Experimental Study and Investigation of Helical Pipe Heat Exchanger with Varying Pitch

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Abstract -

Heat exchangers are the most researched and constantly evolved devices in the research industry. This project is an attempt on experimental investigation of helical coil heat exchangers and its best effectiveness for different pitch values but the rest of the dimensions kept constant. In the process of enhancing the heat transfer capacity of heat exchangers the helical pipe heat exchangers have come in as a passive method of heat enhancement. The reason for this would be that the flow in the helical coils always produces a secondary flow component to the radial velocity. This additional component is the result of centrifugal force due to flow in the curvature.

Present research work is to understand more behavioral effects on the helical pipe heat exchanger on the pitch of the helix is selected. Normal design procedure is followed to design the heat exchanger but the option to vary the pitch of the helix is provided.

The helical coil is enclosed in a vessel to simulate the shell side of heat exchanger. The cold fluid enters the shell through the bottom connection and flows up. It leaves the shell through the outlet at the top. The coil is welded to a bottom flange plate in such a way that coil assembly remains fixed at the bottom of the assembly. By varying the flow rates of the hot and cold water experiment was conducted for all the pith selected. The effectiveness was calculated for each case. Results and plots were recorded

Key Words: helical pipe heat exchanger, helix pitch

1. INTRODUCTION

Heat exchangers are the most researched and constantly evolved devices in the research industry. Basically a Heat exchanger is a device that accommodates the transfer of heat from one fluid to other. It basically consists of an arrangement to allow two fluids; usually liquids to flow in two different passages may be concentric tubes or any other pattern.

As we know heat exchanger is a device in which the heat energy in the form of enthalpy is transferred from one fluid to another fluid through the solid medium with or without external work involved. Major application of heat exchangers involve the heat transfer between the two fluids either evaporation or condensation or just controlling the temperature of the fluid of concern. In many medical or chemical industry related applications it would be with an intention of sterilizing, pasteurizing, distilling, fractionating, crystallizing or also control process the fluid.

1.1 Shell And Tube Heat Exchanger

A shell and tube heat exchanger is one of the classes of heat exchanger types. It is the most commonly used type of heat exchanger in chemical processes and other oil refineries. This type of heat exchanger is best suited for high-pressure and high-temperature applications. This type of heat exchanger basically consists of a shell (a large enclosure to withstand pressure) with a single or bundle of tubes enclosed. Amongst the two fluids, one flows through the shell and the other through the tubes. The surface of the tubes helps the heat transfer from the outer flowing fluid to the inside fluid or vice versa depending on the temperature gradient between the two fluids. If a set of tubes is enclosed in the shell then that set is called bundle of tubes. A tube bundle may be composed by different types of tubes with or without fins longitudinally attached to the tubes. The figure below shows a typical shell and tube heat exchangers.

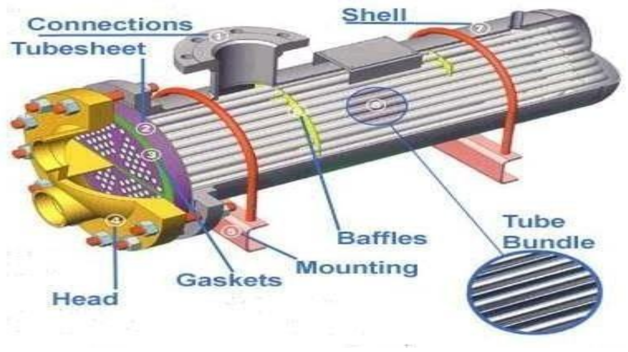

Fig 1.1: Typical Shell And Tube Heat Exchanger

1.2 Helical Pipe Heat Exchanger

In this type of heat exchanger the tube is formed into the helical pipe and placed inside the shell. This provides a secondary flow to the fluid flowing in this pipe. A schematic of the helical pipe heat exchanger is shown in the following figure.

