DESIGN ANALYSIS OF FLUROPOLYMER SPIRAL TUBE HEAT EXCHANGER WITH VARIABLE PITCH CONICAL FRUSTRUM GEOMETRY

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Abstract: Heat exchangers used in process industry, chemical industry applications require that there is no contamination and lesser fouling need of chemically inert and non-corrosive heat exchangers, although the conventional heat exchangers made from copper, aluminium and other metallic materials seldom prove useful in these cases. Polymeric materials heat exchangers although chemically inert, but lack the thermal capabilities suitable to heat exchangers. The only polymeric heat exchangers to offer modest heat transfer abilities are the fluro-polymer heat exchangers. The geometry of the heat exchanger plays a vital role in determining the heat transfer capabilities and also resistance to fouling the spiral tube in tube heat exchangers offer the best compactness although the pumping power required is slightly on the higher side.

The spiral tube in tube heat exchanger design is a challenge to manufacture so also difficult to clean over time for maintenance. The problem of fouling can be dealt as proposed in our project , namely to prevent scaling and fouling by addition of variable pitch where in the shape geometry of the spiral will be changed from a flat spiral to a conical frustrum .The geometry of the tubes plays a significant part in design and development of the heat exchanger. Paper work discusses the development of such heat exchanger where in the fluro polymer 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 approach in the design and development is to deal with the problem of fouling at two levels as proposed in this paper, namely selection of an suitable material to prevent fouling and scaling issues and secondly to add a innovative geometry variation in the form of pitch augmentation where in the flat shape geometry of the spiral can be converted to an to a conical frustum.

Keywords: Fluropolymer, Spiral tube in tube heat exchanger, heat transfer capabilities, corrosion resistance

I. INTRODUCTION

Polymeric heat exchangers find application ideally in process owing to their durability and as they are not brittle like glass or graphite and provide better resistance to corrosion than almost all metals heat exchangers of steel, aluminium or copper rendering them a proffered choice for use in a number of process industry applications. Versatility of the fluoropolymer heat exchanger in addition to resistance to corrosion makes them a singular choice. The same heat exchanger design may be used with variety of chemicals without danger of contamination or intermixing of fluids. From the start of the application of polymeric heat exchangers in the shell-and-tube designs, fluoropolymer heat exchangers have also being used other geometric configurations, especially in the primarily reactor and other forms like immersion coils.

II. DESIGN & ANALYSIS OF CONICAL FLURO-POLYMER OUTER COIL WITH FULL PITCH 28 MM

Fluoropolymers are corrosion resistant to most chemicals according to Wharry (2002). Material selection is limited by the operational temperatures hence polymers like Ethylene tetrafluorethylene (ETFE) or Polyvinylidene difluoride (PVDF) which have lower temperature limits and as they sell at high temperature and ketone resins dissolve were not selected for our application. Teflon (PTFE) polymer which has high resistance to erosion by chemicals and no metallic parts are used and PTPE is highly resistant to hydraulic shock as well as thermal expansion hence we have selected PTFE as the material for tubing.

PTFE has melting point of about 621° F (327° C). whereas the density is 2.13 to 2.19 gm/cc .PTFE has good resistance to chemicals and corrosion PTFE exhibits good mechanical properties for temperature range 0 to 500° F (280° C) and its low coefficient of friction than other metal materialmakes it less prone to scaling and fouling.

Table 1.

Property	ASTM Test Method	Units	Teflon® PTFE
Physical			
Specific Gravity	D792		2.13-2.22
Mechanical			
Tensile Strength	D1457 D1708 D638	psi	3,000-5,000
Elongation	D1457 D1708 D638	%	300-500
Flexural Modulus	D790	psi	72,000
Folding Endurance	D2176	(MIT) cycles	$>10^{6}$
Impact Strength	D256	ft-lb/in	3.5
Hardness, Shore D	D2240		50-65
Coefficient of Friction, Dynamic	D1894	<10 ft/min	0.1
Thermal			
Melting Point	D3418	°F	621
Upper Service Temperature (20,000h)	UL746B	°F	500
Flame Rating	UL94		V-0
Limiting Oxygen Index	D2863	%	>95
Heat of Combustion	D240	Btu/lb	2,200

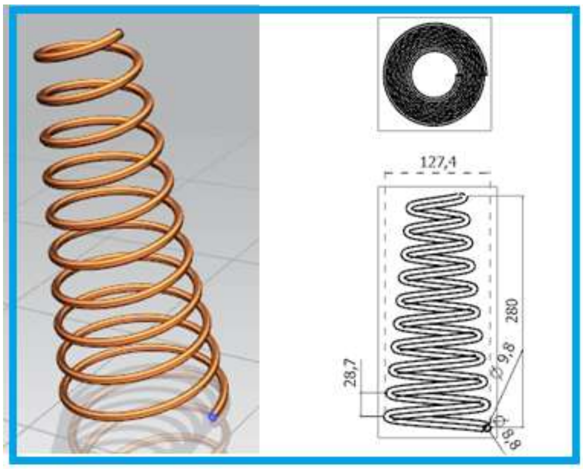

Fig. 1 :

The moderate strength application is selected as the operating pressure will be low, i.e. maximum upto 6 bar, hence a material with better thermal conductivity is selected to achieve maximum heat transfer in given area.

