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# Experimental Investigation of Performance of Pipe in Pipe Helically Coil Heat Exchanger

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## ABSTRACT

**Enhancing the heat transfer by the use of helical coils has been studied and researched by many researchers, because the fluid dynamics inside the pipes of a helical coil heat exchanger offer certain advantages over the straight tubes, shell and tube type heat exchanger, in terms of better heat transfer and mass transfer coefficients. This configuration offers a high compact structure and a high overall heat transfer coefficient; hence helical coil heat exchangers are widely used in industrial applications. Convective heat transfer between a surface and the surrounding fluid in a heat exchanger has been a major issue and a topic of study in the recent years. In this particular study, an attempt has been made to experimental work of various parameters like radius of tubes, pitch of coil, pitch circle diameter, number of turns of helical coil, flow rate and temperature that affect the effectiveness of a heat exchanger and increases heat transfer rate at two different flows (parallel and counter-flow) on the total heat transfer from a helical tube, where the cold fluid flows in the outer pipe and the hot fluid flowing in the inner pipes of the pipe in pipe helical coiled heat exchanger. Copper was chosen as the as metal for the construction of the helical tube.**

***Keywords*— helical coil heat exchangers, Parallel flow and Counter flow, coil configuration.**

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## I. INTRODUCTION

Heat exchangers serve a straight forward purpose controlling a system's or substance's temperature by adding or removing thermal energy. Although there are many different sizes, levels of sophistication, and types of heat exchangers, they all use a thermally conducting element usually in the form of a tube or plate to separate two fluids such that one can transfer thermal energy to the other. Many industrial applications use small heat exchangers to establish or maintain a required temperature. In industry, heat exchangers perform many tasks, ranging from cooling lasers to establishing a controlled sample temperature prior to chromatography. Helical coils are very alluring for various processes such as heat exchangers and reactors because they can accommodate a large heat transfer area in a small space, with high heat transfer coefficients and narrow residence time distributions.

The several studies have indicated the helical 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. Typically, fluid in the core of the tube moves towards the outer wall, then returns to the inner portion of tube by flowing back along the wall, as shown in figure-1.

The fluid motion in curved pipes was first observed by Eustice in 1911. Since then numerous studies have been reported on the flow fields that arise in curved pipes (Dean, 1927, 1928; White, 1929; Hawthorne, 1951; Horlock, 1956; Barua, 1962; Austin and Seader, 1973) including helical coils, which is a subset of curved pipes. The flow fields have been observed experimentally and numerically.

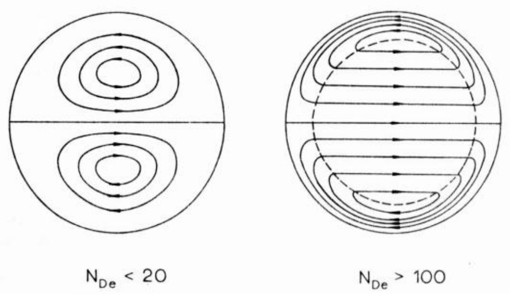


Figure-1: Secondary flow for low and high Dean Numbers

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J.S. Jaya kumar et. al. [1] has analyzed to experimental and cfd estimation of heat transfer in helically coiled heat exchangers. Heat transfer characteristics inside a helical coil for various boundary conditions are compared. Performance of the residual heat removal system, which uses a helically coiled heat exchanger, for various process parameters was investigated by Jaya kumar and Grover. They found that the specification of a constant temperature or constant heat flux boundary condition for an actual heat exchanger. Pramod S. Purandarea et.al.[2] has also studies the various parameters of helical coil heat exchanger for the range of *Re* between 2000 to 4500. Rahul Kharat et. al.[3] has studies the heat transfer coefficient correlation of helical coil heat exchanger. The correlation used in his paper simulates coil gap tube diameter. Timothy J. Rennie et. al. [4] has obtained experimental results for estimation of the overall heat transfer coefficient correlation for two differently sized heat exchanger and flow configuration.

Most studies on helical tube have been carried out on the heat transfer characteristic of coil configuration and flow configuration. As lot of variations are possible in coil geometry, it requires a lot of experimental data to capture the effect of different physical parameters like coil diameter, pitch, pitch circle diameter, tube diameter etc. The several studies have been indicated that helical coiled tubes are superior to straight tubes when employed in heat transfer applications. A comparative study of heat transfer by considering experimental data of variations of flow rate in inner pipe and annulus at constant temperature of hot fluid and cold fluid at inlet conditions

## II. EXPERIMENTAL SPECIFICATION DETAILS

The geometry of the helical pipe or coil of Experimental Setup is shown in fig.2. The experimental study is done on a pipe in pipe helical coil heat exchanger having the specification as listed below: Inner pipe ID = 6 mm; Inner pipe OD = 8 mm; Outer pipe ID = 12 mm; Outer pipe OD = 14 mm; Material of construction = Copper; Heat transfer length = 2000 mm; Curvature Diameter = 170 mm; Insulation thickness = 4 mm.

