

CFD ANALYSIS AND EFFECT OF PROCESS PARAMETERS ON TUBE IN TUBE HELICAL COIL HEAT EXCHANGER

Umesh Kumar Sen¹, Sanjeev Yadav²

¹Student, ²Assistant Professor

^{1,2}Technocrats Institute of Technology, Bhopal (M.P.)

ABSTRACT: Heat exchangers are utilized to transfer heat from the high temperature to the lower temperature. Whereas the helical coil tube in tube heat exchanger utilized to transfer heat in between two fluid at different temperature. Here in this work tube in tube helical coil heat exchanger is considered for the analysis. Here in this analysis hot fluid that is water is moving in the outer tube of the helical coil whereas the cold fluid water is flowing in the inner tube of the helical coil heat exchanger. Here we have analyzed the heat transfer at different mass flow rate of hot fluid and cold fluid. In order to analyze the effect of change in mass flow rate of hot fluid here we have picked up the three different mass flow rate of hot fluid while making the mass flow rate of cold fluid constant. After that to analyzed the influence of change in mass flow rate of cold fluid here we have considered the four different mass flow rate of cold fluid keeping the mass flow rate of hot fluid constant. To maximize the heat transfer rate here we have used the different variety of baffles inside the helical coil to maximize the heat transfer rate. To calculate the influencing of different geometry of baffles on the heat transfer here we have considered the two variated types of baffles that is semi-elliptical and rectangular shape. Through analysis it is found that the semi-elliptical shape baffle shows better result with respect to the other baffles. There we have calculated the heat transfer rate for each mass flow rate of cold and hot fluid, we have also calculated the logarithmic mean temperature difference for each case. Here we have also calculated the outcomes of friction factor for different baffles case.

1. Introduction

They are comprehensively utilized in space heating, refrigeration and air conditioning, power stations, chemical plants, petrochemical plants, petroleum refineries, natural gas processing, and sewage treatment. The standard specimen of a heat exchanger is obtained in an internal combustion engine where a circulating fluid identified as engine coolant moving in radiator coils and air moving from past the coils that cools the coolant and then heats the inbound air. Another illustration is the heat sink, having a passive heat exchanger that transmission the heat generated with an electronic or a mechanical means to a fluid medium, frequently air as well as liquid coolant. In heat exchangers, there are generally no external heat as well as work interactions.

In heat exchanger different input parameters were optimized to enhance the heat transfer rate. Now in this work tube in tube helical coil heat exchanger is analyzed. At this point hot water is moving in the outer pipe whereas cold fluid is moving in the inner tube of helical coil heat exchanger. Here in this work various kind of baffles are analyzed inside the tube, triangular and rectangular type baffles were used to analyze the heat transfer. We have also analyzed the consequence of altered mass flow rate of hot water and cold fluid. For finding the influence of mass flow rate change, the hot water here have taken the three distinguished mass flow rate that is 0.14, 0.168 and 0.196 kg/s and for analyzing the effect of those altered mass flow rate of cold fluid, we have taking into account for four dissimilar mass flow rate of that is 0.084, 0.112, 0.14 and 0.168 kg/s. the complete CFD analysis of tube in tube helical coil heat exchanger is shown in the below section. Here in this analysis hot and cold fluid is moving in the same direction that is the flow arrangement is parallel flow.

2. Solid model

The solid model of helical coil heat exchanger is developing on the fundamental of dimension given in the base paper. Reddy et.al performed the experimental analysis on tube in tube helical coil heat exchanger. Based on the geometric condition taken during the experimental analysis solid model were develop, the geometric condition used to develop the solid model is shown in the below table

Table. 1 Showing the geometric dimension of helical coil heat exchanger

Parameter	Value
Outer tube outer diameter	0.0508 m
Outer tube inner diameter	0.0484
Inner tube outer diameter	0.0254
Inner tube inner diameter	0.023
Pitch	0.1 m
Coil diameter	0.762 m
Inner curvature ratio	0.1737
Outer curvature ration	0.1737

Based on the above geometry solid model of the tube in tube helical coil heat exchanger is develop. The solid model of the helical coil heat exchanger is shown in the below figure.

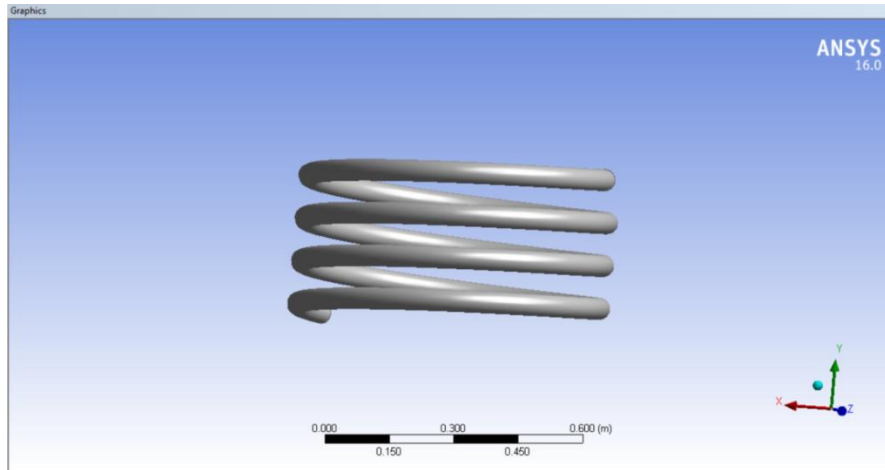


Fig. 1 showing the solid model of tube in tube helical coil heat exchanger

3. Meshing

In order to perform the numerical analysis, the solid model of the helical coil heat exchanger is discretize in to number of small component. Here the complete body of the tube in tube helical coil heat exchanger is discretizing in to number of components and nodes.