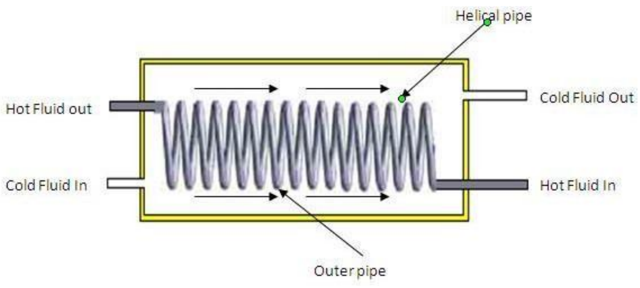

Fig 1.2: Helical Pipe Heat Exchanger

In the process of enhancing the heat transfer capacity of heat exchangers the helical pipe heat exchangers have come in as a passive method of heat enhancement. The reason for this would be that the flow in the helical coils always produces a secondary flow component to the radial velocity. This additional component is the result of centrifugal force due to flow in the curvature.

As lot of literature is available to prove about the flow pattern that is generated in the helical and other curved channels. It is also seen that a symmetrical paired vortices usually affects the main flow stream of the fluid. Also the details of these flow characteristics are discussed in the literature survey.

2. EXPERIMENTAL SETUP

The pipe used to construct the helical section has 10mm inside diameter and 12.7mm outer diameter. The tube material is copper. The Pitch Circle Diameter (PCD) of the coil is 80mm and tube pitch is 20mm. The remaining parts of the setup are made of mild steel. The helical coil is enclosed in a vessel to simulate the shell side of heat exchanger. The cold fluid enters the shell through the bottom connection and flows up. It leaves the shell through the outlet at the top. The coil is welded to a bottom flange plate in such a way that coil assembly remains fixed at the bottom of the assembly. A manually controlled mechanism is provided to push and pull the coil according to the need.

The helical coil test section is connected to a loop, which provides the necessary flow through the tube and shell side of the test section and the required instrumentation. A tank with electric heater is provided to heat the water to be circulated through the helical coil with a total power of 2000W. The manufactured experimental setup is as shown in the following figure.

Fig 2.1: experimental setup

In the process of enhancing the heat transfer capacity of a heat exchangers the helical pipe heat exchangers have come in as a passive method of heat enhancement. The reason for this would be that the flow in the helical coils always produces a secondary flow component to the radial velocity.

3. METHODOLOGY

3.1 Design Procedure

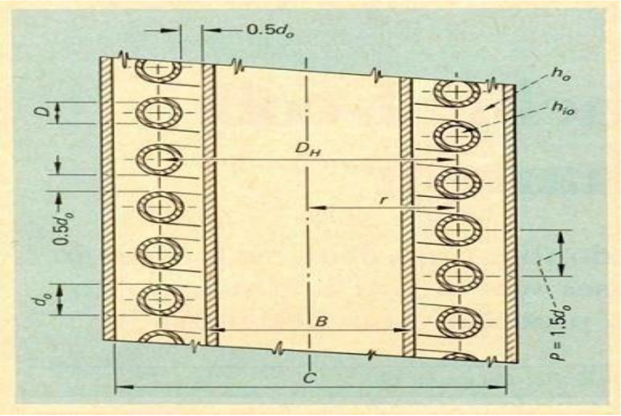

Fig 3.1: sectional view of the helical coil heat exchanger

The design was calculated as per the following equations

1) The coil tube length L for N number of turns

$$L = N\surd\,(2\pi r)\ 2 + p2 \qquad (1)$$

2) The volume utilized by the coil, Vc:

$$Vc = (\pi/4)\ d20L \qquad (2)$$

3) Annulus volume available, Va :

$$Va = (\pi/4)\ (C2 - B2)\ pN \qquad (3)$$

4) The available volume for the fluid to flow in the annulus, Vf :

$$Vf = Va - Vc \qquad (4)$$

5) Equivalent diameter of the coiled tube for shell-side, De:

$$De = 4Vf / \pi doL \qquad (5)$$

3.2 Design Calculations

Assumed Number of coils N = 10

Radius of the helical is r = 80 mm

Pitch of the helical is p = 20 mm

do= 80+6.35 = 86.35 mm

di = 80-6.35 = 73.65 mm

B = 73.35 – 6.35 = 67.3 mm

C = 86.35 + (1.5 ∗12.7) = 105.4 mm

Therefore:

L = 10√ (2π 80) 2 + 202= 2016 mm = 2.016 m

Vc = (π/4) 86.352 ∗ 2016 = 1470 m3

Va = (π/4) (105.42 – 67.32) 20 ∗ 10 = 1.033 m3

Vf = 14.70 – 1.033 = 13.667 m3

De = (4 ∗ 13.667 ∗ 106) / (π ∗ 86.35 ∗ 2016) = 99.96 mm

4. RESULTS AND DISCUSSION

The experiment was conducted for different parameters. The results are tabulated as follows.