Figure- 2 Experimental setup

The basic heat exchanger is hooked up to both hot and cold water flows in parallel as well as counter flow mode. The cold water flow is an open circuit while the hot water flow is a closed circuit. The tank with electrical heater is provided to heat the water to be circulated through the inner tube.

There are three heaters, with a total power of 500W. A controller is provided to maintain the temperature of water at the inlet of the test section. The hot fluid from the tank is pumped through the test section using the centrifugal pump of ½ hp power rating. Flow rate of hot and cold water is measured using electromagnetic flow meter. Both inlet and outlet temperature of the hot and cold water are measured by using RTDs and the values are available on digital displays.

## III EXPERIMENTAL PROCEDURE

Measurements are taken only after the temperatures attain steady values. Experiments are conducted for five different flow rates through the coil and for three different values of temperature at inlet of the inner helical pipe. During the course of each set of experiments, the flow rate through the annulus side is kept constant. The experiments are carried out by changing the flow rate through the tube. Once a steady state is attained, the values of flow rates of the hot and cold fluids, temperature at the inlet and outlet of the hot and cold fluid, and the power input to the heater and pump are noted. The following relations are used for calculating the experimental results and they are;

Cross sectional area, $\mathbf{A_o} = (\boldsymbol{\pi} \mathbf{d_o})\ \mathbf{x}\ (\boldsymbol{\pi}\ \mathbf{D_h})\ \mathbf{x}\ \mathbf{n}$

Heat transfer, $Q = (m_f \text{ x } C_p \text{ x } \Delta T)$

Heat transfer, $Q = (\mathbf{U\ x\ A_o\ x\ T_{LMTD}})$

LMTD for Parallel flow $\Delta T = \dfrac{(\mathbf{Th_i - Tc_i}) - (\mathbf{Th_o - Tc_o})}{\mathbf{ln}\frac{(\mathbf{Th_i - Tc_i})}{(\mathbf{Th_o - Tc_o})}}$

LMTD for counter flow $\Delta T = \dfrac{(Th_i - Tc_o) - (Th_o - Tc_i)}{\ln\frac{(Th_i - Tc_o)}{(Th_o - Tc_i)}}$

Dean Number $De = Re\sqrt{\frac{d_i}{Dc}}$

| Results of heat exchanger at fixed inlet temperature of hot water @ 40°C | | | | | |
|---|---|---|---|---|---|
| m(c)L PH | m(h)L PH | LMTD(°C) | Q(KW) | U(KW/m² K) | ε |
| 100 | 100 | 3.91 | 0.59 | 3.34 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | .4 |
| 100 | 200 | 4.17 | 0.94 | 5.35 | 0.54 |
| 100 | 300 | 3.91 | 1.05 | 5.99 | 0.6 |
| 100 | 400 | 3.91 | 0.94 | 5.35 | 0.7 |
| 100 | 500 | 5.81 | 1.79 | 6.79 | 0.4 |
| Results of heat exchanger at fixed inlet temperature of hot water @ 50°C | | | | | |
| 100 | 100 | 5.65 | 1.06 | 4.18 | 0.41 |
| 100 | 200 | 7.28 | 1.41 | 4.31 | 0.55 |
| 100 | 300 | 7.51 | 1.88 | 5.19 | 0.63 |
| 100 | 400 | 7.81 | 1.76 | 5.36 | 0.7 |
| 100 | 500 | 7.81 | 2.93 | 8.37 | 0.65 |
| Results of heat exchanger at fixed inlet temperature of hot water @ 60°C | | | | | |
| 100 | 100 | 9.82 | 1.88 | 4.26 | 0.35 |
| 100 | 200 | 12.25 | 3.05 | 5.55 | 0.5 |
| 100 | 300 | 12.25 | 4.92 | 8.96 | 0.47 |
| 100 | 400 | 14.25 | 7.03 | 11 | 0.35 |
| 100 | 500 | 14.25 | 8.79 | 13.76 | 0.36 |

**Table 1** Results of helical coil heat exchanger in Parallel flow condition

Table 1 presents the results for the parallel flow whereas Table 2 presents the results for counter flow.