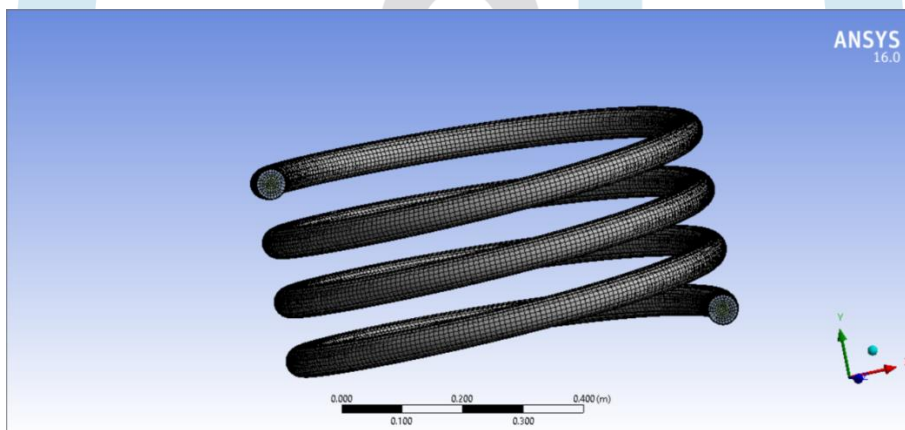


Fig. 2 showing the mesh of tube in tube helical coil heat exchanger

4. Selection of model

Different models were used to analyze the helical coil heat exchanger. During the analysis different model is utilized to verify out the temperature of water at the exit of helical coil heat exchanger and on the basis of this temperature we calculate the heat transfer coefficient and select the best suitable case for the analysis.

5. Selection of materials

Here in this analysis water is used as a fluid and aluminium is used to manufacture tube and fins. The properties of water and aluminium used in this work is shown in the below table.

Table.2 Showing the properties of aluminium

Properties	Value
Density (kg/m ³)	2719
Specific heat (J/kg-K)	871
Thermal conductivity (W/m-K)	202.4

Here in this work water is used as a hot and cold fluid in the helical coil heat exchanger. The hot water is moving in the outer tube whereas cold water is flowing in the inner tube. The properties of water is shown in the below table.

Table.3 Showing the properties of water

Properties	Value
Density (kg/m ³)	998.2
Specific heat (J/kg-K)	4182
Thermal conductivity (W/m-K)	0.6
Viscosity (kg/m-s)	0.001003

6. Result

Here first we analyzed the helical coil heat exchanger without baffles as experimentally analyzed by Reddy et.al. Here we find the temperature of hot and cold water at the exit of heat exchanger for changed mass flow rate of hot and cold water. Based on temperature we compute the importance of logarithmic mean temperature difference (LMTD) at various mass flow rate for inner and outer flow and then it is compare with the value of LMTD getting from the base paper and validate the CFD model of tube in tube helical coil heat exchanger. After validating the CFD model we find out the effect of different types of baffles used inside the tube to increase the heat transfer. Here we have taken the two different types of baffles that is rectangular and semi-elliptical and finding the temperature at the exit for different mass flow rate of hot and cold fluid. During the analysis, hot water at inlet is at 350 K, whereas cold fluid at the inlet is near about 298 K.

6.1 Section 1- Change in mass flow rate of hot fluid, keeping the mass flow rate of cold fluid constant

6.1.1 Case 1- For hot fluid of mass flow rate 0.14 kg/s

Here in this case the mass flow of hot fluid is 0.14 kg/s whereas the mass flow rate of cold fluid is remain constant that is 0.084 kg/s. the temperature contours for this case is shown in the below figure.

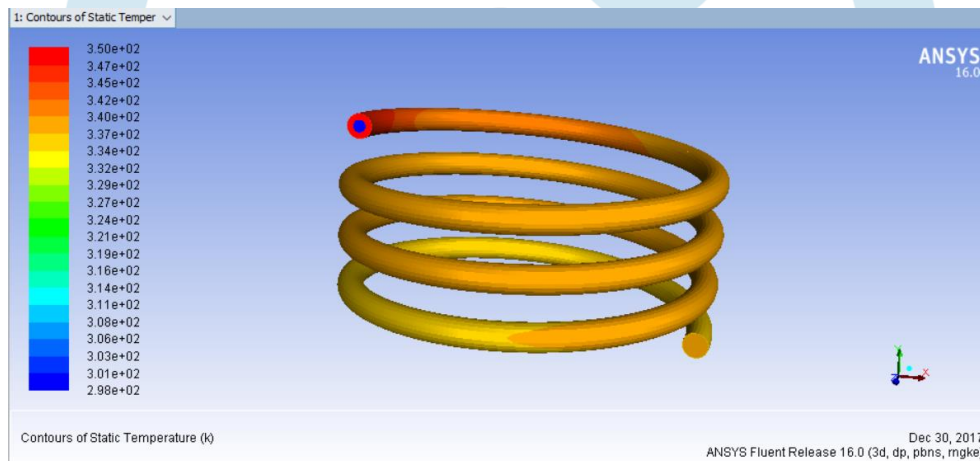


Fig.3 showing the contours of temperature for case 1

From the above fig., it shows that the temperature of hot water at the exit is about 339 K.

6.1.2 Case 2- For hot fluid of mass flow rate 0.168 kg/s

Here in this case the mass flow rate of hot water is 0.168 kg/s, whereas the mass flow rate of cold water will remain constant that is 0.084 kg/s. the temperature contours for this case shown in the fig. below