Case 1: Full Length

4.1 Gap between Coils = 20 Mm, Parallel Flow & Full Length

4.1.1 For Constant Cold water flow as 1 LPM

		Hot Water Temperature 0C		Cold Water Temperature 0C	
Flow Rate Of Hot Water (kg/s)	Flow Rate Of Cold Water (kg/s)	Inlet	Outlet	Inlet	Outlet
0.01	0.0167	69	46	38	43
0.0133	0.0167	69	57	39	47
0.0167	0.0167	69	56	38	47

Table 4.1 Temperatures recorded for 20 mm gap between coils 1 LPM Cold water constant flow

Ch	Cc	Cmin	Qmax	Qh	Qc	Q	E
41.86	69.91	41.86	1297.75	1608.15	349.59	978.87	0.75
55.67	69.91	55.67	1670.33	839.03	559.35	699.19	0.41
69.91	69.91	69.91	2167.24	908.95	629.27	769.11	0.35

Table 4.2: Calculated Effectiveness for 20 mm gap between coils 1 LPM Cold water constant flow

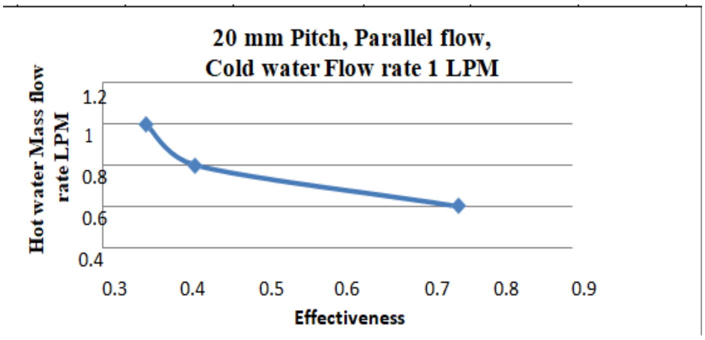

Fig 4.1: Plot for effectiveness 20 mm gap between coils, Parallel flow, Cold water Flow rate 1 LPM

Sample Calculation

Heat Flow capacity of cold water:

Cc = mcCpc where for water Cpc = 4.187 kJ/ kg K

mc = 1 LPM = (1000 * 10-6 * 1000) / 60 = 0.0167 kg/s

∴ Cc = 0.0167 * 4.187 = 69.91121 kJ / K

Heat Flow capacity of Hot water:

Ch = mhCph where for water Cph = 4.187 kJ/ kg K

.mh = 1 LPM = (600 * 106 * 1000) / 60 = 0.01 kg/s

∴ Ch = 0.0167 * 4.187 = 41.87 kJ / K

From the above we can see that:

Cmin = 41.87 kJ / K and Cmax = 69.91121 kJ / K

Maximum Heat transfer theoretically:

Qmax = Cmin (th1 – tc1) = 41.87 (69 – 38) = 1297.753 kJ / s

Heat Transfer in Cold water:

Qc = mc (tc2 – tc1) = 0.0167 (43 – 38) = 349.5978 kJ / s

Heat Transfer in hot water:

Qh = mh (th1 – th2) = 0.01 (69 – 46) = 1608.15 kJ / s

Average Heat transfer:

Q = (Qh+Qc) / 2 = (1608.15 + 359.5978) / 2 = 978.8738

Effectiveness:

ε= (Q / Qavg) = 978.8738 / 1297.753

ε = 0.754284

4.1.2 For Constant Hot water flow as 1 LPM

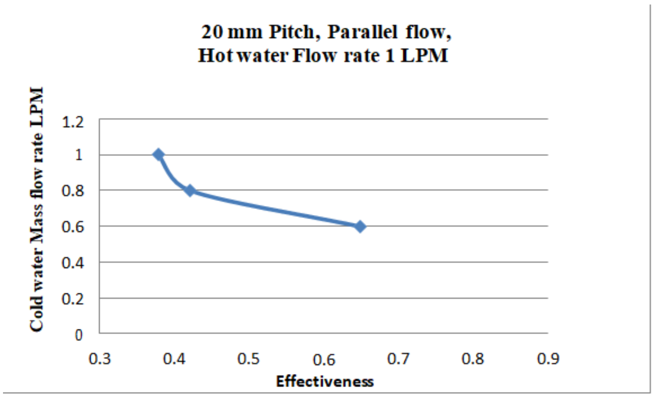

Fig 4.2: Plot for effectiveness 20 mm Gap between coils, Parallel flow, Hot water Flow rate 1 LPM

