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Design and finite element analysis of concentric pipe heat exchanger

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ABSTRACT

The dissertation work describes the design optimization & FEA of concentric pipe heat exchanger. It is proposed to study the abnormal behaviour of inner pipe of heat exchanger. The concentric pipe heat exchanger using material SA 516 Grade 70 which is discussed in this report has covered making the design (thickness) optimization of inner pipe when inner pipe is subjected to deflection & stresses under self-weight, induced internal pressure & temperature in heat exchanger. Deflection &Von Mises Stress developed in inner pipe at different stage evaluated in ANSYS.In order to reduce the high stress developed in inner pipe can be reduced by making addition of saddles to the extreme end of inner pipe.The objective of this project to use Finite Element of Analysis to optimize the inner pipe thickness of the concentric pipe heat exchanger, reducing its stresses & deflection induced in the inner pipe during operating condition of heat exchanger by making analysis of concentric pipe heat exchanger.

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I. INTRODUCTION

Heat exchanger may be defined as equipment which transfers the energy from a hot fluid to a cold fluid, with maximum rate and minimum investment and running cost. Heat exchangers are mostly used devices in many areas of the industries such as material processing, food preparation refrigerators, radiators for space vehicles, automobiles and air conditioning etc. A lot of methods are applied to increase the thermal performance of heat transfer devices such as treated surfaces, rough surfaces, swirling flow devices, coiled tubes, and surface tension devices.

A great deal of research has focused on various augmentation techniques with emphasis on rough surfaces, transverse or spiral ribs, transverse grooves, knurling, corrugated and spirally corrugated tubes, straight fins, and spiral and annular fins. Nano fluids have been found to possess enhanced thermo physical properties such as thermal conductivity, thermal diffusivity, viscosity, and convective heat transfer coefficients compared to those of base fluids like oil or water.

Large heat transfer area leads to high thermal efficiency of the device. Its working principle is to cool rapidly large amount of gaseous or liquid medium. Because of its compact size, it is possible to use it for easy installation in various systems, like the heating, drying, air conditioning and the other systems [1].

A. Classification of Heat Exchanger

There are three main types of heat exchangers:

1) RecuperativeType:In this type the flowing fluids exchanging heat are on either side of a dividing wall.
2) Regenerative Type:In this type the hot and cold fluids pass alternately through a space containing a matrix of material that provides alternately a sink and a source for heat flow.
3) Evaporative Type:In this type a liquid is cooled evaporatively and continuously in the same space as the coolant.
The relative directions of the flow of the hot and cold fluids in concentric pipe heat exchanger, into two types:
a. Co-Current Flow:
When both the fluids move in parallel in the same direction.
b. Counter Current Flow:
When both the fluids move in parallel but in opposite directions. [2]

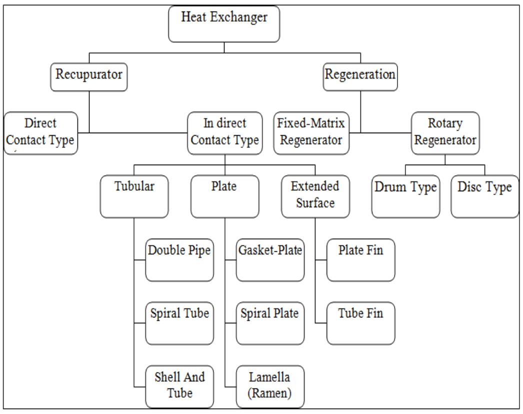

Fig. 1 Classification of Heat Exchanger [3]

B. Concentric Pipe Heat Exchanger
A typical concentric pipe heat exchanger consists of one pipe placed concentrically in side another of larger diameter with appropriate fittings to direct the flow from one section to the another section. One fluid flows through the inner pipe and other fluid flows through the annular space. Concentricpipe heat exchangers can be arranged in various series and parallel arrangements to meet pressure drop and mean temperature difference requirements.
The major use of double pipes exchangers for sensible heating or cooling of process fluids where small heat transfer area required. This configuration is also very suitable for one or both fluids are at high pressure because of the smaller diameter of the pipe. The major disadvantage is that concentricpipe heat exchangers are bulky and expensive per unit transfer surface. Inner tube being may be single tube or multi-tubes. If heat transfer coefficient is poor in annulus, axially finned inner tube can be used. Concentric pipe heat exchangers are built in modular concept, i.e., in the form of hairpins [3].