Material of tube = PTFE (allowable stress 66 N/mm2)
Hoope's stress due to pressure:-Maximum pressure induced in =6 bar= 0.6Mpa

$$fc_h = \frac{P \times d}{2t}$$

$$fc_{act} = \frac{0.6 \times 9.8}{2 \times 1}$$

$$\mathbf{fc_{act} = 2.94\ N/mm^2}$$

As $fc_h < fc_{all}$; helical coil pipe is safe

Longitudinal stress due to pressure:-
Maximum pressure induced in system = 6bar= 0.6Mpa

$$.fc_1 = \frac{P \times d}{4t}$$

$$fc_{act} = \frac{0.6 \times 9.8}{4 \times 1}$$

$$\mathbf{fcl_{act} = 1.47\ N/mm^2}$$

As $fc_l < fc_{all}$; conical outer coil pipe is safe

A. Analysis of the outer coil:

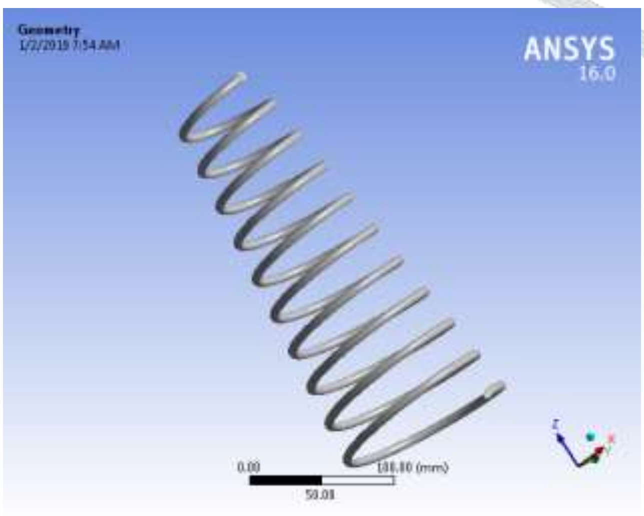

Fig. 2 : Analysis of the outer coil

Solid model of the tube structure and heat exchanger was developed using Unigraphix Nx-8 software, using the helix curve, sweep and Boolean operations, etc. commands. Once the model was developed the drafting was done to make the working drawings and then step203 file was developed using the export command. This exchange file was used to generate the geometry in ANSYS software modeler by use of Import external geometry file command. One the geometry was imported the Generate command was used to transfer geometry to the solver model section.

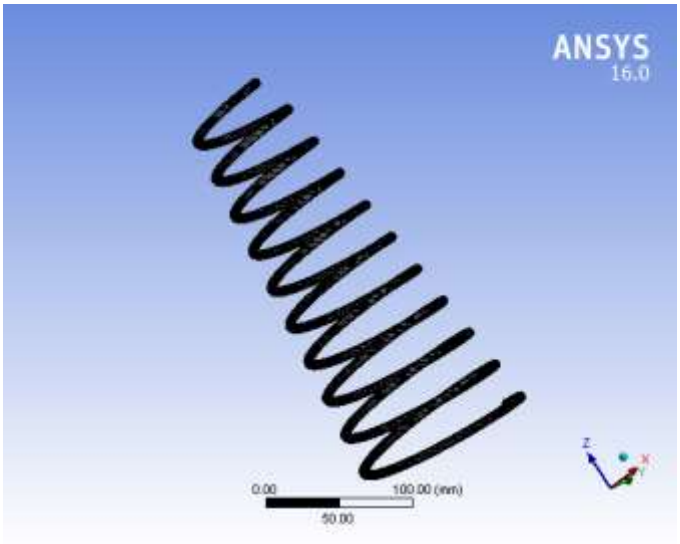

Fig. 3 :

Ansys Workbench free mesher was used to generate the mesh, first the meshing was done and then the generate command was used to apply it, details of the mesh parameter set by the workbench have been displayed in the table below:

Table 2.

Statistics	
Nodes	783161
Elements	123845
Mesh Metric	None

B. Boundary Conditions:

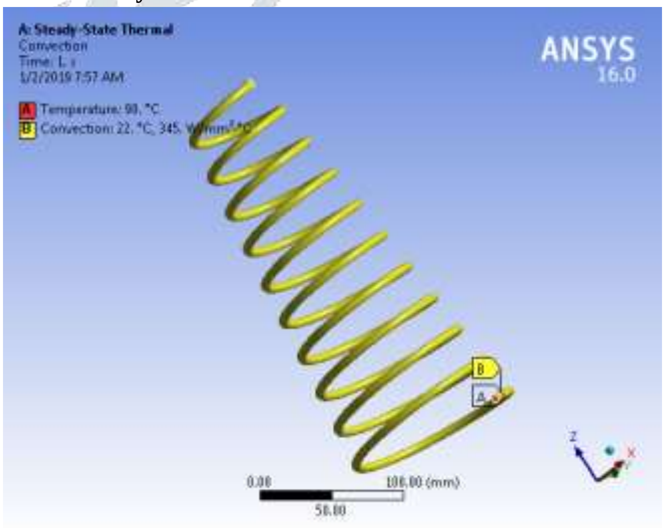

Fig. 4 :

An appropriate physics based boundary condition is must for successful solution of governing equation. In design of heat exchanger, the problem boundary i.e. inlet boundary receives hot fluid and pass towards bottom finally fluid exit through outlet boundary. Boundary conditions for tubes are: Pipe inlet temperature: Inlet temperature up to 95^0C. Rigid Wall boundary: No-slip adiabatic.