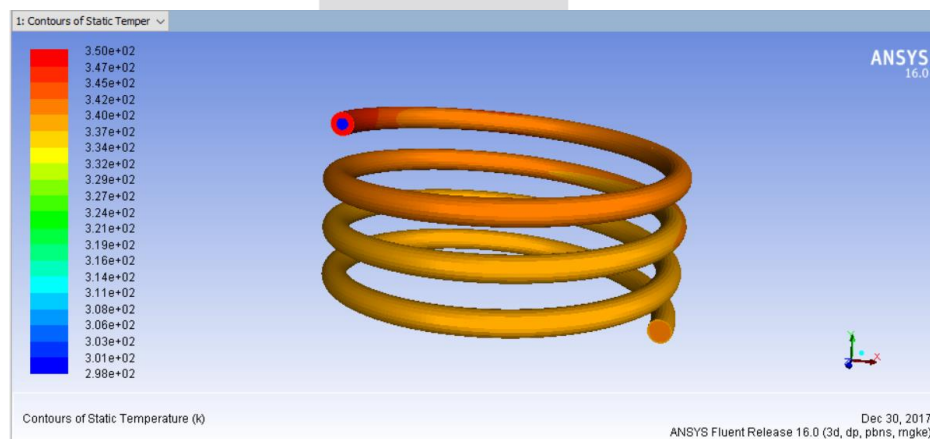


Fig.4 showing the temperature contours for case 2

From the above analysis it is found that the temperature of hot water at the exit of heat exchanger is about 340 K. likewise the above analysis here we calculate temperature of hot water at exit for mass flow rate 0.196 kg/s, where keeping the mass flow rate of cold water is constant as 0.084 kg/s. The temperature of hot water inlet and outlet for different mass flow rate of hot water shown in the below fig.

Table. 4 Showing the value of temperature for different mass flow rate of hot fluid

Mass flow rate (kg/s)	Temperature (k)
0.14	339
0.168	340
0.196	341.5

From the table it is found that the temperature of hot water at exit is increasing with the increase in mass flow rate of hot fluid, means it shows that as the mass flow rate of hot fluid increases the temperature of hot water at the exit get increases. With the help of temperature of hot and cold fluid here, we have calculated the logarithmic mean temperature difference (LMTD). In order to calculate the value of LMTD following formula where used

$$LMTD = \frac{\theta_1 - \theta_2}{\ln\left(\frac{\theta_1}{\theta_2}\right)} \tag{1}$$

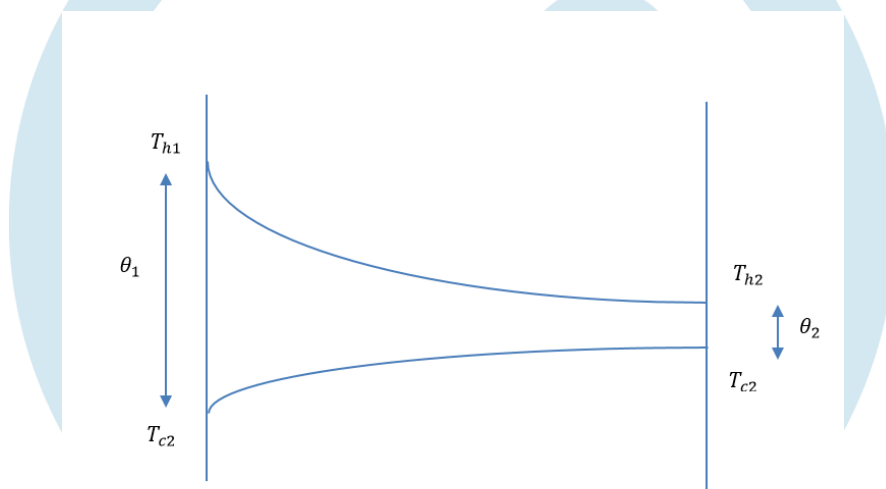


Fig. 5 showing the flow pattern of heat exchanger

Where T_{h1} the temperature of hot water inlet is, T_{h2} is the temperature of hot water outlet, T_{c1} is the temperature of cold fluid at inlet and T_{c2} is the temperature of cold fluid at outlet.

Where,

$$\theta_1 = T_{h1} - T_{c1} \tag{2}$$

$$\theta_2 = T_{h2} - T_{c2} \tag{3}$$

With the help of above formulas, we calculate the value of LMTD for different mass flow rate of hot water. The value of LMTD for different mass flow rate of hot fluid is shown in the below table.

Table. 5 Showing the comparison of value of LMTD calculate from CFD and in base paper

Mass flow rate (kg/s)	LMTD calculated from CFD analysis	LMTD calculated from base paper	Error %
0.14	12.7	12.3	3.2
0.168	12.1	11.8	2.5
0.196	11.9	11.5	3.4

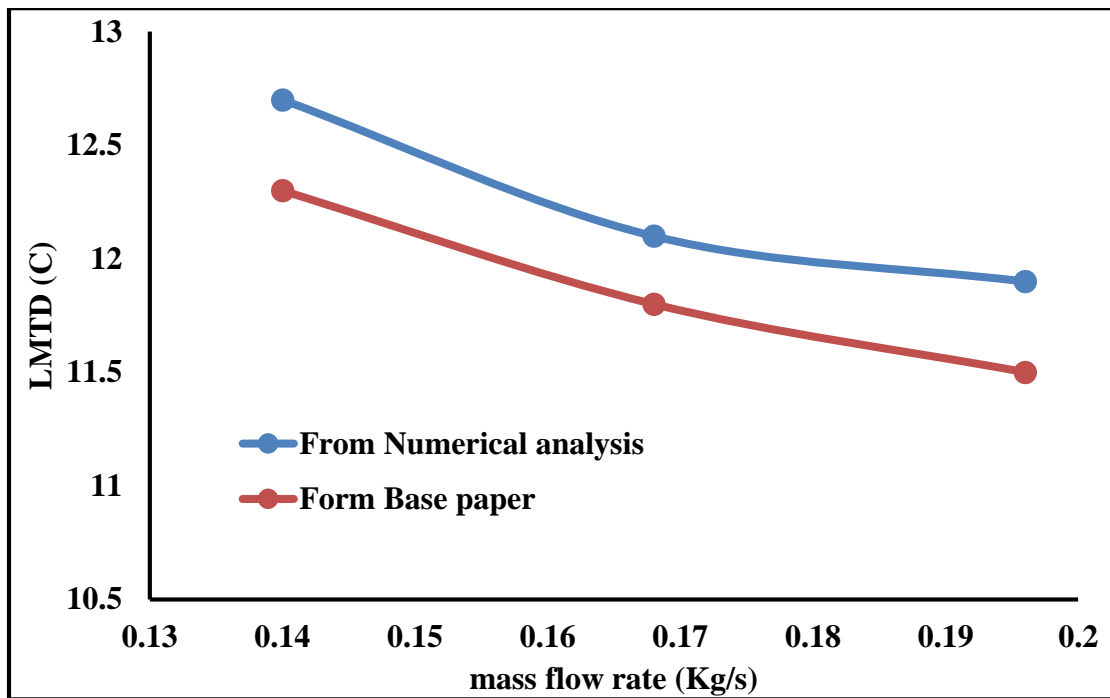


Fig.6 showing the comparison of LMTD values

After comparison, it is found that the value of LMTD value obtained from the CFD is close to the value of LMTD given in the base paper so the above CFD analysis is correct. With the help of value of temperature at the exit, heat transfer rate is calculated. Heat transfer rate is calculated with the help of following given formula

