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Design Analysis and Comparative Performance of Variable Pitch Tube in Tube Conical Spiral Heat Exchanger

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Abstract

Lower heat transfer rate in heat exchangers as a result of fouling is a common problem in process industry. Shell and tube heat exchanger are subjected to fouling as result of prolonged use as the materials get deposited on the heat transfer surfaces or wetted area of the tubes and also occupies more space. Fouling brings down the heat transfer rate and effectiveness of the heat exchanger. Requirement of heat exchangers used in process industry, chemical industry applications is that there should be no contamination and lesser fouling. The above problem is addressed in our project. The spiral conical tube in tube heat exchanger offers the best compactness although the pumping power required is slightly on the higher side. The spiral conical tube in tube heat exchanger design is a challenge to manufacture so also difficult to clean over time for maintenance. The problem of fouling is easily dealt with in the project, by addition of variable pitch where in the shape geometry of the spiral will be changed from a flat spiral to a conical frustum. The geometry of the tubes plays a significant part in design and development of the heat exchanger. Paper work discusses the design & analysis of inner and outer tube of the heat exchanger where in the copper tube is wound in a spiral shape and hot fluid is always passed from inside of spiral to outside of spiral, but path of the cold fluid be changed to attain the parallel flow or counter flow configuration. The modeling is done using Unigraphix Nx-8 and analysis has been done using Ansys work bench 16.0. Test and performance comparison has been done in counter flow configuration for three pitch positions namely 0 mm (close coil), 10mm and 20 mm respectively.

Keywords— Heat Exchanger, Parallel flow and Counter flow, Spiral Conical tube in tube heat exchanger, Variable pitch, Shell and Tube

I. INTRODUCTION

Heat Exchangers are devices that used to transfer heat from one fluid to another at different temperatures by either intermixing or coming in contact with each other indirectly. The fluids which are required to transfer heat may be interfaced by a solid wall to prevent intermixing or they may be in direct contact with each other. They are widely used in different applications that include power generation, process industries, chemical industries, electronics devices, environmental engineering, Waste heat recovery system, manufacturing industries, space heating requirements, refrigeration, air-conditioning, chemical plants, petrochemical plants, petroleum refineries, natural-gas processing unit, sewage treatment plant. One of the typical example of a heat exchanger is found in an IC engine in which a circulating fluid flows through radiator coils and air flows over the fin coils, which cools the coolant and heats the incoming air.
Various factors are taken into consideration while designing heat exchanger including the nature of the material to be cooled or heated, size, pressure, temperature.

A. Types of heat exchangers

- Shell and tube heat exchanger
- Plate heat exchanger
- Plate fin heat exchanger
- Pillow plate heat exchanger
- Fluid heat exchangers
- Waste heat recoveryPlate and shell heat exchanger
- Adiabatic wheel heat exchanger units
- Dynamic scraped surface heat exchanger
- Phase-change heat exchangers
- Spiral Coil Heat Exchanger
- Helical Coil Heat Exchanger
- Tube in Tube Spiral Heat Exchanger

B. Tube in Tube Spiral Heat Exchanger

A tube in tube spiral heat exchanger may refer to a helical(coiled) tube configuration and is manufactured by placing the coils of different diameters inside each other concentrically. The tube in tube spiral heat exchangers are generally used in electronics, manufacturing industry, waste heat recovery system, air conditioning i.e. less place available. These are preferred as heat exchangers because of higher mass and heat transfer coefficients, compact structure, suitable for handling high flow rate and high temperature fluid, easy to handle, low material requirement and less cost. But these heat exchangers require more pumping power because of increased pressure drop.