4.2 Gap between Coils = 20 Mm, Counter Flow & Full Length

		Hot Water Temperature 0C		Cold Water Temperature 0C	
Flow Rate Of Hot Water (kg/s)	Flow Rate Of Cold Water (kg/s)	Inlet	Outlet	Inlet	Outlet
0.01	0.0167	70	53	36	49
0.0133	0.0167	69	56	38	50
0.0167	0.0167	69	57	37	50

Table 4.3: Temperatures recorded for 20 mm gap between coils 1 LPM Cold water constant flow

4.2.1 For Constant Cold water flow as 1 LPM

Ch	Cc	Cmin	Qmax	Qh	Qc	Q	E
41.86	69.91	41.86	1423.34	1188.63	908.95	1048.79	0.73
55.67	69.91	55.67	1781.68	978.87	839.03	908.95	0.51
69.91	69.91	69.91	2237.15	839.03	908.95	873.99	0.39

Table 4.4: Calculated Effectiveness for 20 mm gap between coils 1 LPM Cold water constant flow

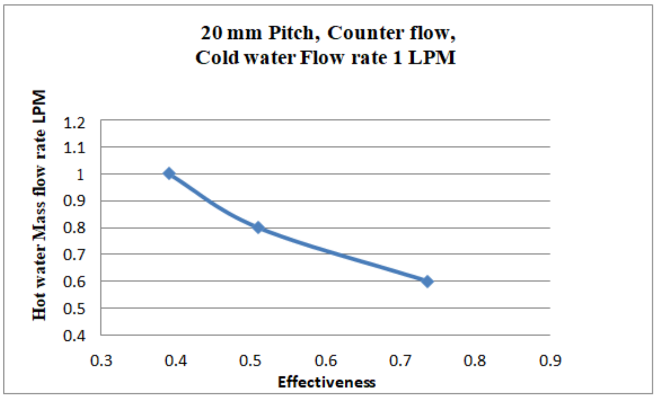

Fig 4.3 Plot for effectiveness 20 mm Gap between coils, Counter flow, Cold water Flow rate 1 LPM

4.2.2 For Constant Hot water flow as 1 LPM

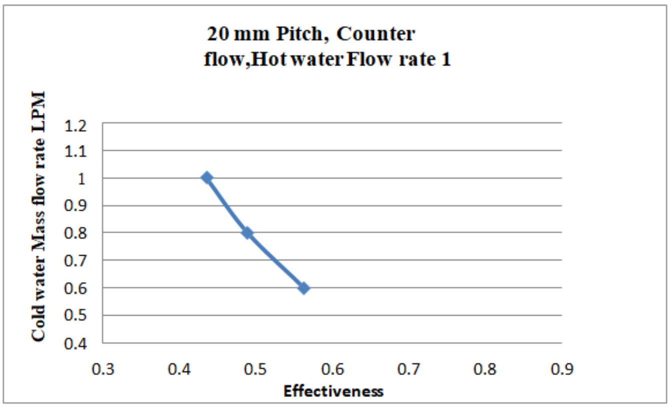

Fig 4.4: Plot for effectiveness 20 mm Gap between coils, Counter flow, Hot water Flow rate 1 LPM

Similarly the work was continued for 10 mm pitch and 0 mm pitch for full length pipe with same flow conditions in cold and hot flow and the results are shown below.