$$q = \dot{m}C\Delta T \tag{4}$$

Where q is the heat transfer rate, \dot{m} is the mass flow rate of hot fluid, C is the specific heat of water and ΔT is the temperature difference in between the inlet and outlet of hot fluid. With the help of eq. 4 we have calculated the heat transfer rate from the hot fluid.

With the help of heat transfer rate and LMTD here we can calculate the value of overall heat transfer coefficient (U), following relation used to calculate the overall heat transfer coefficient

$$q = UA(LMTD) \tag{5}$$

Where q is the heat transfer rate, U is the overall heat transfer coefficient; LMTD is the logarithmic mean temperature difference. With the help of eq. 5 value of U is calculated, the value of U for different mass flow rate is mentioned in the below table.

Table. 6 showing the values of overall heat transfer coefficient

Mass flow rate of hot fluid (kg/s)	Heat transfer rate (Watt)	Overall heat transfer coefficient (W/m ² K)
0.14	7124	506.85
0.168	7022	580.33
0.196	6437	598.65

From the above table it is obtained that as the mass flow rate of hot fluid increases the heat transfer and overall heat transfer coefficient get increased.

6.2 Section 2- Change in mass flow rate of cold fluid, keeping the mass flow rate of hot fluid constant

After analyzing the outcome of variation in mass flow rate of hot fluid while making the mass flow rate of cold fluid constant. Here we are also analyzing the influence of alteration in mass flow rate of cold fluid while making the mass flow rate of hot fluid constant that is 0.14 kg/s. for analyzing the effect of change in mass flow rate of cold fluid here we have considered the four different mass flow rate of cold fluid that is 0.084, 0.112, 0.14, 0.168 kg/s.

6.2.1 Case-1. For cold fluid of mass flowrate 0.084 kg/s

0.084 mass flow rate of cold fluid we have already analyze in the above section.

6.2.2 Case-2. For cold fluid of mass flow rate 0.0112 kg/s

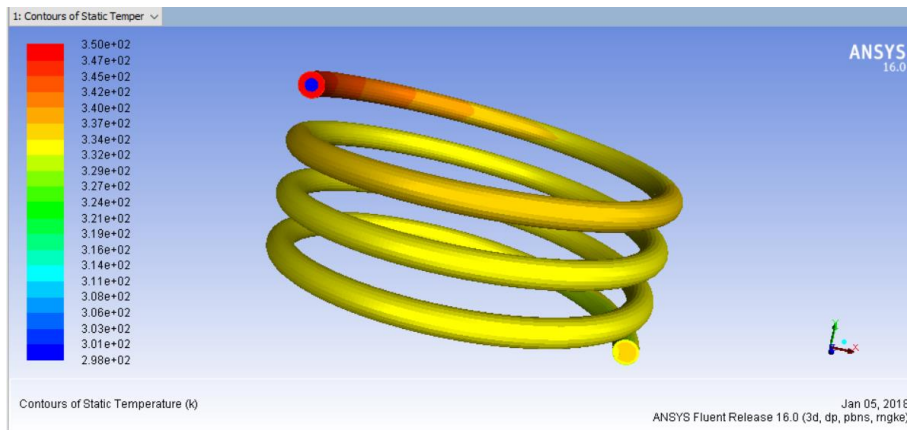


Fig.7 showing the contours of temperature for mass flow rate 0.0112

From the above analysis, the temperature of water at the exit of helical coil heat exchanger is 337

After calculating the value of LMTD for different mass flow rate of cold fluid numerically, it is then compared with the LMTD values calculated in the base paper. The comparison of numerical and base paper values are shown in the table below

Table. 7 Shows the comparison

S. No	Mass flow rate of cold fluid (kg/s)	LMTD (C) through CFD analysis	LMTD through (C) Base paper	Error %
1	0.084	13.2	12.5	5.6
2	0.112	15.5	14	10.71
3	0.14	16.2	15	8
4	0.168	17.1	15.6	9.6