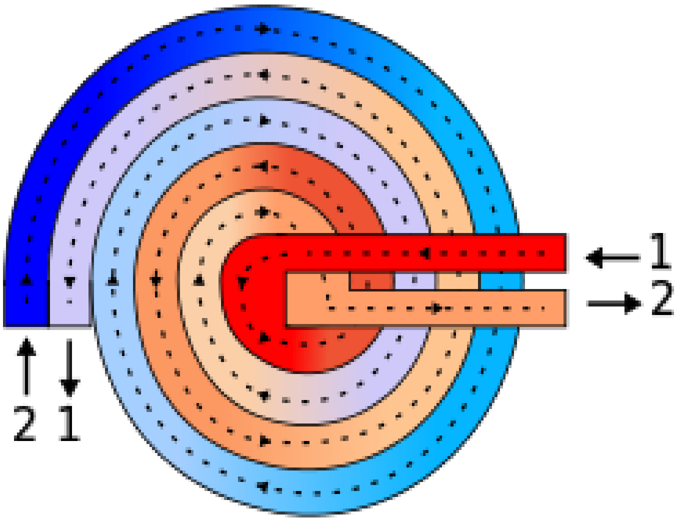

Fig.1.Spiral Heat Exchanger

C. Different Configurations of the Tube in Tube Spiral Heat Exchanger

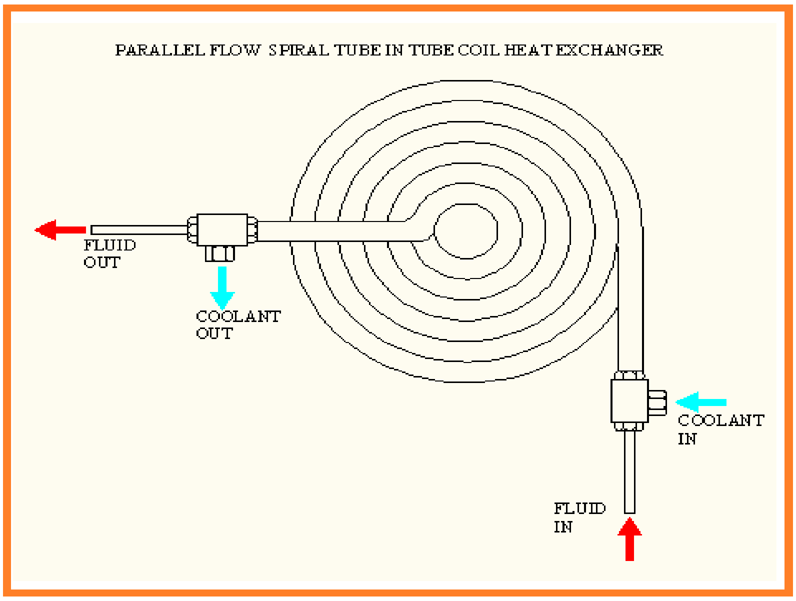

Fig. 2a. shows the tube in tube spiral heat exchanger in parallel as the flat form.

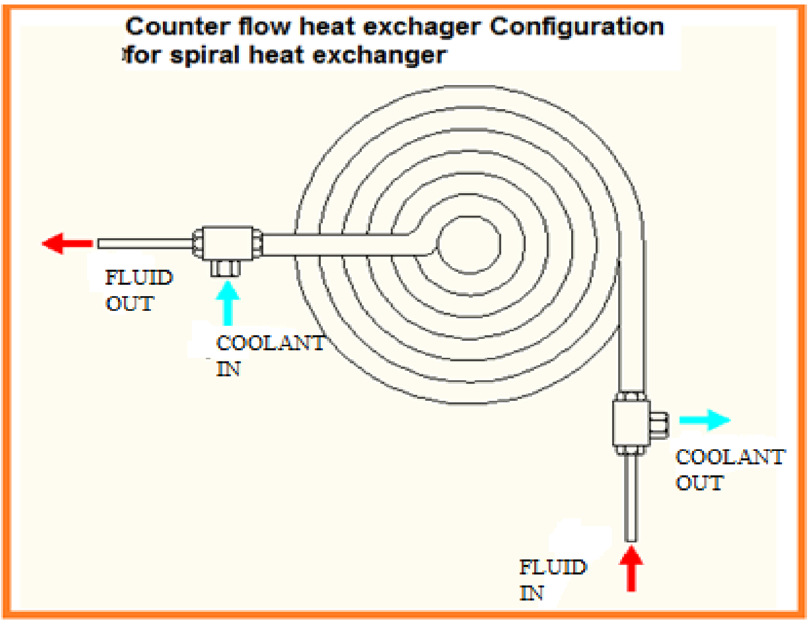

Fig.2b. shows the tube in tube spiral heat exchanger in counter flow as the flat form.

