat transfer coefficients and the outer heat transfer coefficients of the coiled tube heat exchanger.

[3] Fabricated experimental setup to study fluid–fluid heat transfer in a helically coiled heat exchanger. Heat transfer characteristics of the heat exchanger with helical coil are also studied using the CFD code FLUENT. The CFD predictions match reasonably well with the experimental results within experimental error limits. Based on the results a correlation was developed to calculate the inner heat transfer coefficient of the helical coil.

[4] Worked on pipe-in-pipe helical coil heat exchanger. He performed work under two different sized specimens. He found that the heat transfer rate in counter flow direction is much higher due to large average temperature. Also the inner Nussult number in both coil configurations in the counter flow direction is higher as compared to the parallel flow.

[5] Carried experimental study of a wire wound tube-in-tube helical coiled heat exchanger considering hot water in the inner tube at various flow rate conditions and with cooling water in the outer tube. The mass flow rates in the inner tube and in the annulus were both varied and the counter-current flow configuration. It was observed that the overall heat transfer coefficient increases with increase in the inner-coiled tube flow rate, for a constant flow rate in the annulus region. It was also observed that when wire coils are compared with a smooth tube, it was also observed that overall heat transfer coefficient is increases with minimum pitch distance of wire coils.
The efficiency of the tube-in-tube helical coil heat exchanger is 15-20% more as compared to the convention heat exchanger and the experimentally calculated efficiency is 93.33%.

From above study I concluded that the helical pipe is having the greater surface area which allows the fluid to be in contact for greater period of time period so that there is an enhanced heat transfer compared to that of straight pipe. The effectiveness of pipes either helical or straight in counter flow is greater than parallel configuration. For the same space or volume in industry the helical coil heat exchangers are more efficient than straight tube heat exchangers. The influencing parameters on effectiveness and overall heat transfer coefficient in the decreasing order are: Cold and hot water flow rates, cold and hot water temperatures and number of turns. The present study deals with analysis of helical coiled tube heat exchangers by using three different coil pitches.

Experimental setup

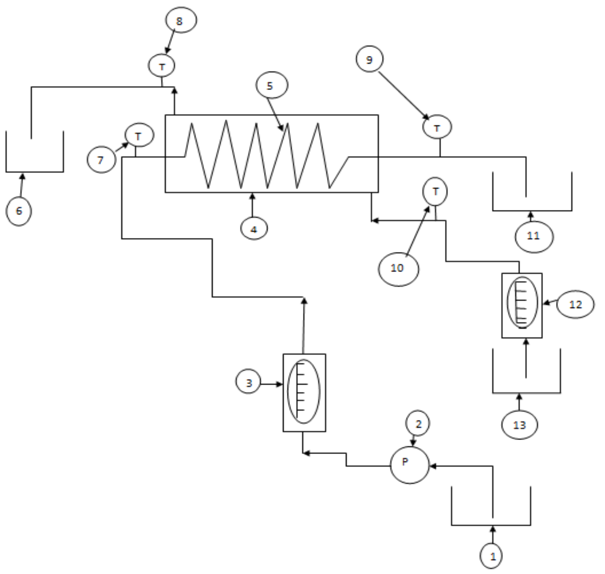

Fig.1 Block diagram of shell and helical coil heat exchanger [6]

1. Hot water storage
2. Centrifugal pump
3. Coil inlet rotameter
4. Shell
5. Helical coil
6. Shell outlet tank
7. Coil inlet thermometer
8. Shell outlet thermometer
9. Coil outlet thermometer
10. Shell inlet thermometer
11. Coil outlet tank
12. Shell inlet rotameter
13. Cold water storage

Fig.2 Experimental Setup for shell and helical coiled tube heat exchanger

The schematic diagram of experimental set-up is shown in Fig.2 the set-up is a well instrumented single-phase heat exchanging system in which a hot water stream flowing inside the tube-side is cooled by a cold water stream flowing in the shell-side. The main parts of the cycle are coiled tube heat exchanger, centrifugal pump, storage tank, and heater. The heat exchangers include a copper coiled tube and an insulated shell. The dimensions of the heat exchangers are depicted in Table. The water of storage tank is heated using an electric heater. Reaching to a prescribed temperature, pump is started to circulate the hot water in the cycle. A ball valve is used to control the flow rate of coolant water and hot water, respectively. To measure the flow rate of the cold stream a rotameter with the accuracy of 2.78 *10^-4 kg/s is installed upstream of the heat exchanger while for the hot stream a measuring pot with the accuracy of 3.3 *10^-3 kg/s is used. The inlet and outlet temperatures of hot and cold water were recorded manually using 4 glass alcohol thermometers inserted in the small holes made in the inlet and outlet tubes of each heat exchanger and sealed to prevent any leakage. Also, all the pipes and connections between the temperature measuring stations and heat exchanger were duly insulated. All the temperatures were measured three times with accuracy of 0.1C in the time steps of 10 min, and the average values were used for further analysis. Appropriate arrangements were provided to measure the pressure loss of both tube-side and shell side streams. All the tube- and shell-side fluids properties were assessed at the mean temperature of the fluids (average of inlet and outlet temperatures).