| Results of heat exchanger at fixed inlet temperature of hot water @ 40°C | | | | | |
|---|---|---|---|---|---|
| m(c)LPH | m (h) LPH | LMTD(°C) | Q(KW) | U(KW/m²K | Ɛ |
| 100 | 100 | 4.48 | 0.7 | 3.5 | 0.5 |
| 100 | 200 | 4.48 | 1.64 | 8.16 | 0.54 |
| 100 | 300 | 4.48 | 2.64 | 12.25 | 0.5 |
| 100 | 400 | 4.48 | 2.34 | 11.65 | 0.6 |
| 100 | 500 | 3.92 | 2.93 | 16.66 | 0.7 |
| Results of heat exchanger at fixed inlet temperature of hot water @ 50°C | | | | | |
| 100 | 100 | 8.25 | 1.64 | 4.44 | 0.45 |
| 100 | 200 | 7.4 | 2.34 | 7.05 | 0.68 |
| 100 | 300 | 8.49 | 3.87 | 10.17 | 0.63 |
| 100 | 400 | 8.49 | 5.63 | 14.79 | 0.53 |
| 100 | 500 | 9.49 | 6.45 | 15.29 | 0.55 |
| Results of heat exchanger at fixed inlet temperature of hot water @ 60°C | | | | | |
| 100 | 100 | 9.86 | 1.88 | 4.22 | 0.71 |
| 100 | 200 | 13.97 | 4.22 | 6.73 | 0.51 |
| 100 | 300 | 13.9 | 6.68 | 10.72 | 0.48 |
| 100 | 400 | 13.78 | 9.38 | 15.2 | 0.45 |
| 100 | 500 | 13.44 | 11.13 | 18.42 | 0.52 |

**Table 2** Results of helical coil heat exchanger in Counter flow condition

Graphs have been generated based data presented in Table 1 and Table 2 to illustrate the experimental results.

## III.RESULT & DISCUSSION

Fig.3 presents the relation between mass flow rate of hot water and heat loss from cold from hot flow in parallelflow whereas Fig.4 presents counter flow for all variations. It is observed from the fig. 3 is that the pipe in pipe helical coil heat exchanger at 60°C temperature has highest heat loss from cold flow followed by heat exchanger another temp-erature at 50°C and heat exchanger at 40°C. The amount of heat loss also increases with increases in mass flow rate of hot water.

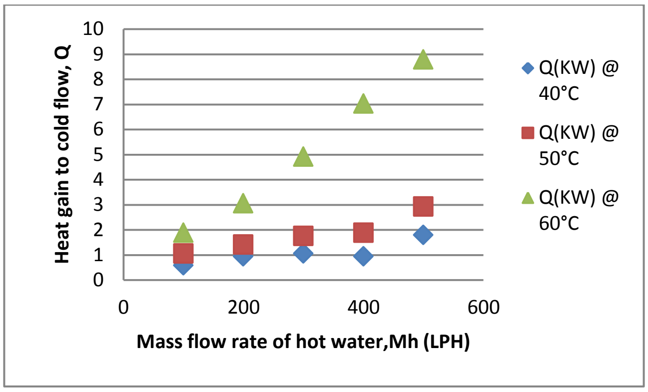


Fig. 3 Parallel flows ($M_h$ vs Q)

Fig.4 in case of counter flow it is observed that the pipe in pipe helical coil heat exchanger heat exchanger at 60°C temperature has highest heat loss from cold flow followed by

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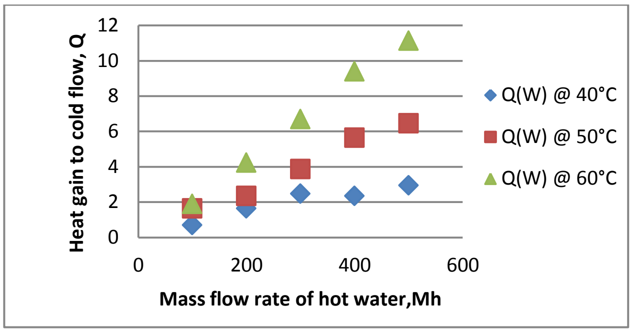


Fig. 4 Counter flow ($M_h$ vs Q)

heat exchanger another temperature at 50°C and heat exch-anger at 40°C. The amount of heat loss also increases in counter flow and heat loss found are increasing with increases in mass flow rate of hot water

Fig.5 shows the relation between mass flow rate of hot water and overall heat transfer coefficient in parallel flow whereas Fig.6 presents counter flow for all variations. From the fig.5 in case of parallel flow, it is observed that the pipe in pipe helical coil heat exchanger at 60°C temperature has highest overall heat transfer coefficient followed by heat exchanger another temperature at 50°C and heat exchanger at 40°C. The overall heat transfer coefficient also increases with increases in mass flow rate of hot water.