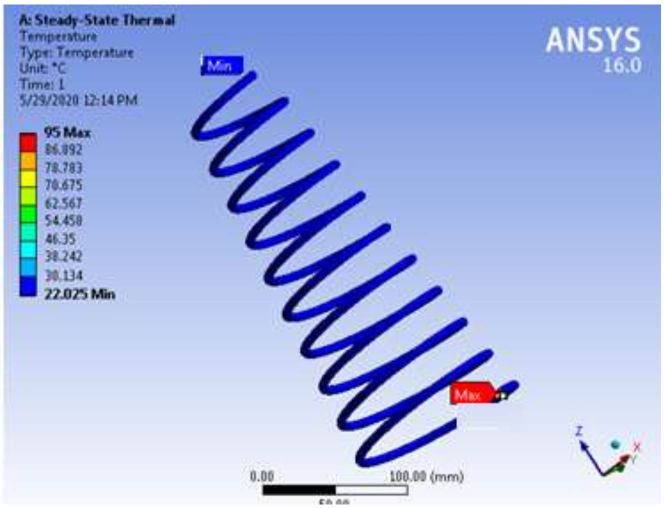

Fig.5 :

C. Temperature Variation Contour

Temperature variation contour is obtained when given boundary condition are applied to the problem. The results obtained from ANSYS software simulation for temperature contour is shown in figure. From figure we can say that as fluid entered into tube firstly it comes in contact with inner member therefore maximum temperature exists there temperature goes on decreasing as we go away from inlet to exit of heat exchanger outer coil

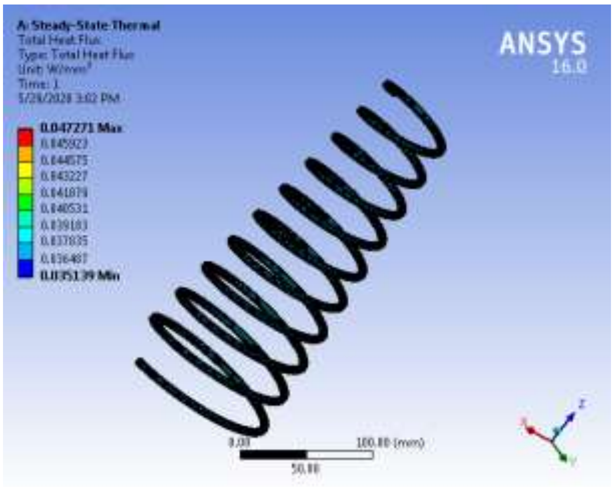

Fig.6 :

Heat flux or thermal flux is the rate of heat energy transfer through a given surface per unit time. The results obtained from ANSYS software simulation for heat flux contour is shown in figure From figure we can say that heat flux is maximum at inner portion of heat exchanger because hot fluid is at the centre. It is also observed that heat flux is 0.047 watt from outer coil.

D. Coupling the results:

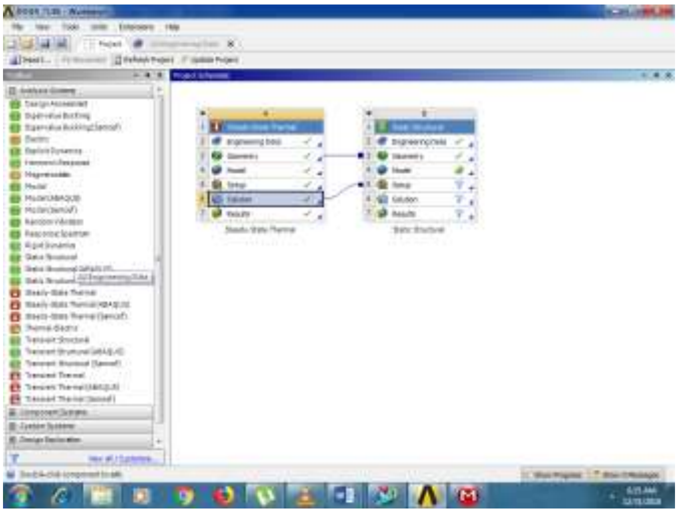

Fig.7 :

The heat exchanger is designed for maximum pressure of 6 bar inside the heat exchanger hence the results of thermal analysis are coupled to the static structural analysis the figure above shows the coupling of the modules

E. Boundary Conditions :

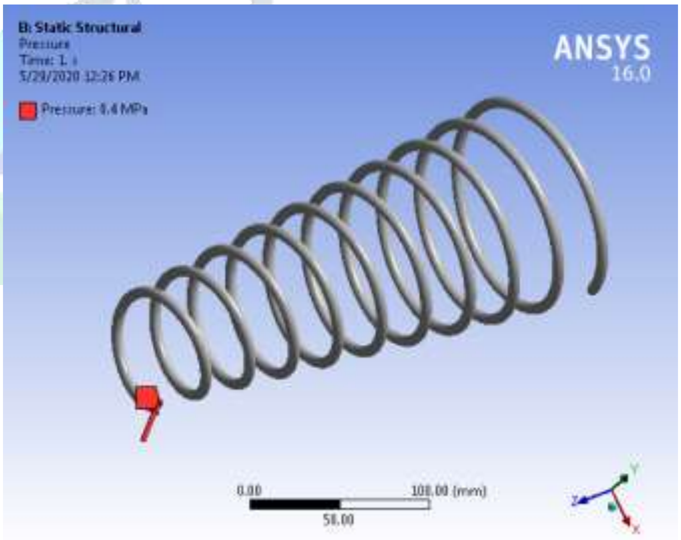

Fig.8 :