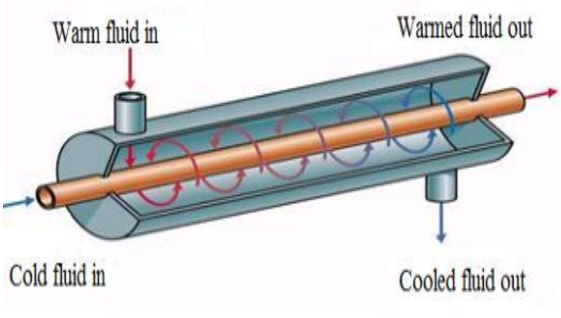

Fig 2Concentric Pipe Heat Exchanger [3]

C. Heat Transfer Augmentation Techniques
Heat transfer augmentation techniques are generally classified into three categories namely: Active techniques, Passive techniques and Compound techniques.

1) Active Techniques: Active techniques involve some external power input for enhancement of heat transfer.
Example: Mechanical aids, Surface vibrations, Fluid vibrations and Jet impingement.

2) Passive Techniques: Passive techniques do not require any direct input of external power. They generally use geometrical or surface modifications to the flow channel by incorporating inserts or additional devices.
Example: Rough Surfaces, Extended Surfaces, Swirl Flow Devices and Coiled Tubes.

3) Compound Techniques: Combination of active and passive techniques may be employed simultaneously to obtain enhancement in heat transfer that is greater than that produced by any of those techniques separately. This simultaneous utilization is termed compound enhancement

II. LITERATURE REVIEW

A. Prior Work Review on Concentric Pipe Heat Exchanger
1) Antony Luk. A & Ganesan M:Heat transfer enhancement in dimpled tubes heat exchanger with varying geometry were used for comparison with standard smooth plain concentric tubes. Augmented surface has been achieved with dimples strategically located in a pattern along concentric tube heat exchanger with the increased area on the tube side. In this design hot flue gas is used in inner tube and nano fluid is used in outer tube. Here In this study the properties of nano fluid from the alumina as the nano fluid with ethyl glycol as the base fluid.
From this design calculation, the heat transfer co-efficient is increased compared to plain concentric tube heat exchanger. Similarly the effectiveness is 8% increased compared to plain concentric tube heat exchanger. The theoretical results show that the using dimpled tube in concentric tube heat exchanger gives better performance. modeling and analysis is carried out to vary the dimple tube cross sections, ellipsoidal and spherical shapes From theoretical results shows that dimpled tube heat exchanger gives better performance [1].

2) Folaranmi Joshua:Thisstudy describes an overviewof an analytical method applicable to the design of concentric tube heat exchanger (counter flow type). During the design

of heat exchange method of logarithmic mean heat exchanger is adopted & the temperatures of the hot and cold water supplied to the equipment were 87°C& 27°C respectively and the outlet temperature of the water after the experiment was 73°C for hot and 37°C for cold water.
The results of the experiment were tabulated. The heat exchanger was 73.4% efficient and has an overall coefficient of heat transfer of 711W/m^{2}k &48° Clog mean temperature difference. The overall heat coefficientand the efficiency were computed. Results obtained show that the heat exchanger waseffective [2].