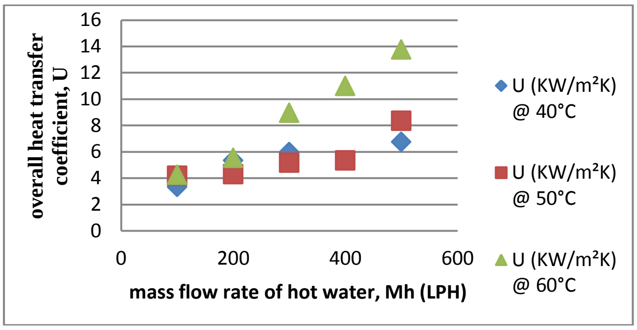


Fig. 5 Parallel flows ($M_{\square}$ vs U)

Fig.6 indicates the results of counter flow and it observed that the pipe in pipe helical coil heat exchanger at 60°C temperature has highest overall heat transfer coefficient
followed by heat exchanger another temperature at 50°C and
heat exchanger at 40°C. The overall heat transfer coefficient also increases with increases in mass flow rate of hot water.

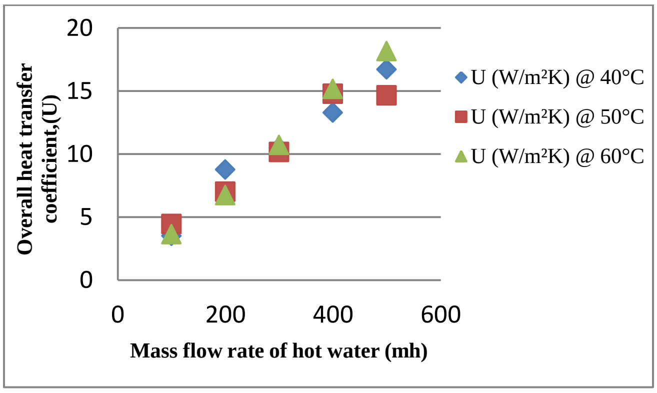


Fig. 6 Counter flows ($M_{\square}$ vs U)

Fig.7 shows the comparisons between Dean Number and overall heat transfer coefficient in parallel flow at three different temperatures. From the fig.7 in case of parallel flow, it is observed that the pipe in pipe helical coil heat exchanger at 60°C temperature has overall heat transfer coefficient is high at high Dean number. From figure 3.5 at same Dean Number the value of overall heat transfer coefficient is high at 60°C temperature as compare to 40°C temperature and 50°C temperature of the hot water flow rate.

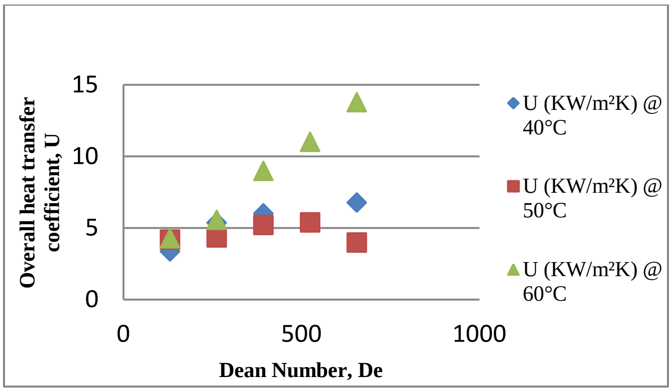


Fig. 7 Comparison of Overall heat transfer coefficient in Parallel flows

Fig.8 shows the comparisons between Dean Number and Overall heat transfer coefficient in counter flow at three different temperatures. From figure 8, the effect of overall heat transfer coefficient is very less as compared to parallel flow conditions.

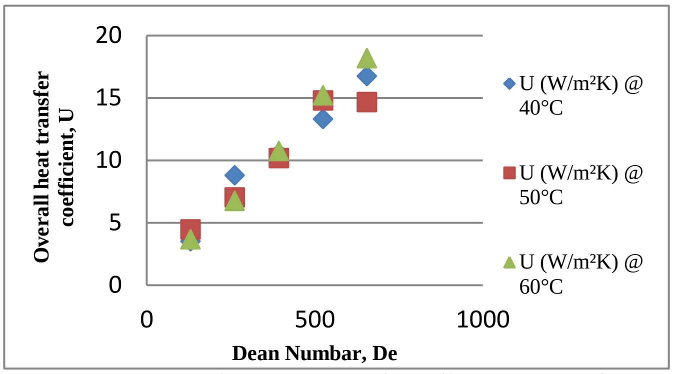


Fig. 8 Comparison of Overall heat transfer coefficient in Parallel flows

## V.CONCLUSION

Various heat enhancement techniques are identified for pipe in pipe helical coil heat exchanger. Based on results obtained by conducting the experiments on helical coil (parallel and counter flow), the following are the conclusions drawn:

- The helical pipe is having the greater surface area which allows the fluid to be contact for greater period of time.
- The inside overall heat transfer coefficient for helical pipe in counter flow conditions is approximately 58 % more from the parallel flow condition.
- The effectiveness of the pipes is higher in counter flow condition.
- The overall heat transfer coefficient and heat transfer rate increases with maximum amount of hot water flow rate at 60°C temperature.
- At high mass flow rate and high temperature Dean Number affect the overall heat transfer coefficient.


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