An appropriate physics based boundary condition is must for successful solution of governing equation. In design of heat exchanger, the problem boundary i.e. inlet boundary receives high pressure fluid and pass towards bottom finally fluid exit through outlet boundary. Boundary conditions for tubes are:
Pipe inlet pressure 0.6 Mpa.
Rigid Wall boundary: No-slip adiabatic

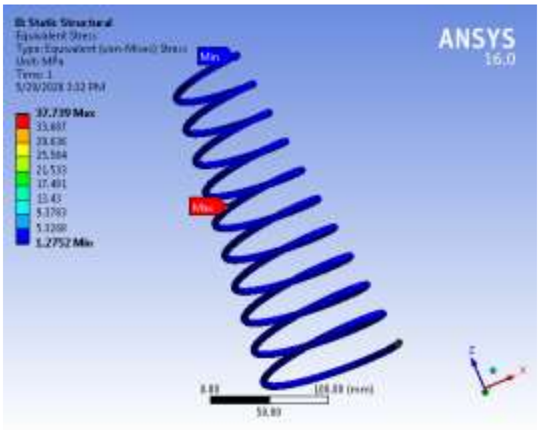

Fig.9 :

The maximum stress induced in the tube is 37.739 Mpa at maximum design pressure of 0.6 Mpa which is below the permissible stress of 66 Mpa hence the heat exchanger outer tubing is safe.

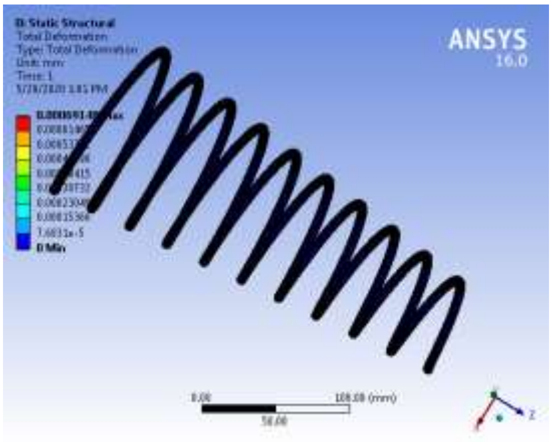

Fig.10 :

The maximum deformation induced is 0.000691 mm which is negligible hence the outer tubing is safe under given design pressure and thermal conditions.

III. DESIGN &ANALYSIS OF CONICAL FLURO-POLYMER INNER COIL WITH FULL PITCH 28 MM

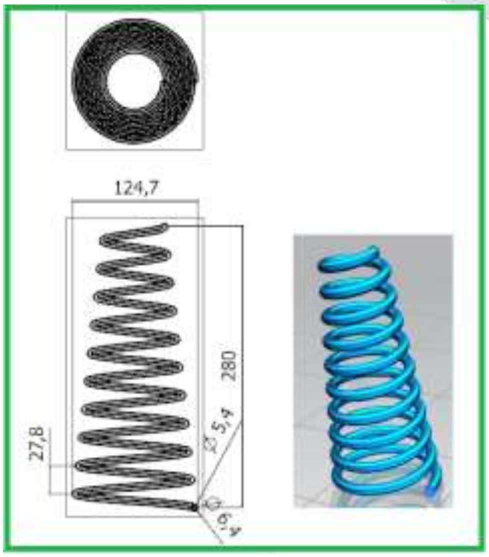

Fig.11 :

The moderate strength application is selected as the operating pressure will be low, ie maximum upto 6 bar, hence a material with better thermal conductivity is selected to achieve maximum heat transfer in given area.

Material of tube = PTFE (allowable stress 66 N/mm^2)

Hoope's stress due to pressure:-Maximum pressure induced in =6 bar= 0.6Mpa

$$fc_h = \frac{P \times d}{2t}$$

$$fc_{act} = \frac{0.6 \times 6.4}{2 \times 1}$$

$$\mathbf{fc_{act} = 1.92\ N/mm^2}$$

As $fc_h < fc_{all}$; helical coil pipe is safe

Longitudinal stress due to pressure:-

Maximum pressure induced in system = 6bar= 0.6Mpa

$$fc_1 = \frac{P \times d}{4t}$$

$$fc_{act} = \frac{0.6 \times 6.4}{4 \times 1}$$

$$\mathbf{fcl_{act} = 0.96\ N/mm^2}$$

As $fc_l < fc_{all}$; conical outer coil pipe is safe

A. Analysis of the inner coil :

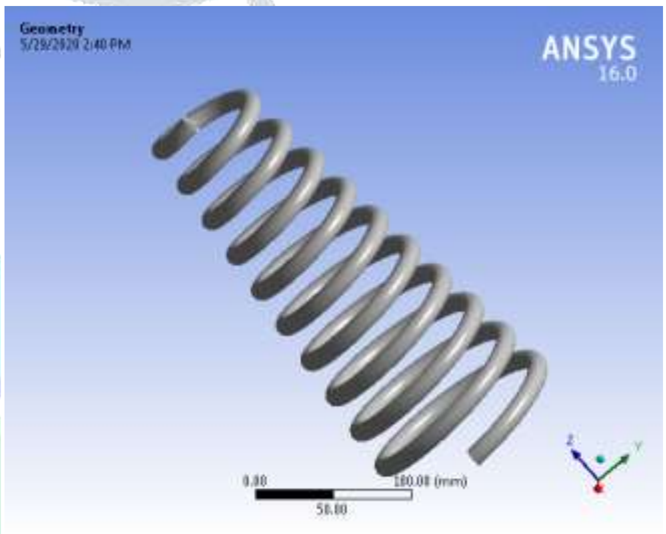

Fig.12 :

Solid model of the tube structure and heat exchanger was developed using Unigraphix Nx-8 software , using the helix curve , sweep and Boolean operations , etc. commands. Once the model was developed the drafting was done to make the working drawings and then step203 file was developed using the export command. This exchange file was used to generate the geometry in ANSYS software modeler by use of Import external geometry file command. One the geometry was imported the Generate command was used to transfer geometry to the solver model section.