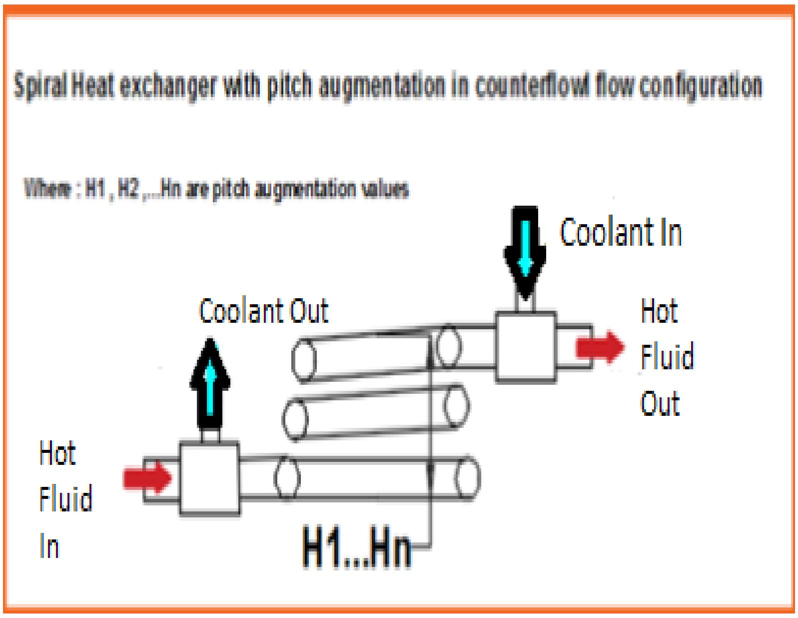

Fig.2c. Shows tube in tube spiral heat exchanger with variable pitch in counter flow configuration

Here three values of pitch augmentation Ho (closed coil), H1 (10 mm pitch) & H2 (20 mm pitch) will be used as subject factors and the testing will be done in counter flow configuration to study the effect of variation in pitch on the performance of the heat exchanger