3) M. Kannan, S. Ramu, S. Santhanakrishnan, G. Arunkumar, Vivek M.: The experimental comparison of different types of heat transfer enhancement techniques or methods in heat exchangers by extended surfaces, obstruction devices and swirl flow device. The system has followed different geometric profiles for attainable heat transferred in experimental result and compare with simulation result. The objective of these Experiments is to assist the general heat transfer processes and the methods and devices that can be implemented to enhance more heat transfer rate. The experimental setup and apparatus required to carry out the double pipe heat exchanger experiment.
The apparatus includes tube-within-a-tube heat exchangers with threaded thermometer at each end, measuring flask, a water pump and electric geyser device.Three of the four heat exchangers are modified by one type of the above-mentioned heat transfer enhancement techniques. These methods used to found out the heat loss from the surface and related temperature of fluid motions also used to found the effectiveness, the effectiveness are having to compare the different flow rates forwhich one is maximum possible heat transfer in double pipe heat exchanger.Annular method is higher rate of heat transfer than other three methods.
This project has discussed and outlined an experimental setup for the evaluation of different heat exchanger enhancement techniques. Different mass flow rate readings were recorded. It was observed that the heat transfer loss and gain by hot and cold fluid. Finally, from the experimental and analytical results it is concluded that the annular method reached higher heat transfer than other methods [5]
.4) Sameer H. Ameen, Deyaa Mohammed N. Mahamood, Laith Najim A. Alameeer: The heat exchanger of double pipes was constructed in the present paper from a copper alloy with inclined parabolic fins fixed over the outer surface of its inner pipe with different angles. The Parabolic fins improved the local heat convection to about 2.42 more than pipes without fins.
All combinations of fin's angle have enhanced performance of heat exchanger concerning the heat fluxand the temperature gradient to about 2.42. Heat exchanger inner pipe which has 60° fin's angle has proved to be the best among other angles due to its higher ζ factor of 24.72 W/MN for both structural and thermal analyses [6].

III.DESIGN INPUT PARAMETERS & CALCULATION FOR CONCENTRIC PIPE HEAT EXCHANGER

A.Input Parameters
Table 1 Input Parameter of Heat Exchanger

Sr No.	Parameter Description	Notations	Given value
1	Internal Pressure	P	0.2 MPa
2	External Pressure	P_o	Atm.
3	Vessel Radius	R	2100 mm
4	Nozzle Diameter	D_n	1715 mm
5	Number of Nozzle	n	8
6	Support Height	h	2000 mm
7	Heat Transfer Coefficient	hc	11.3 w/m^{2}k
8	Length of Shell	L_o	26635 mm
9	Thickness of Shell	n_t	18 mm
10	Length of Shell with Exterior Projection	$L_{0\ (\text{Exterior Proj})}$	36135 mm
11	Length of Pipe	L_p	45835 mm
12	Shell & Nozzle Corrosion	nca	3 mm
13	Diameter of Tube sheet	$D_{\text{Tube Sheet}}$	3430 mm
14	Thickness of Tubesheet	$T_{\text{req(Tube Sheet)}}$	6 mm
15	Thickness of Circular Plate	h	30 mm
16	Diameter of Reinforcing Pad	D_{RP}	2572.5 mm
17	Diameter of Inner Pipe	$D_{\text{Inner Pipe}}$	2425 mm
18	Saddle Height	h_s	2000 mm
19	Saddle Length	L_s	3800 mm

B. Material Properties of Concentric Pipe Heat Exchanger
Material = SA 516 Grade 70.
Maximum allowable stress (S)= 20000 psi =137.8951MPa.
Modulus of Elasticity (E) = 200 GPa.
Poisson's Ratio (μ) = 0.29.
Density = 7850 kg/m^3.

C. Theoretical Analysis

1) Thickness of Inner Pipe:
Now, we have to calculate thickness of inner pipe,
From ASME SECTION VIII, div –I, UG27
Inner pipe diameter
$D_{\text{Inner Pipe}}$ = 2425 mm
$R_{\text{Inner Pipe}}$ = 1212.5 mm
Inner pipe corrosion allowance = 3 mm

$$T_{\text{req(Inner Pipe)}} = \frac{PR}{SE-0.6P} + \text{Corrosion allowance}$$

$$= \frac{0.2\times1212.5}{137.895\times1-0.6\times0.2} + 3$$

$$= 1.76 + 3$$

$$= 4.76 \text{ mm}$$

Nominal thickness of inner pipe is 6 mm.
Inner pipe thickness can be taken as 12 mm i.e. (2t + Inner Pipe Dia.).
Similarly, Inner pipe optimization can be done for 12mm, 18mm, 24 mm & 30 mm thickness & can be analysed under self-weight, internal pressure & temperature 250 Degree in ANSYS.
Their deflection & stresses of inner pipe evaluated in ANSYS results have been given in the table.