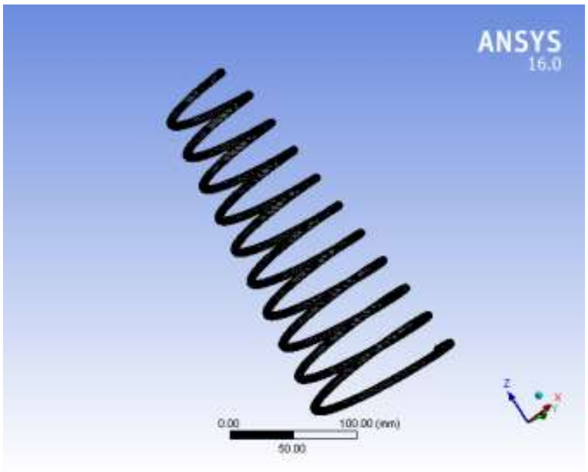

Fig.13 :

Ansys Workbench free mesher was used to generate the mesh, first the meshing was done and then the generate command was used to apply it, details of the mesh parameter set by the workbench have been displayed in the table below:

Table 3.

Statistics	
Nodes	499558
Elements	77180
Mesh Metric	None

B. Boundary Conditions:

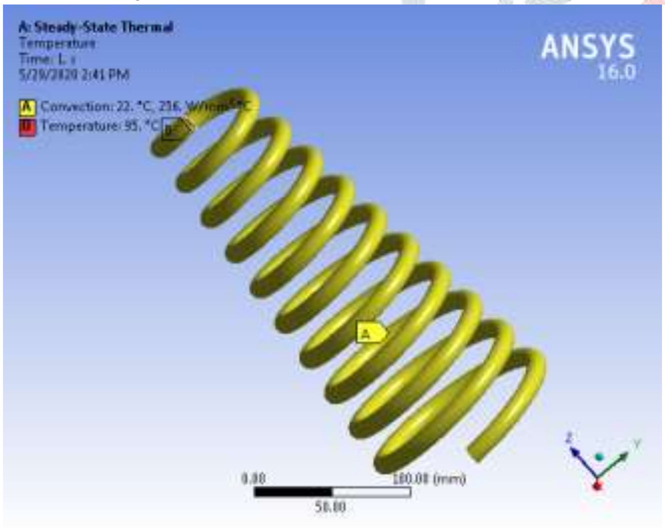

Fig.14 :

An appropriate physics based boundary condition is must for successful solution of governing equation. In design of heat exchanger, the problem boundary i.e. inlet boundary receives hot fluid and pass towards bottom finally fluid exit through outlet boundary. Boundary conditions for tubes are: Pipe inlet temperature: Inlet temperature up to 95^0C.

Rigid Wall boundary: No-slip adiabatic

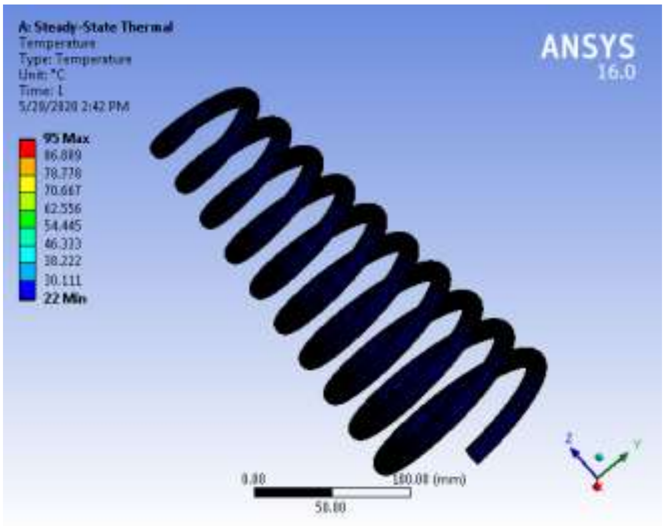

Fig.15 :

C. Temperature Variation Contour

Temperature variation contour is obtained when given boundary condition are applied to the problem. The results obtained from ANSYS software simulation for temperature contour is shown in figure. From figure we can say that as fluid entered into tube firstly it comes in contact with inner member therefore maximum temperature exists there temperature goes on decreasing as we go away from inlet to exit of heat exchanger.