II. DESIGN AND ANALYSIS

A. Geometry Inner Coil of Heat Exchanger

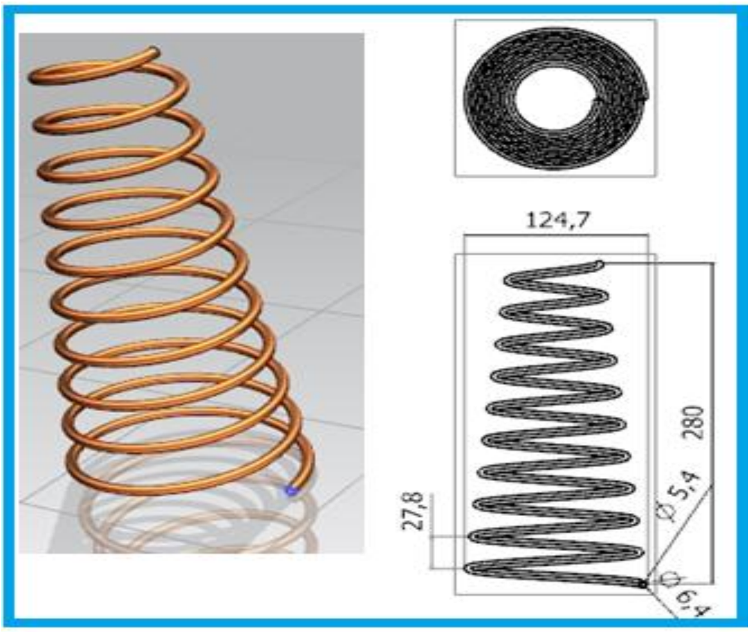

Fig 3. Geometry and 3-D model of Inner Coil

B. Heat Flux of Inner Coil

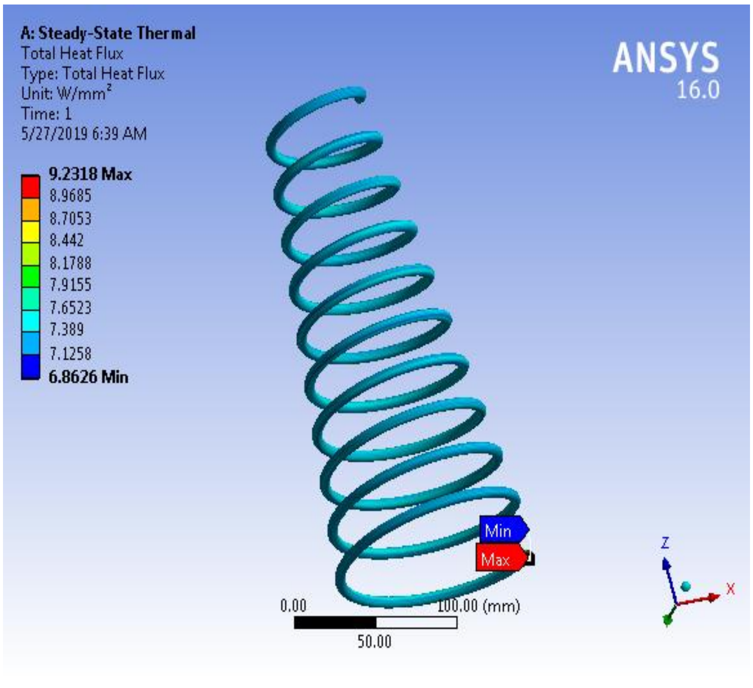

Fig 4. Heat Flux of Inner Coil

The thermal analysis of the inner coil shows that the total heat flux is 9.2318 watt/mm^{2}k .

C .Structural analysis of the inner coil as a result of the temperature and pressure as a coupling

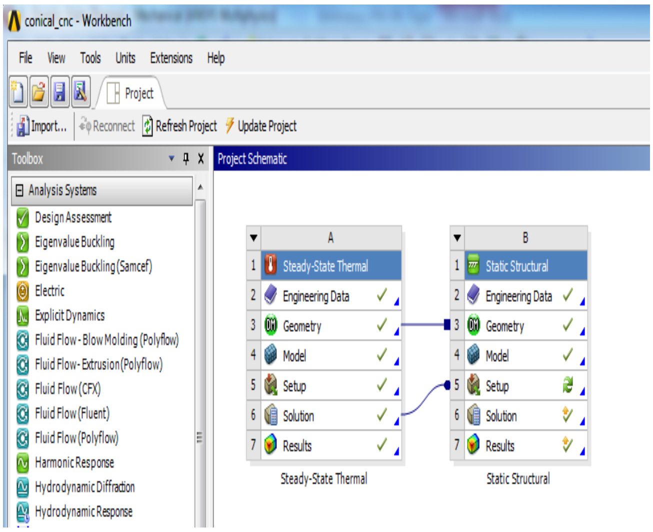

Fig 5. Structural analysis of Inner Coil as a result of Temperature and Pressure

Here the coil is subjected to 1.5 bar pressure on the inner side and results have been calculated for the maximum stress and maximum deformation