IV. FINITE ELEMENT ANALYSIS

The present work uses ANSYS for finite element analysis of concentric pipe heat exchanger. The modeling of concentric pipe heat exchanger has done in ANSYS 15.0;Static Structural Analysis is carried out to evaluate ANSYS results for Deflection & Von Mises stresses of inner pipe under self-weight, induced internal pressure & temperature 250 °C.

A. Generating Concentric Pipe Heat Exchanger Model & Static Structural Analysis in ANSYS

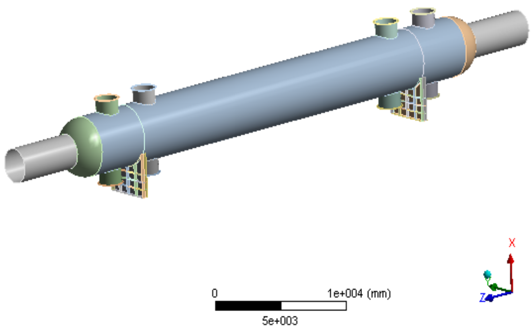

Fig. 3 Model of Concentric Pipe heat Exchanger (t=12mm)

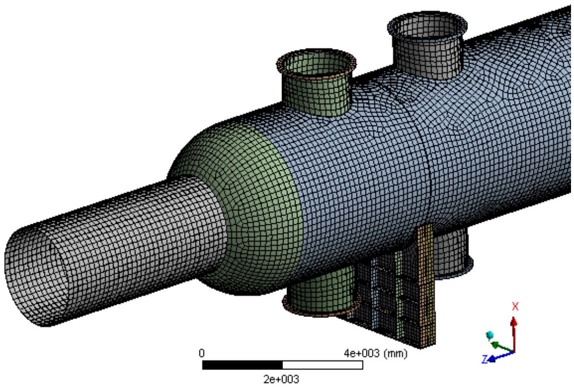

Fig. 4 Meshing of the Model of Concentric Pipe heat Exchanger (t=12mm)

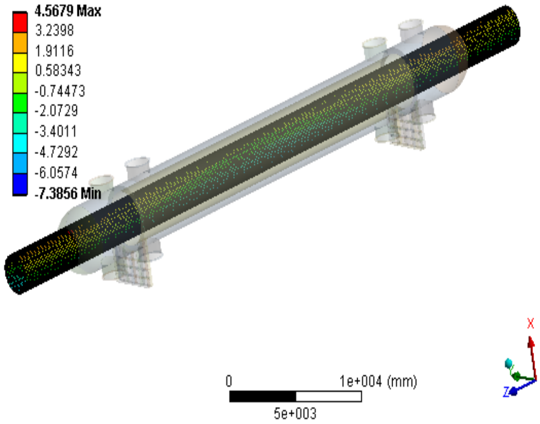

Fig. 5 Deflection of Inner Pipe heat Exchanger(t=12mm)

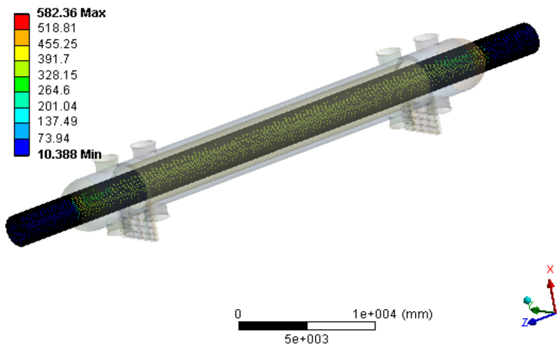

Fig. 6 Von-Mises Stress of Inner Pipe heatExchanger (t=12mm)

B. Results & Discussion

Table 2ANSYS Inner Pipe Results under Self Weight

ANSYS Inner Pipe Results Under Self Weight				
Sr No	Thickness	Deflection Upper Side (mm)	Deflection Lower Side (mm)	Stress (MPa)
1	12 mm	0.972	-6.167	26.362
2	18 mm	0.733	-6.585	27.013
3	24 mm	0.474	-6.939	27.045
4	30 mm	0.208	-7.269	28.127