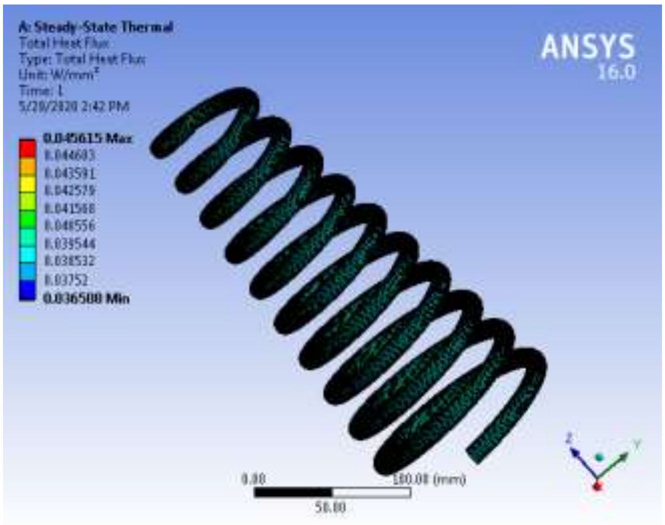

Fig.16 :

Heat flux or thermal flux is the rate of heat energy transfer through a given surface per unit time. The results obtained from ANSYS software simulation for heat flux contour is shown in figure From figure we can say that heat flux is maximum at inner portion of heat exchanger because hot fluid is at the centre. It is also observed that heat flux is 0.4561 watt in inner tube

D. Coupling the results :

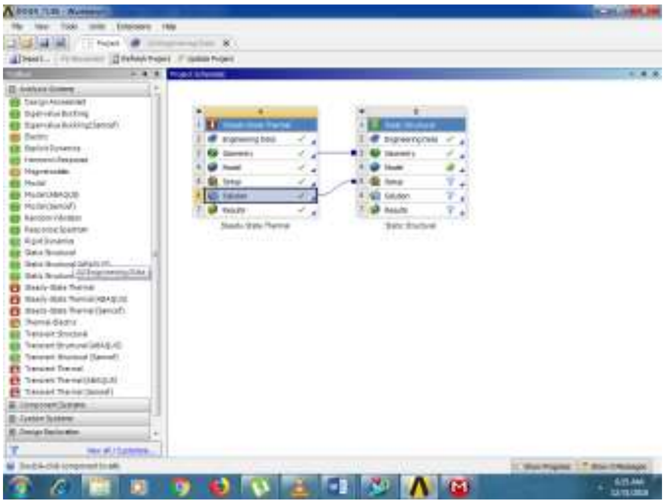

Fig.17 :

The heat exchanger is designed for maximum pressure of 6 bar inside the heat exchanger hence the results of thermal analysis are coupled to the static structural analysis the figure above shows the coupling of the modules

E. Boundary Conditions:

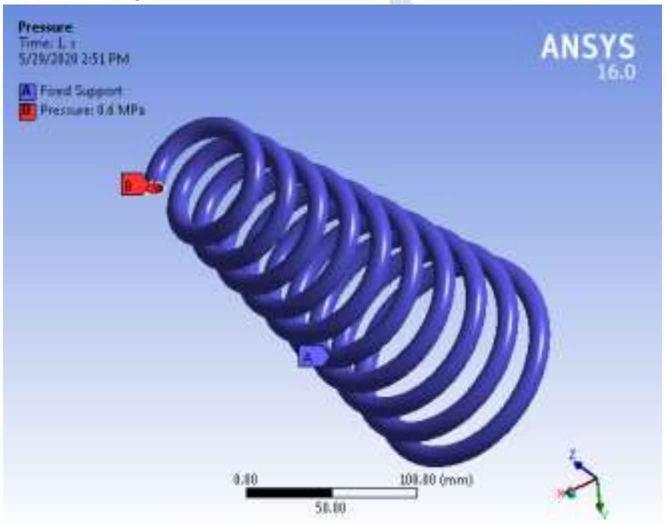

Fig.18 :

An appropriate physics based boundary condition is must for successful solution of governing equation. In design of heat exchanger, the problem boundary i.e. inlet boundary receives high pressure fluid and pass towards bottom finally fluid exit through outlet boundary. Boundary conditions for tubes are:
Pipe inlet pressure 0.6 MPa
Rigid Wall boundary: No-slip adiabatic

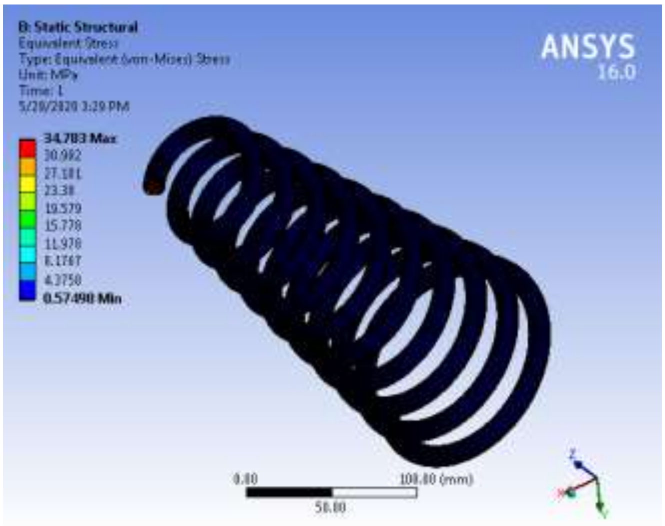

Fig.19 :

The maximum stress induced in the tube is 34.783 Mpa at maximum design pressure of 0.6 Mpa which is below the permissible stress of 66 Mpa hence the heat exchanger inner tubing is safe.