D. Static Structure analysis of Stress

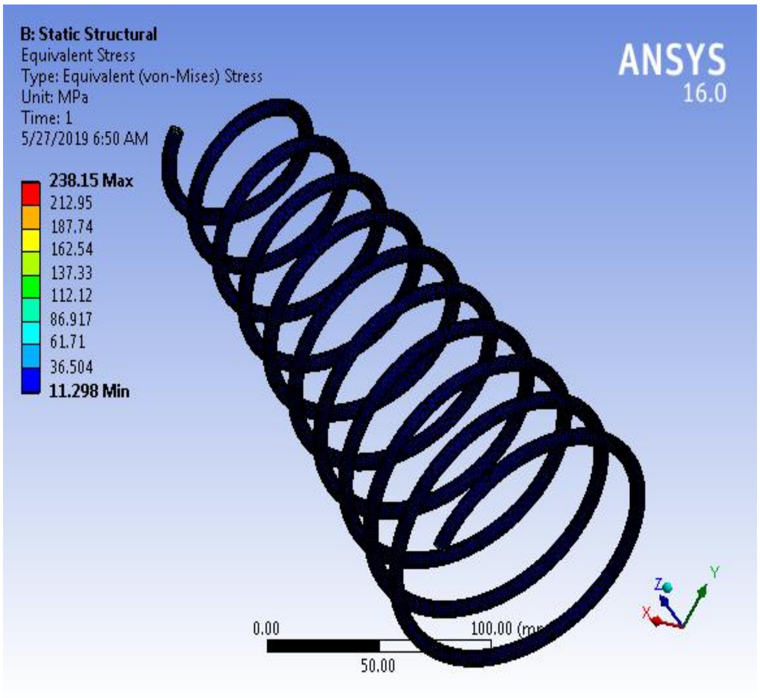

Fig. 6. Static Structure analysis of Stress

The maximum stress induced at 1.5 bar working pressure is 238.15 Mpa which is less that the allowable stress of 460 Mpa, Hence the coil is safe.

E. Static Structure analysis of Deformation

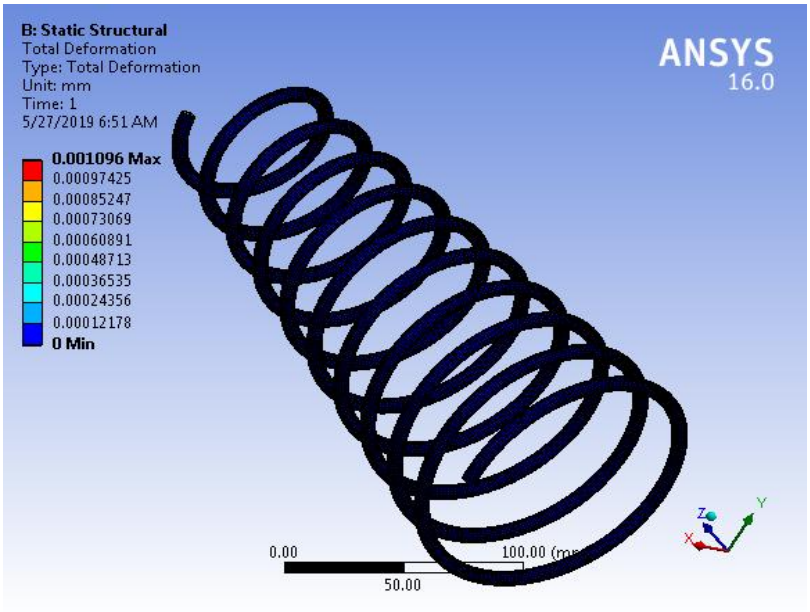

Fig. 7. Static Structure analysis of Deformation

The maximum deformation of coil as result of the combined thermal and structural load is 0.001096 which is negligible hence the coil is safe