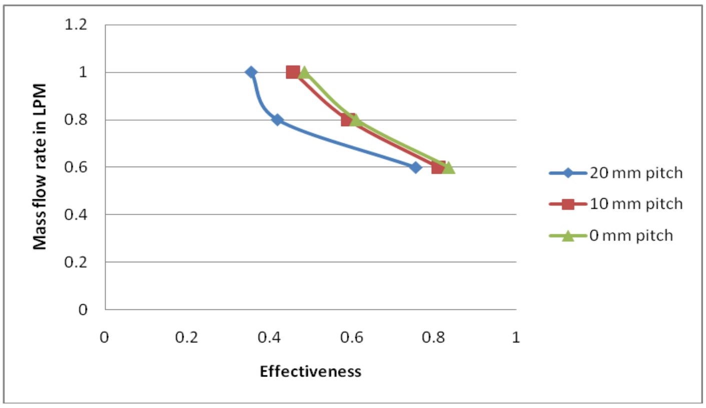

Fig 4.5: Plot for effectiveness Vs Mass flow rate consolidated for parallel flow (cold water flow rate 1LPM)

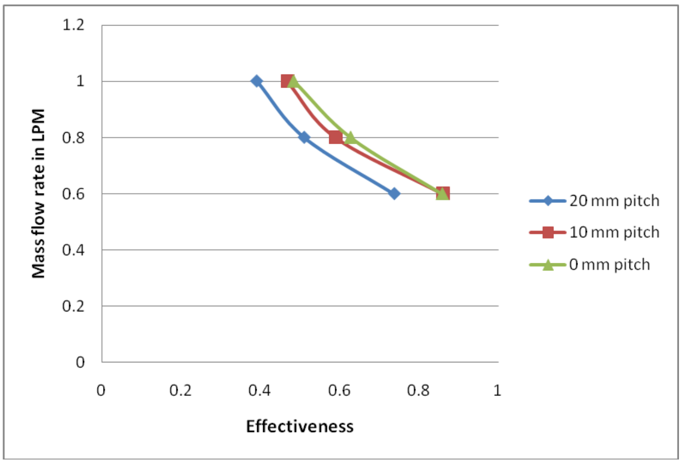

Fig 4.6: Plot for effectiveness Vs Mass flow rate consolidated for counter flow. (cold water flow rate 1LPM)

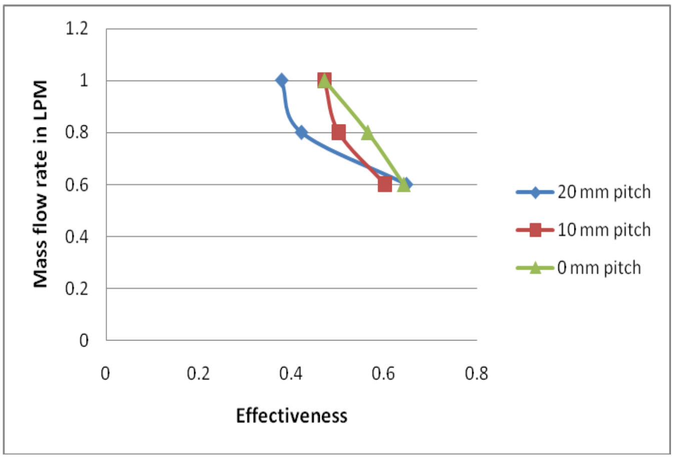

Fig 4.7: Plot for effectiveness Vs Mass flow rate consolidated for Parallel flow (Hot water flow rate 1LPM)

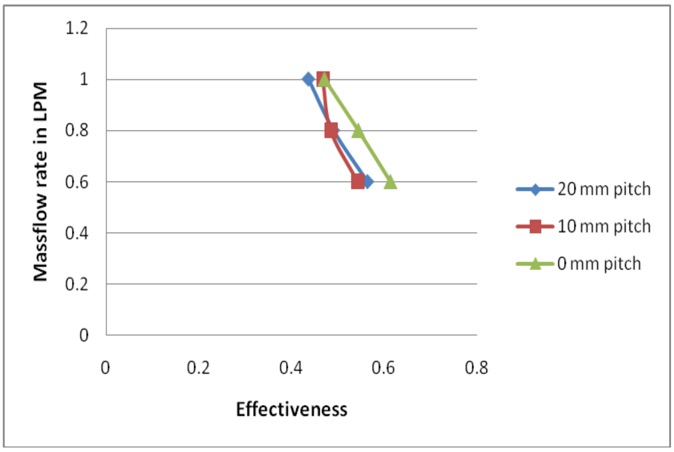

Fig 4.8: Plot for effectiveness Vs Mass flow rate consolidated for counter flow (Hot water flow rate 1LPM)