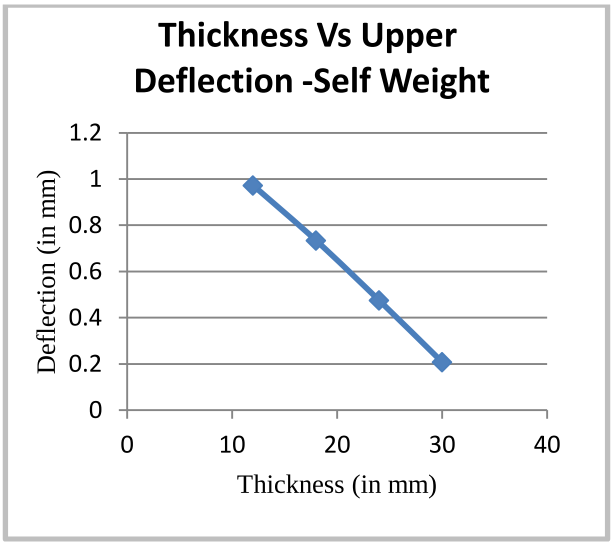

Fig.7Thickness Vs. Deflection UpperSide-Self Weight

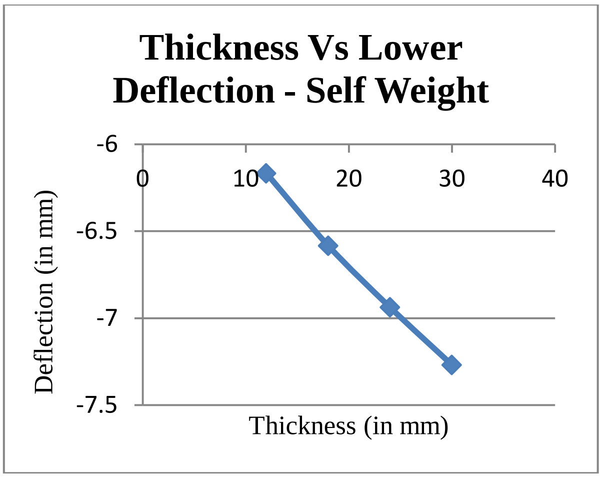

Fig.8Thickness Vs. Deflection Lower Side-Self Weight

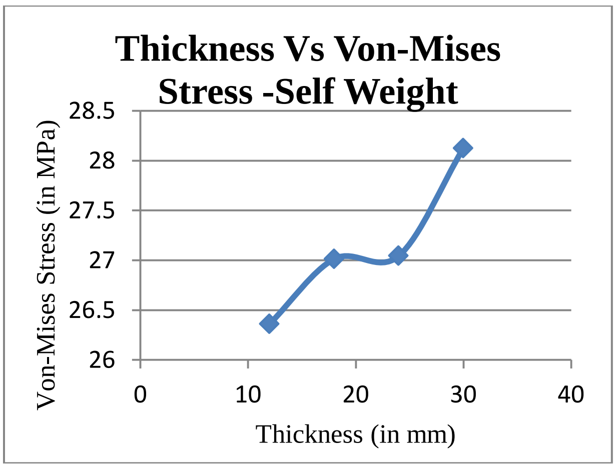

Fig. 9Thickness vs. Von-MisesStress-Self Weight

Table 3 ANSYS Inner Pipe Results under Self Weight + 0.2 MPa Pressure.

ANSYS Inner Pipe Results Under Self Weight + 0.2 MPa Pressure				
Sr No	Thickness	Deflection Upper Side (mm)	Deflection Lower Side (mm)	Stress (MPa)
1	12 mm	1.087	-6.255	29.157
2	18 mm	0.819	-6.640	29.265
3	24 mm	0.543	-6.976	29.331
4	30 mm	0.265	-7.295	29.086