III. TEST AND TRIAL

A. Experimental set-up

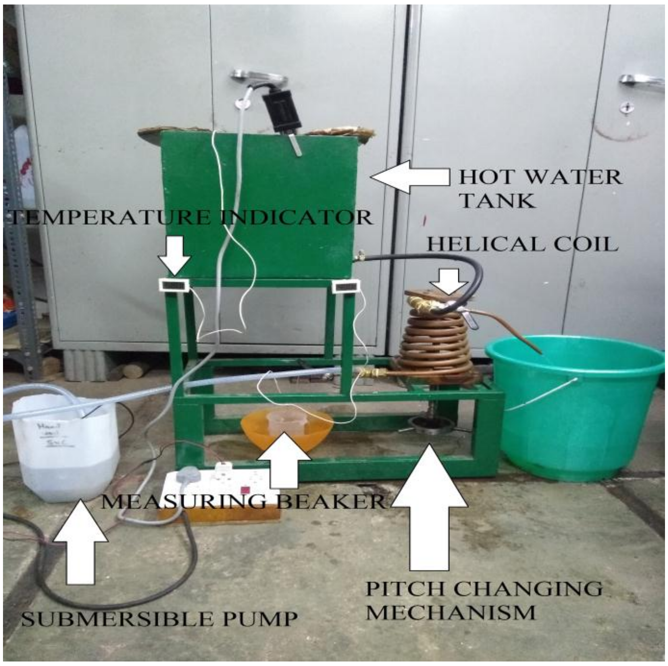

Fig. 8. Experimental set up

The pitch changing mechanism in the tube in tube spiral heat exchanger (Helical Coil) is in the form of square threaded screw and nut arrangement. By turning the nut, the screw that is constrained only to have translator motion, is made to move up and down, there by effecting pitch change. The objective of pitch change is to increase the gradient of flow by increasing the lead angle of the tube- in- tube helical coil. The effect of this change is reflected in the test – trial which is conducted on zero pitch (closed coil), 10 mm pitch and 20 mm pitch.

B.. Details of Immersion Heater

Type: Coil water heater
Wattage: 350 watt
Temperature range: Up to 80^0C

C. Specifications of Water Circulation Pump

230-volt ac
1.5 amp
Flow rate = 250 LPH
Maximum head = 1850
Power = 18 Watt

Fig. 9. Water Circulation pump

IV. RESULTS OF EXPERIMENTS

Table 1. Counter flow Closed Coil Spiral Heat Exchanger (Ho = 0 mm)

SR NO.	Mass flow rate (kg/sec)	LMTD (°C)	Overall HTC (W/ m^2k)	Effectiveness
1	0.00469	45.49817	74.89733917	0.134615385
2	0.005051	41.84982	77.50379045	0.16
3	0.005472	40.39868	85.50610945	0.2
4	0.005794	38.94228	96.16080366	0.254901961
5	0.006156	36.67374	98.79071673	0.31372549

Table 2. Counter flow Closed Coil Spiral Heat Exchanger (H_1 = 10 mm)

SR NO.	Mass flow rate (kg/sec)	LMTD (°C)	Overall HTC (W/ m^2k)	Effectiveness
1	0.00469	45.07863	74.20671432	0.165384615
2	0.005051	42.0476	77.87007134	0.17
3	0.005472	39.68354	83.99247052	0.234
4	0.005794	38.9586	96.20110814	0.278431373
5	0.006156	37.22416	100.2734306	0.341176471

Table 3. Counter flow Closed Coil Spiral Heat Exchanger (H_2 = 20 mm)

SR NO.	Mass flow rate (kg/sec)	LMTD (°C)	Overall HTC (W/ m^2k)	Effectiveness
1	0.00469	46.73583	76.7626986	0.17338462
2	0.005051	44.36364	81.4872055	0.184
3	0.005472	43.71476	88.86453461	0.249
4	0.005794	42.44276	100.8868449	0.289431373
5	0.006156	40.23356	104.0129043	0.352276471

V. GRAPHS

A. Comparison Graphs of LMTD Vs Flow rate

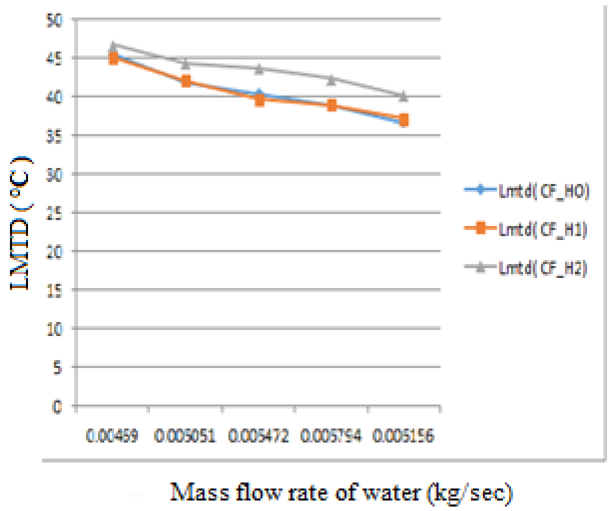

Fig. 10. Shows Comparision between LMTD and Flow Rate

The LMTD is a function of the pitch of the helix. The LMTD will increase with the increase in pitch and hence the maximum LMTD will be attained for any constant flow rate for maximum pitch of 22mm. The test is carried out up to 20 mm pitch. The comparison shows that the LMTD of 20 mm pitch configuration is highest amongst the three configurations.