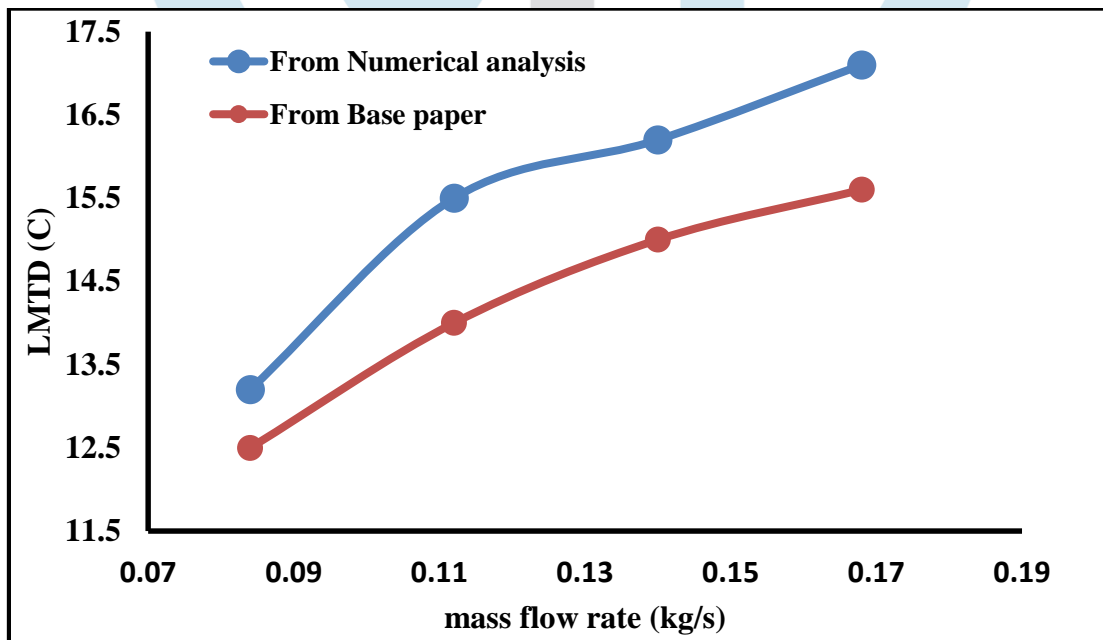


Fig. 8 showing the comparison of LMTD values

From the above graph it is found the value of LMTD for different mass flow rate of cold fluid is near about to the value of LMTD obtained in the base paper, so it is analyzed that the numerical model of tube in tube helical coil heat exchanger is correct. From eq. 4 here we have calculated the value of heat transfer rate.

7. Comparison of different parameters for different cases

In order to find out the optimum design of tube in tube helical coil heat exchanger, here we have compared the heat transfer rate, temperature of hot fluid at the exit and the logarithmic mean temperature difference. All these parameters were find out for change

in mass flow rate of cold fluid as well as change in mass flow rate of hot fluid. The comparison graph for different parameters where shown in the below fig.

7.1 For change in mass flow rate of cold fluid while keeping the mass flow rate of hot fluid constant

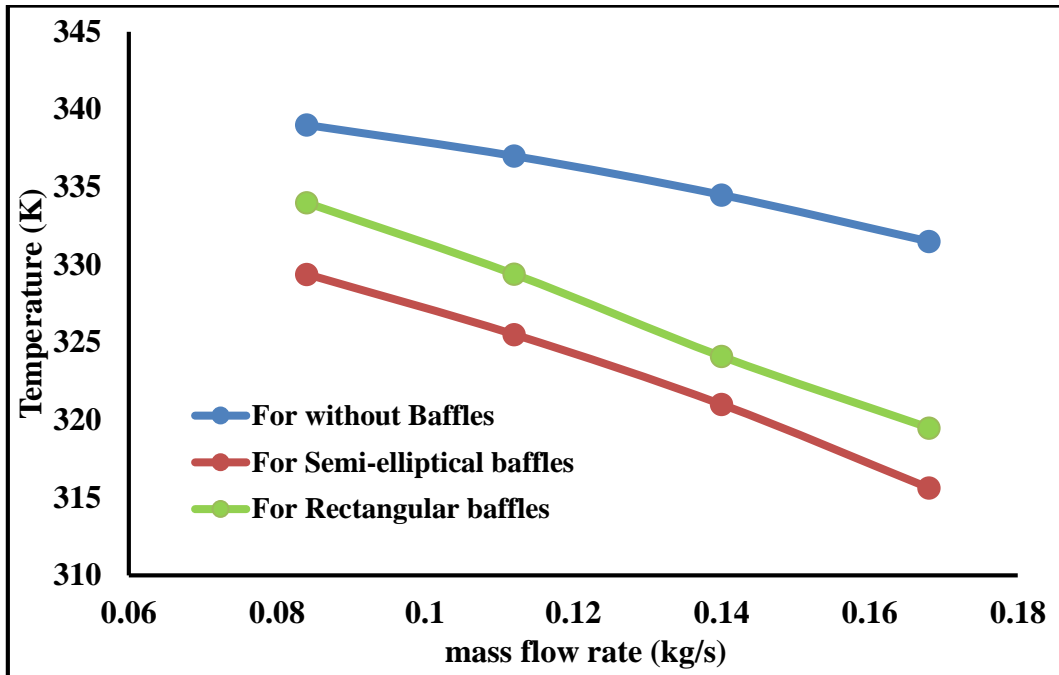


Fig. 9 showing the comparison of temperature for different mass flow rate of cold fluid

From the above graph, it is found that the temperature of hot water is decreasing with increase in mass flow rate of cold fluid. From the above graph, it is found that the temperature of helical coil tube in tube having semi-elliptical baffles shows the minimum temperature for all the mass flow rate of cold fluid.