For half length:

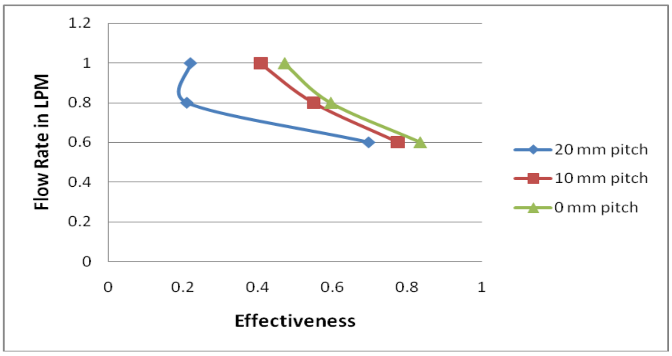

Fig 4.9: Plot for effectiveness Vs Mass flow rate consolidated for parallel flow, for half length (cold water flow rate 1LPM)

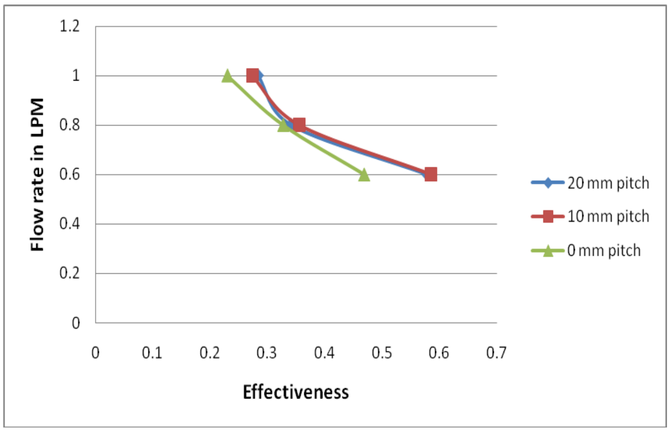

Fig 4.10: Plot for effectiveness Vs Mass flow rate consolidated for counter flow, for half length (cold water flow rate 1LPM)

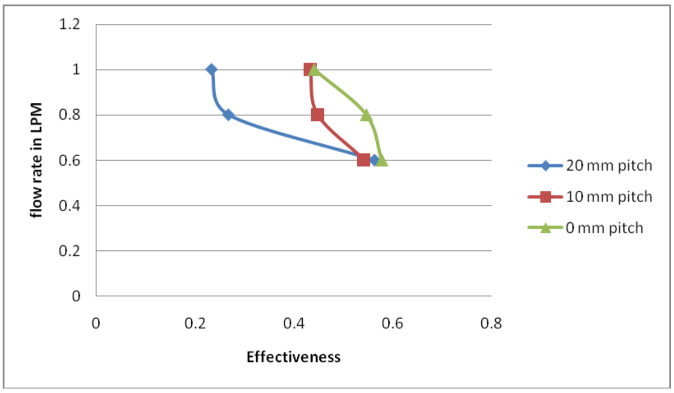

Fig 4.11: Plot for effectiveness Vs Mass flow rate consolidated for Parallel flow, for half length (Hot water flow rate 1LPM)

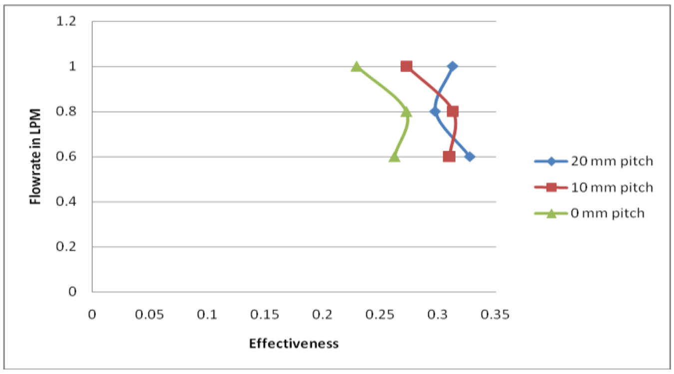

Fig 4.12: Plot for effectiveness Vs Mass flow rate consolidated for counter flow for half length (Hot water flow rate 1LPM)