Material and dimensions of shell and tube

Following table gives the dimensions of the three coils i. e. tubes & shell.

Table 1 Characteristics of helical coil

Sr. No.	Diameter ⇨ parameter ⇩	$\frac{3^{th}}{8}$ (inch)	$\frac{5^{th}}{16}$ (inch)	$\frac{5^{th}}{16}$ (inch)
1	Pitch	24mm	21mm	17mm
2	Length	325mm	310mm	290mm
3	Coil nos.	12	15	15
4	I. D. of tube	8.3mm	7mm	7mm
5	O.D. of tube	9.8mm	8mm	8mm
6	Mean coil diameter	80mm	78mm	78mm

Table 2 Characteristics of shell

Sr. No	**Component**	**Material**
1	helical coil	Copper(k=386 W/mK)
2	Shell	polyvinyl chloride(k=0.027 W/mK)
3	Insulation	Asbestos(k=0.046 W/mK)
4	end cap	polyvinyl chloride
5	FT socket	ultra polyvinyl chloride
6	Packing	Rubber
7	Solution	UPVC

Table 3 Quantity and Specification

Sr. No.	**Description**	**Quantity**
1	Hollow tube(shell)	3nos
2	Diameter of shell	100mm
3	Length of shell	2ft
4	End cap	6 nos.
5	Diameter of end cap	110mm
6	Thickness of shell	2mm
7	Thickness of end cap	5mm
8	FT socket	6 nos.
9	Packing	6 nos.
10	Solution tube	3 nos.
11	Insulation rope	3 nos.

Method

The helical coiled tubes with circular described above were used for conducting the experiment. The experiments were carried out in a counter-flow configuration. The normal water is heated by heater with capacity 3 kW where the temperature of hot water is controlled by thermostatic controller. The hot water flows through the helical coil which cooled by cold water circulated inside the shell. Heat recovered from the hot water by passing the water through the coiled tube. The hot water flow rate and cold water flow rate were controlled by flow control valve. The flow rate of hot water and cold water is measured by rotameter respectively. In this work, the flow rate of the cold water inside shell and the inlet temperature of the hot water were kept constant. The mass flow rate hot water varies from 20 to 40 LPH on coil tube side by keeping the constant flow rate of cold water through the shell. The range operating parameters are given in Table below.

Table 4 Range of operating parameters

Sr. No.	Parameters	Range
1	Tube side water flow rate	20-40 LPH
2	Shell side water flow rate	10-42 LPH
3	Tube inlet temperature	40-51 ^{O}C
4	Tube outlet temperature	36-48 ^{O}C
5	Shell inlet temperature	Room temperature °C
6	Shell outlet temperature	33-44 ^{O}C

After reach set temperature, pump was started and starts to circulate hot water from tube side. The temperature data recorded for every 10 min. this data was taken after temperature is stabilized. The input – output temperature of flowing fluid measured with varying mass flow rate in tube and shell-side. The shell side and tube side inlet-outlet temperatures measured with alcohol glass thermometer. The title of the figure is to be placed below the figures as shown.

Several assumptions were made, while determining the performance of the helical coils-

Assumption:

- Roughness of inner surface of tube is low
- Tube side fouling factor is negligible
- The heat losses to or from the surroundings are negligible
- Pressure losses in end connector are neglected

Available data:

- Tube side inlet temperature of hot water.
- Tube side outlet temperature of hot water.
- Shell side inlet temperature of water.
- Shell side outlet temperature of water
- Tube side mass flow rates of hot water.
- Shell side mass flow rates of water.

Assume standard sizes of the diameters

The above input output temperatures data taken for various mass flow rates from test setup. In result table overall heat transfer coefficient, friction factor and heat transfer rates calculated. The collected data is processed, analyzed and presented versus Reynolds number, and mass flow rate. Data were collected for the laminar flow region up to 2000 Reynolds number. The data were collected for various flow rate of water for the calculation.