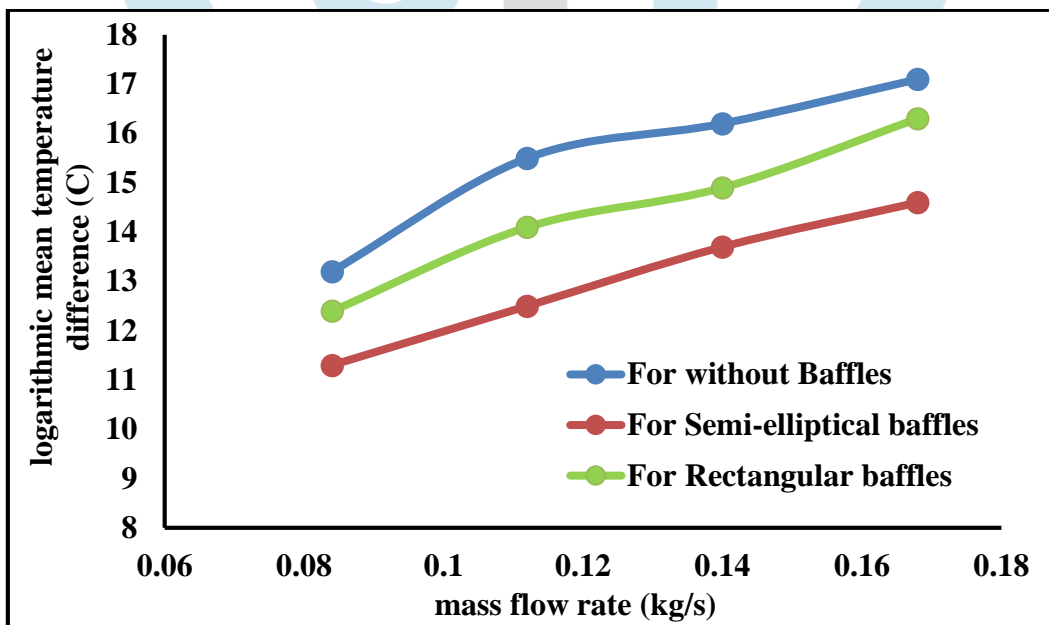


Fig. 10 showing the comparison of logarithmic mean temperature difference for different mass flow rate of cold fluid

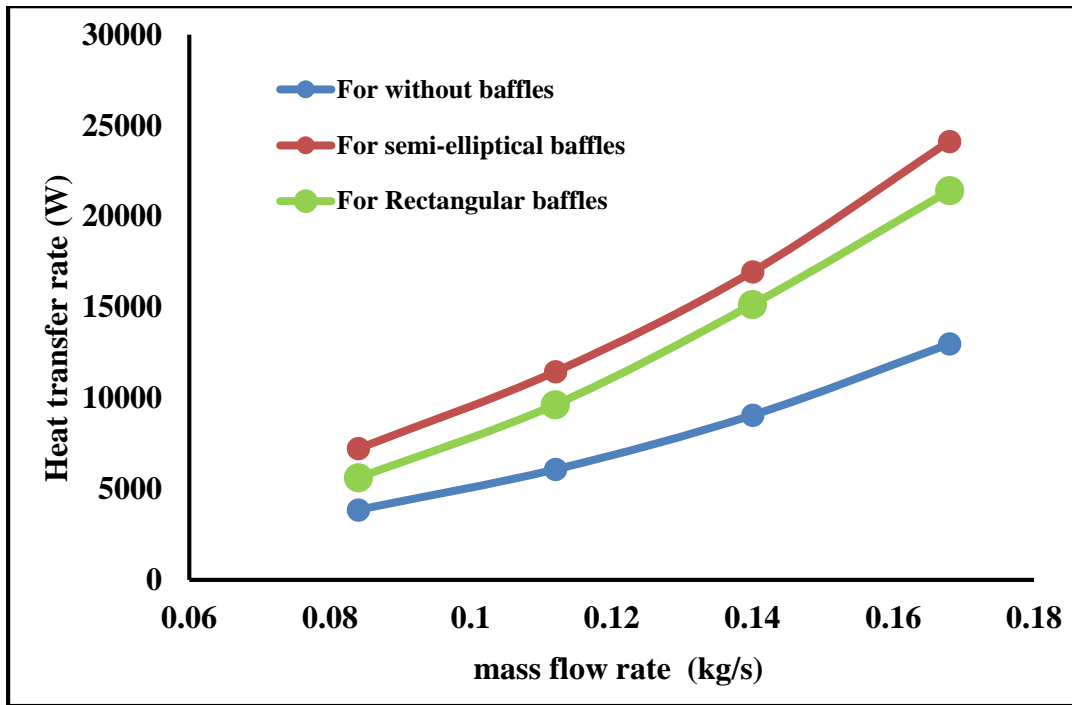


Fig.11 showing the comparison of heat transfer rate for different mass flow rate of cold fluid

➤ For change in mass flow rate of hot fluid while keeping the mass flow rate of cold fluid constant

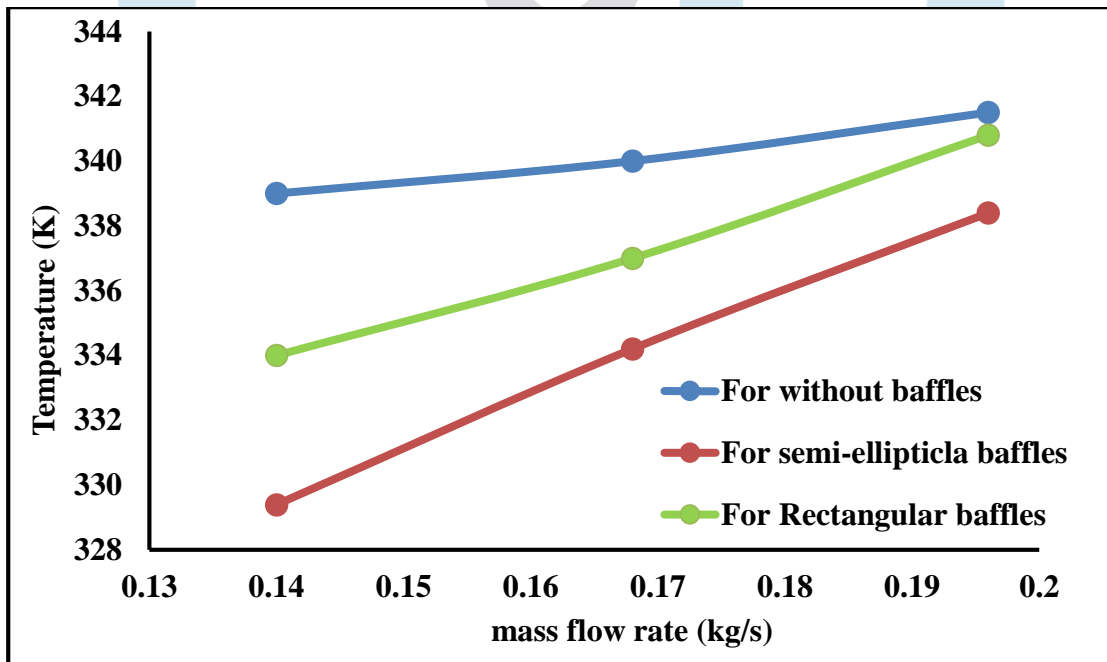


Fig. 12 showing the comparison of temperature for different mass flow rate of hot fluid