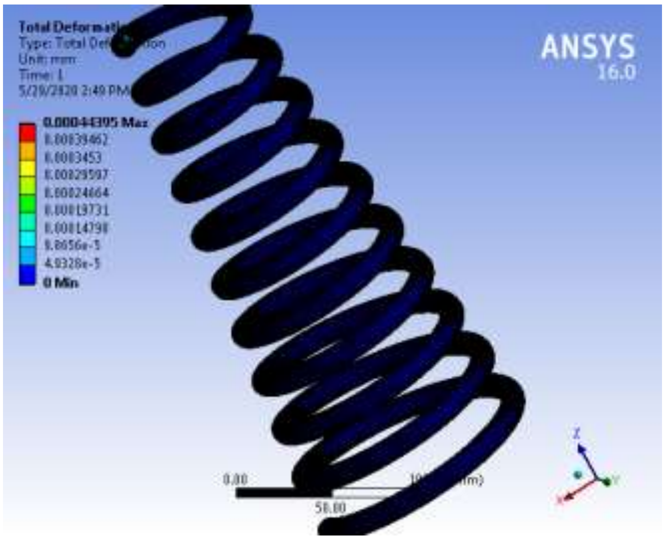

Fig.20 :

The maximum deformation induced is 0.0004439 mm which is negligible hence the inner tubing is safe under given design pressure and thermal conditions

F. Components of Variable Pitch mechanism

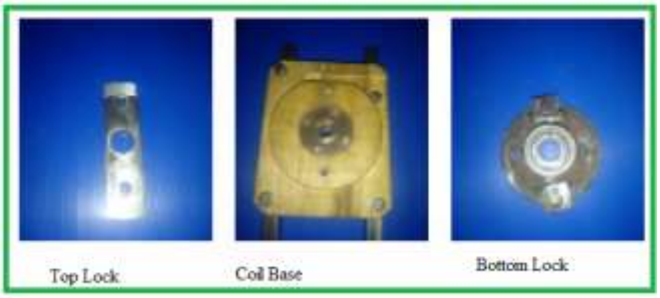

Fig.21 :

IV. STAGES OF EXPERIMENTATION

Stage I: Heat exchanger made from ptfe material and test and trial will be conducted in the parallel flow and counter-flow configurationto determine the LMTD, Capacity ratio, Effectiveness (NTU-Method), Reynolds Number and Overall Heat transfer coefficient and fouling factor. Here two values H1 and H2 will be taken into consideration for the test.

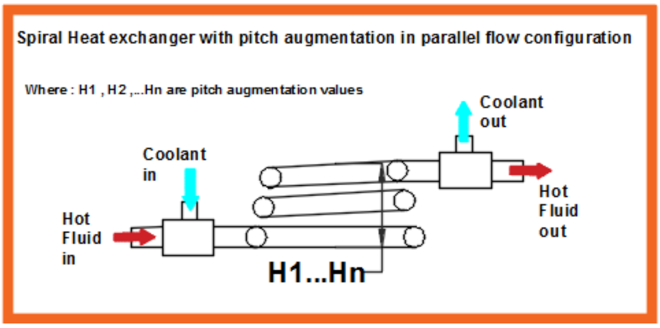

Fig.22 : Conical frustrum Heat Exchanger with Pitch augmentation in Parallel Flow Configuration

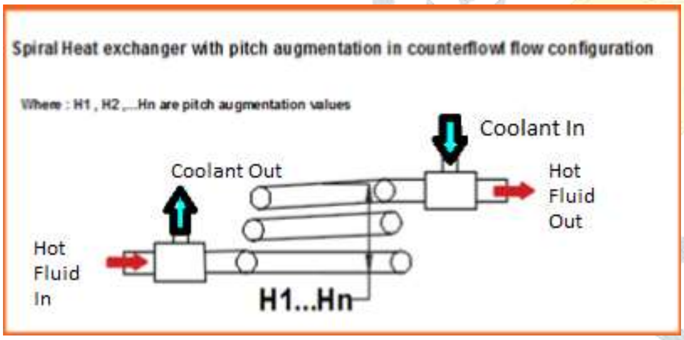

Fig.23 : Conical frustrum Heat Exchanger with Pitch augmentation in Counter Flow Configuration

The arrangement is suitable designed to change the pitch of the coil , the variation is done by rotating the nut in the coil base , and the motion of the screw which translates up or down will cause the pitch to change as it pulls or pushes the top lock along with the movable top end of the coil.

Result and Discussion:

The following results for design of the Fluropolymer Spiral tube in tube heat exchanger

1. Fluropolymer exchangers exhibit excellent corrosion resistance and modest heat transfer abilities and hence can be applied to process industry heat exchangers.
2. The temperature variation contours exhibits the temperature distribution in the tubing with maximum temperature of 950C at the inlet and lowering towards the exit.
3. The heat flux is maximum at inner portion of heat exchanger because hot fluid is at the centre. It is also observed that heat flux is 0.047 watt/mm2 in outer tube.
4. Coupling is introduced between the thermal results and the structural analysis to see the combined effect of thermal and pressure inputs to the heat exchanger.
5. The maximum stress induced in the tube is 37.73 Mpa at maximum design pressure of 0.6 Mpa which is below the permissible stress of 66 Mpa hence the heat exchanger outer tubing is safe.
6. The maximum deformation induced is 0.000691 mm which is negligible hence the outer tubing is safe under given design pressure and thermal conditions.
7. The heat flux is maximum at inner portion of heat exchanger because hot fluid is at the centre. It is also observed that heat flux is 0.0456 watt/mm2 in inner tube.
8. Coupling is introduced between the thermal results and the structural analysis to see the combined effect of thermal and pressure inputs to the heat exchanger.
9. The maximum stress induced in the inner tube is 34.786 Mpa at maximum design pressure of 0.6 Mpa which is below the permissible stress of 66 Mpa hence the heat exchanger outer tubing is safe.
10. The maximum deformation induced is 0.000491 mm which is negligible hence the outer tubing is safe under given design pressure and thermal conditions.
11. The components of the pitch variation mechanism are displayed.