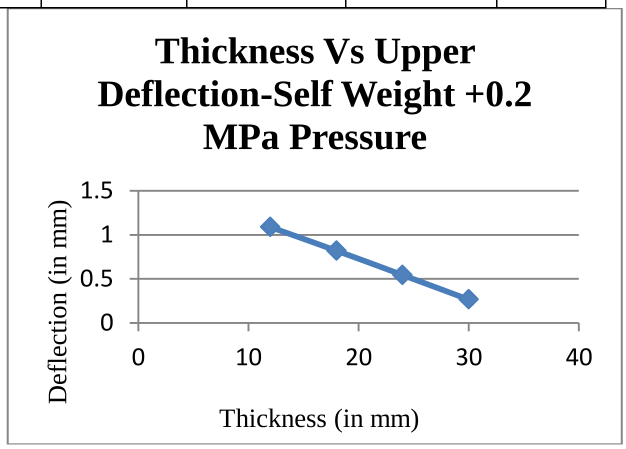

Fig. 10 Thickness vs. Deflection Upper Self Weight+0.2 MPa Pressure

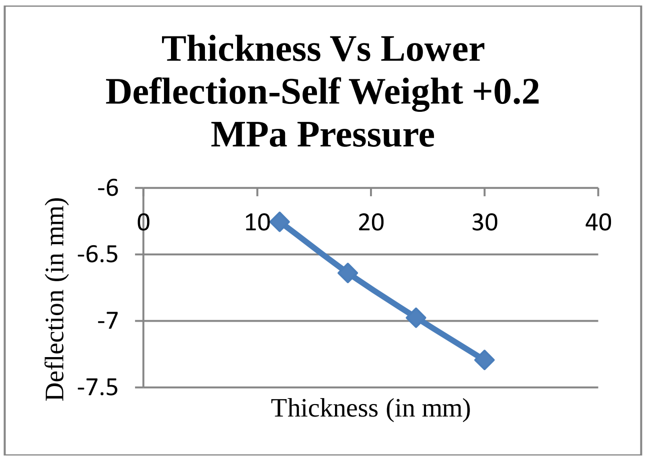

Fig. 11Thickness vs. Deflection LowerSelf Weight+0.2 MPa Pressure

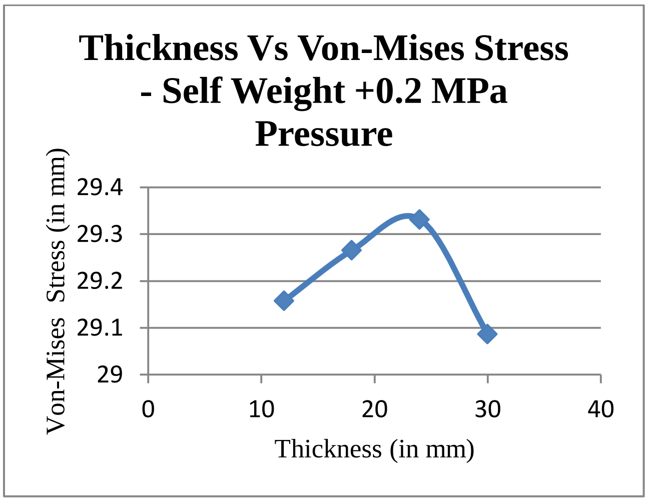

Fig. 12 Thickness vs. Von-Mises Stress Self Weight+0.2 MPa Pressure

Table 4 ANSYS Inner Pipe Results under Self Weight + 0.2 MPa Pressure + Temp 250 Deg.

ANSYS Inner Pipe Results Under Self Weight + 0.2 MPa Pressure + 250 Deg Temperature				
Sr No	Thickness	Deflection Upper Side (mm)	Deflection Lower Side (mm)	Stress (MPa)
1	12 mm	4.567	-7.385	582.358
2	18 mm	4.126	-8.169	549.700
3	24 mm	3.629	-8.798	506.121
4	30 mm	3.114	-9.364	471.807