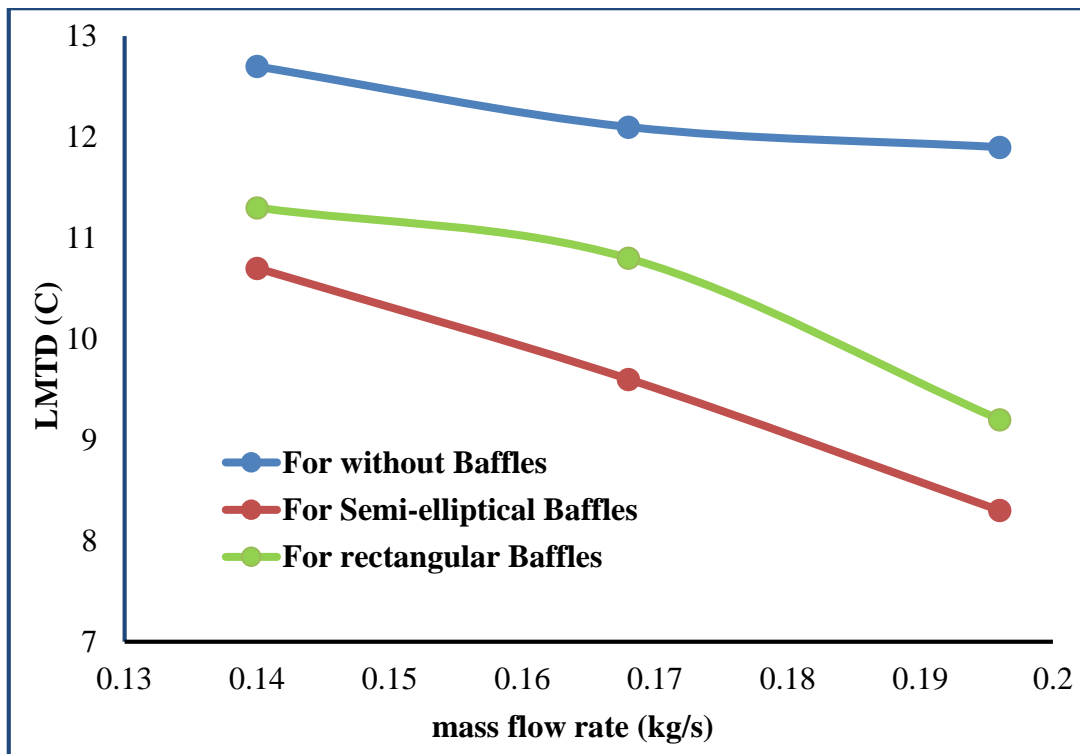


Fig. 13 showing the comparison of LMTD for different mass flow rate of hot fluid

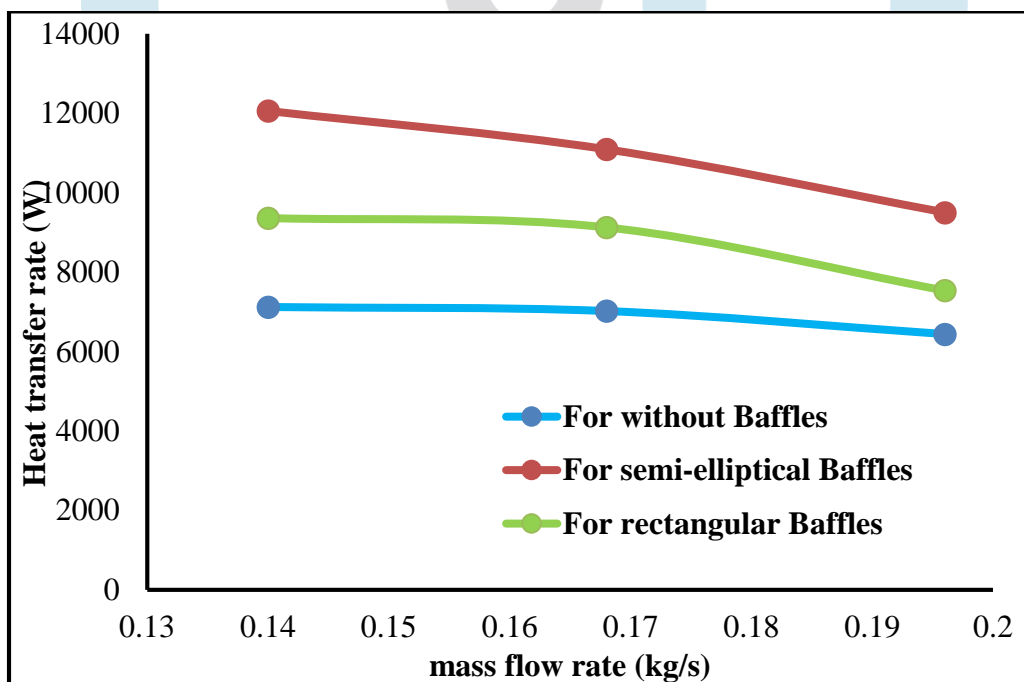


Fig. 14 showing the comparison of heat transfer rate for different mass flow rate of hot fluid

8. For comparison of Friction Factor

Here we have compare the value of friction factor for different types of baffles used during the analysis. The comparison is shown in the below fig.