4.3 POWER LOSSES

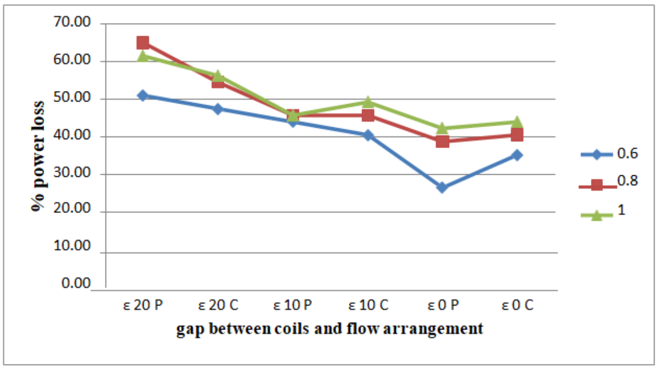

Fig 4.13: losses when cold water flow rate maintained at 0.0167 kg/s.

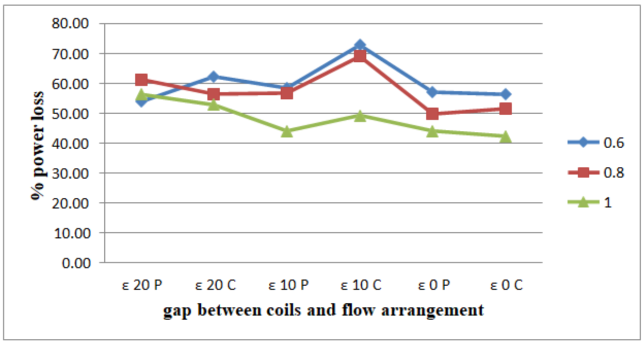

Fig 4.13: losses when hot water flow rate maintained at 0.0167 kg/s

5. CONCLUSIONS

The heat exchanger was designed first according to the normal design procedure. The heat exchanger was manufactured as the dimensions obtained from the design. The same was repeated for the different flow rates of the cold water, keeping the hot water flow rate constant. Effectiveness was calculated for all the flow rates. The work was done for pitch of 20 mm,10 mm,0 mm in full length and half length conditions.

We observe that the effectiveness in general reduces with the increase of the mass flow rate irrespective of the pitch.

From the research it can be easily conclude from the results that when the gap between the coils was 10 mm and 0 mm the effectiveness was consistent for both parallel and counter flow arrangements, in both half length and full length readings.

The consolidated graphs plotted also reveal for the half length readings that the length chosen according to the design i.e. 2 m is accurate and the length of the copper pipe cannot be reduced further.

It is been observed that when power losses were calculated and plotted accordingly, the maximum power loss has occurred when the flow rate of cold fluid was 0.6 kg/s at 10 mm gap between the coils for counter flow. And the value was 72.76%. It is also observed that the minimum power losses are occurred at when the hot fluid flow rate was maintained at 0.6 kg/s when there was no gap between the coils for parallel flow arrangement. And the value was 25.58%.

REFERENCES

[1] " Numerical and experimental studies of a double-pipe helical heat exchanger" by Timothy j. Rennie department of bioresource engineering, mcgill university, montreal, submitted august 2004, a thesis submitted to mcgill university in partial fulfillment of the requirements of the degree of doctor of philosophy.

[2] "Helically Coiled Heat Exchangers - Basic design Applications" by J. S. Jayakumar Professor, Dept. of Mechanical Engineering, Amrita Vishwa Vidyapeetham, Amrita School of Engineering, Amritapuri, Kollam, India.

[3] "Fabrication and Analysis of Tube-In-Tube Helical Coil Heat Exchanger" by Mrunal P.Kshirsagar, Trupti J. Kansara, Swapnil M. Aher, International Journal of Engineering Research and General Science Volume 2, Issue 3, April-May 2014 ISSN 2091-2730.

[4] " Thermal Analysis of a Helical Coil Heat Exchanger"by Amol Andhare, V M Kriplani, J P Modak, International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163

[5] "Thermal Analysis Validation for Different Design Tubes in a Heat Exchanger" by Roshan. V. Marode and Ashok. J.Keche, International Journal of Engineering Research and General Science Volume 3, Issue 1, January-February, 2015, ISSN 2091-2730.