Conclusion:

The design analysis of spiral tube in tube fluropolymer heat exchanger is done successfully done and the dimensions of the inner and outer tube have being determined have being validated using ANSYS workbench using coupling of the thermal and structural analysis. PTFE is selected as the material for the tubes, the heat exchanger will be first developed as a flat spiral and testing will be done in both parallel and counter flow configurations to determine the performance characteristics will be determined.

References:

[1] Jamshid Khorshidi, Salman Heidari , Advances in Chemical Engineering and Science, 2016, 6, 201-208 , Design and Construction of a Spiral Heat Exchanger.

[2] JAY J. BHAVSAR, V K. MATAWALA, S. DIXIT, International Journal of Mechanical and Production Engineering, ISSN: 2320-2092, Volume-1, Issue-1, July-2013, DESIGN AND EXPERIMENTAL ANALYSIS OF SPIRAL TUBE HEAT EXCHANGER.

[3] S R Wharry (Jr), Fluropolymer heat exchnagers , Science Direct Metal Finishing Volume 98, Issue 1, January 2000, Pages 767-768, 770-777.

[4] Kondahkar, G.E. and Kapatkat, V.N. (2012) International Journal of Modern Engineering Research, 2, 930-936Performance Analysis of Spiral Tube Heat Exchanger Used in Oil Extraction System.

[5] Naphon, P. (2007) International Communications in Heat and Mass Transfer, 34, 321-330. Thermal Performance and Pressure Drop of the Helical-Coil Heat Exchangers with and without Helically Crimped Fins. http://dx.doi.org/10.1016/j.icheatmasstransfer.2006.11.009.

[6] Deshpande, P.M. and Dwande, S. (2012) International Journal of Advanced Engineering Research and Studies, **1**, 112-114. Study of Hydrodynamics of Horizontal Spiral Coil Tube.

[7] Tandale, M.S. and Joshi, S.M. (2008) Proceedings of the International Conference on Heat and Mass Transfer, Acapulco, January 2008, 1790-2769. Design of Heat Exchanger for Waste Heat Recovery from Producer Gas.

[8] Ke, Y., Qi, G.P., Cay, S.Y. and Bo, B.W. (2010) Journal of Hydrodynamics, 22, 816-822. Mathematical Analysis of Transverse Vibration of Conical Spiral Tube Bundle with External Fluid Flow.

[9] "Experimental investigation of single phase convective heat transfer coefficient in a corrugated plate heat exchanger for multiple plate configurations" by, T.S. Khan, M.S. Khan, Ming-C. Chyu, Z.H. Ayub..

[10] P. Naphon, "Thermal performance and pressure drop of the helical–coil heat exchangers with and without helically crimped fins." International Communications in Heat and Mass Transfer, vol.34, PP – 321 – 330, 2007.

[11] J.P. Hartnett & W.J. Minkowycz, "An Experimental Study on The in Tube Convective Heat Transfer Coefficient In Spiral Coil Heat Exchanger." International Communication in Heat Mass Transfer, vol. 29, PP– 797 – 809, 2002.

[12] Kondahkar, G.E. and Kapatkat, V.N. (2012) Performance Analysis of Spiral Tube Heat Exchanger Used in Oil Extraction System. International Journal of Modern Engineering Research, 2, 930-936

[13] M. P. Nueza & G.T. Polley & L. C.Davalos & G. M. Rodriguez, "Design Approach For Spiral Heat Exchangers." Institution of Chemical Engineers, Vol. 85, PP–322–327, 2007.

[14] A.M. Fuentes, & L.C. Davalos, & M. P. Nunez, "Alternative design approach for spiral plate heat exchangers.

[15] A numerical and experimental study of chevron, corrugated-plate heat exchangers" by, Xiao-Hong Han, Li-Qi Cui, Shao-Jie Chen, Guang-Ming Chen, Qin Wang.

[16] Aydin Durmus, Huseyin Benli, Irfan Kurtbas, Hasan Gul, "Investigation of heat transfer in plate heat exchangers having different surface profiles", International Journal of Heat and Mass Transfer 52 (2009) 1451–1457.

[17] R. K. PATIL, & B.W. SHENDE,&P.K.GHOSH,"Designing Of Helical Coil Heat Exchanger."Chemical Engineering, PP – 85 – 88, Dec. 1982.

[18] Dr. M. S. Tandale & S. M. Joshi., "Design Of Heat Exchanger For Waste Heat Recovery From Producer Gas." International Conference on Heat and Mass transfer, Acapulco, Mexico, ISSN No. 1790 – 2769,Jan. 2008.

[19] Nueza, M.P., Polley, G.T., Davalos, L.C. and Rodriguez, G.M. (2007) Design Approach for Spiral Heat Exchanges. Institution of Chemical Engineering, 85, 322-327.

[20] Sadik Kakac & Hongton Liu (2002), Heat Exchangers: Selection,Rating and Thermal Design,Department of Mechanical Engineering University of Miami.