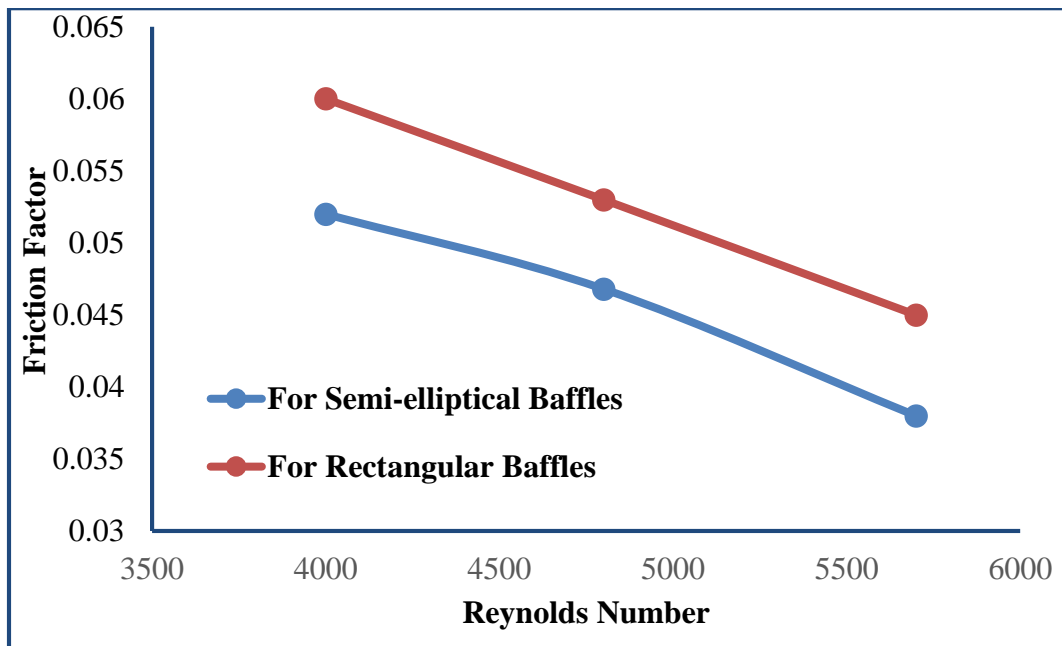


Fig. 15 showing the comparison of friction factor for different Reynolds number of cold fluid

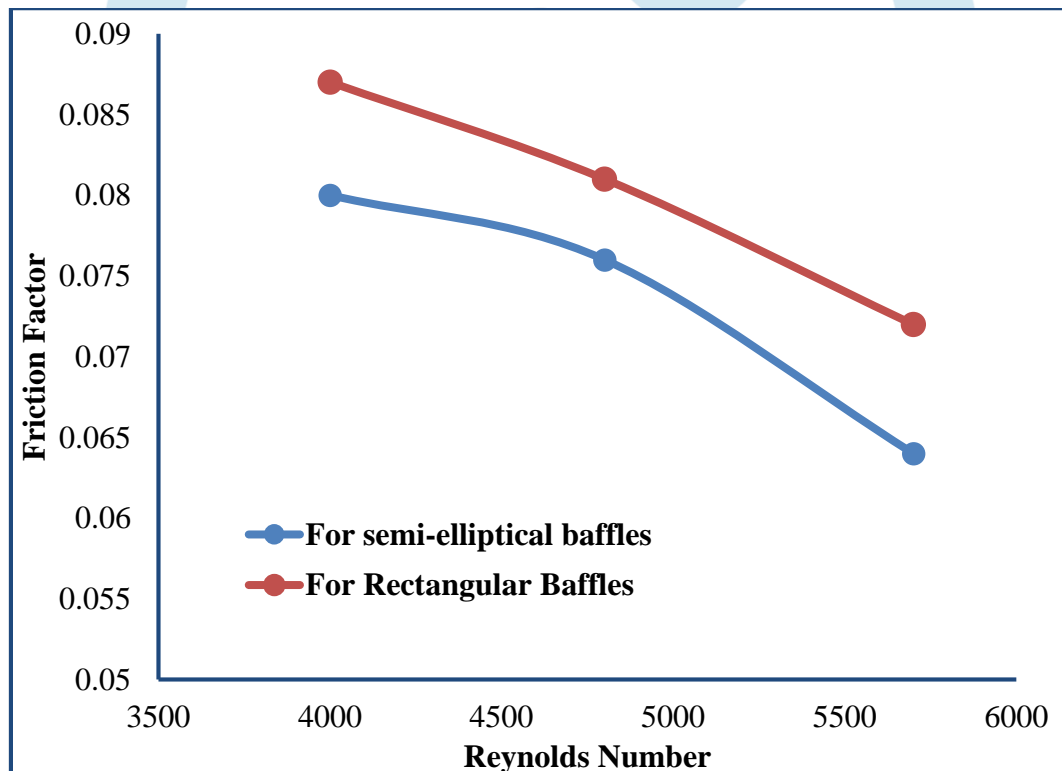


Fig. 16 showing the comparison of friction factor for different Reynolds number of cold fluid

9. CONCLUSION

- As the mass flow rate of cold fluid increase the value of temperature of hot fluid at the exit get decreases.
- From the analysis it is found that the outcomes of temperature of hot fluid during the change in mass flow rate of cold fluid is minimum in case of semi-elliptical baffles at all mass flow rate.
- For change in mass flow rate of cold fluid it is found that the magnitude of LMTD increases as the mass flow rate of cold fluid increases, it is maximum in without baffles condition and minimum in semi-elliptical baffles condition.
- For change in mass flow rate of cold fluid it is analyzed that as the mass flow rate of cold fluid increases the heat transfer rate get increases.
- The heat transfer is highest for the semi-elliptical baffle and lowest for the without baffle case.
- In case of change in mass flow rate of hot fluid it is seen that value of temperature increases as the mass flow rate of hot fluid increases.

- The value of temperature of hot fluid at the exit is higher for without baffle case and lower for semi-elliptical case in mass flow rate of hot fluid section.
- For change in mass flow rate of hot fluid section the outcomes of heat transfer rate decreases with the increase in mass flow rate of hot fluid.
- From both the section analysis that is change in mass flow rate of hot and cold fluid it is found that the helical coil tube in tube heat exchange having semi-elliptical baffles show the greatest heat transfer as compared to rectangular and without baffles helical tube heat exchanger. So it is the best one.
- For analysis it is also defined that the results of friction factor is minimum in case of semi-elliptical baffles as related to the rectangular type baffles.

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