B. Comparison Graphs of Overall Heat Transfer Coefficient Vs Flow rate

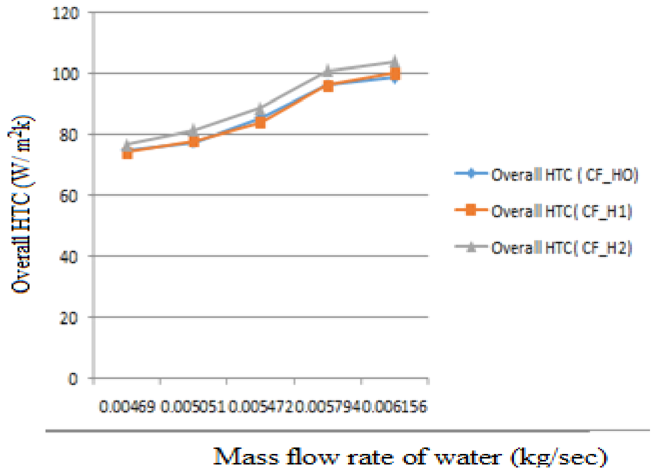

Fig.11. shows Comparison between Overall Heat Transfer Coefficient and Mass Flow Rate

The comparison shows that the Overall heat transfer coefficient of 20 mm pitch configuration is the highest amongst the three configurations. This is as a result of increased lead angle and gradient which increases the intermixing of particles

C. Comparison Graphs of Effectiveness Vs Flow rate

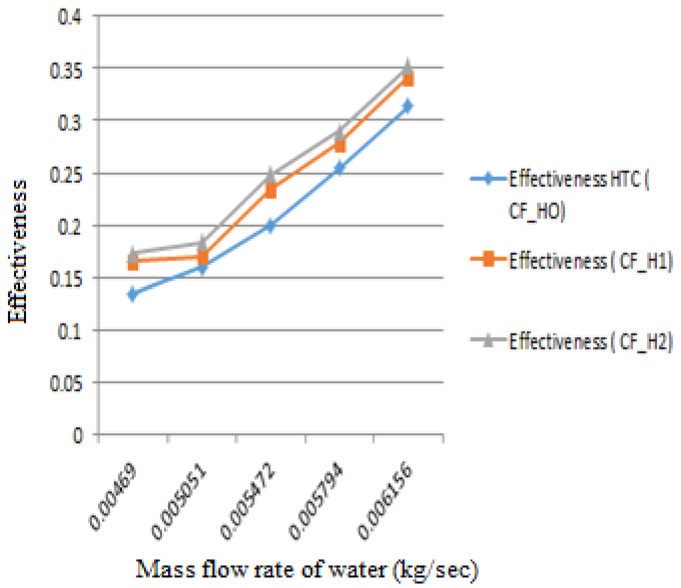

Fig 12. Shows Comparison between effectiveness and flow rate

The comparison shows that the effectiveness of the 20 mm pitch configuration is better than that of other two configurations, this is as a result of increased lead angle and gradient which increases the intermixing of particles.

VI. CONCLUSION

1. The thermal analysis of the inner coil shows the maximum heat flux is 9.238 watt /mm2.
2. The combined analysis of the inner coil shows the maximum stress induced is 238.15 MPa which is below allowable stress of 460 Mpa hence the coil is safe.
3. The combined analysis of the inner coil shows the maximum deformation induced is 0.0019 mm which is negligible hence the coil is safe.
4. Testing revealed that the LMTD of 20 mm pitch is highest amongst three configurations.
5. Testing revealed on basis of comparison that the effectiveness of the 20 mm pitch configuration is better than that of other two configurations, this is as a result of increased lead angle and gradient which increases the intermixing of particles.

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