Results

Thermal performance of the helical coiled tube

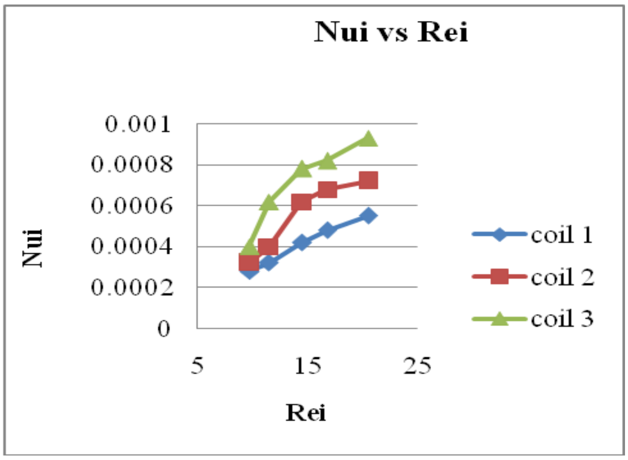

Fig.3 coil side Nussult No. vs coil side Reynolds No.

The graph Nussult number vs Reynolds number shows heat transfer rate for different coils. The value of Nussult number and Reynolds number are the average values of all readings for different flow rates. The graph shows as pitch of the helical coil varies heat transfer rate also varies and also shows maximum heat transfer rate occurs for maximum pitch. The Nussult number increases with increase in Reynolds number and pitch of the coil.

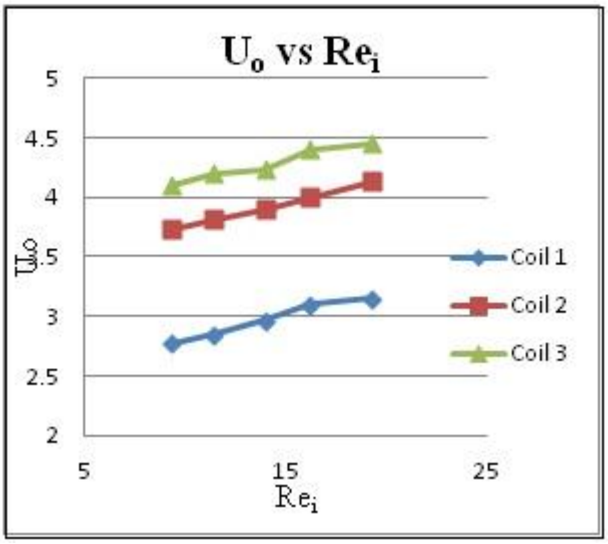

Fig.4 Overall heat transfer vs Reynolds number

The graph overall heat transfer coefficient vs Reynolds number shows heat transfer rate for different coils. The value of heat transfer coefficient and Reynolds number are the average values of all readings for different flow rates. The graph shows as pitch of the helical coil varies heat transfer rate also varies and also shows maximum heat transfer rate occurs for maximum pitch.

The heat transfer coefficient increases with increase in Reynolds number and pitch of the coil.

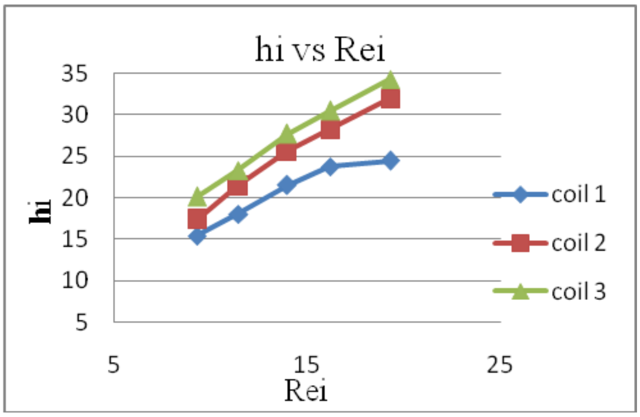

Fig.5 inside heat transfer coefficient vs inside Reynolds No.

The graph heat transfer coefficient of inner side of the tube vs. Reynolds number shows heat transfer rate for different coils. The value of heat transfer coefficient of inner side of the tube and Reynolds number are the average values of all readings for different flow rates. The graph shows as pitch of the helical coil varies heat transfer rate also varies and also shows maximum heat transfer rate occurs for maximum pitch.

The heat transfer coefficient of inner side of the tube increases with increase in Reynolds number and pitch of the coil.

II. CONCLUSION

In this work, heat transfer from the hot water to cold water by using helical coiled tubes by varying the pitch of the coils are investigated experimentally for the heat recovery system.

1. From the figure 4 it is clear that the overall heat-transfer coefficient increases with increase in the coil side Reynolds number for a constant flow rate inside the shell.
2. From the figure 5 it is clear that the tube side heat transfer coefficients of the greater pitch shows higher value of heat transfer coefficient.

III. REFERENCES

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