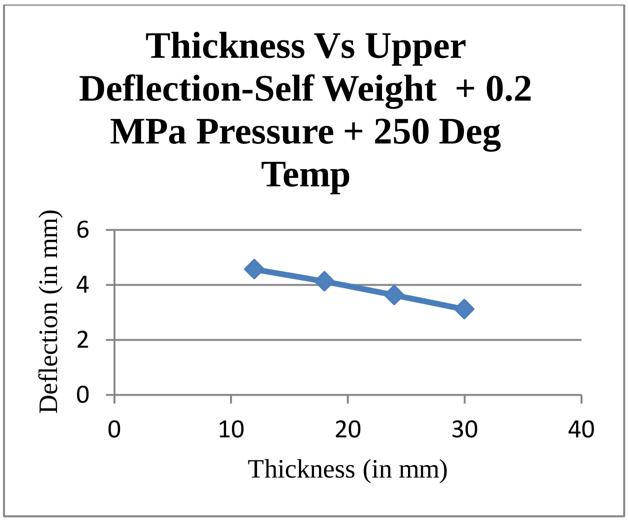

Fig. 13Thickness vs. Deflection UpperSelf Weight+0.2 MPa Pressure+Temp250 Deg

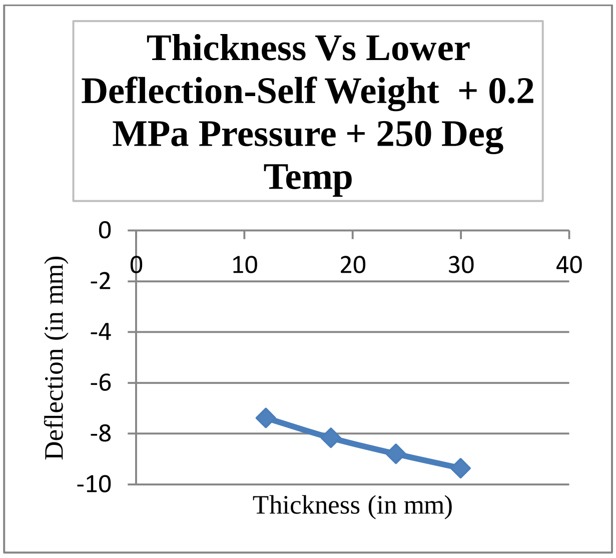

Fig. 14 Thickness vs. Deflection LowerSelf Weight+0.2 MPa Pressure+Temp 250 Deg

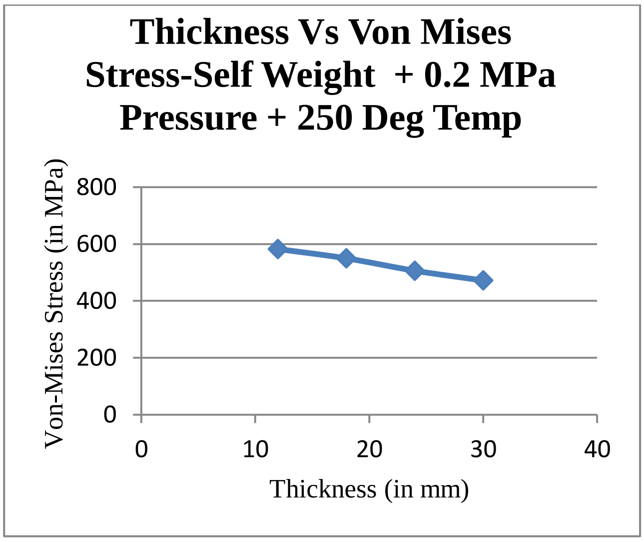

Fig. 15 Thickness vs. Von-Mises Stress Self Weight+ 0.2 MPa Pressure+Temp 250 Deg

C. Modificationin the Concentric Pipe Heat Exchanger

After optimizing thickness, considering 12 mm as final thickness with less deflection in the inner pipe, but stress induced with this thickness is more.
In order to reduce the stresses in the inner pipe, the extreme end of the pipe is supported with additional saddle inner pipe stress & deflection is evaluated in ANSYS.
Results for different thickness are tabulated in the table below.

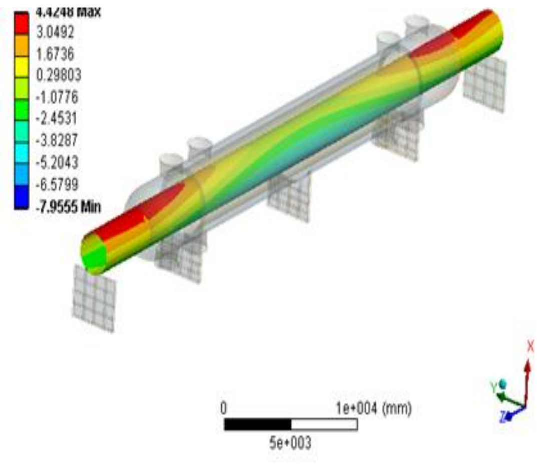

Fig. 16 Deflection of Inner Pipe heat Exchanger(t=12mm)

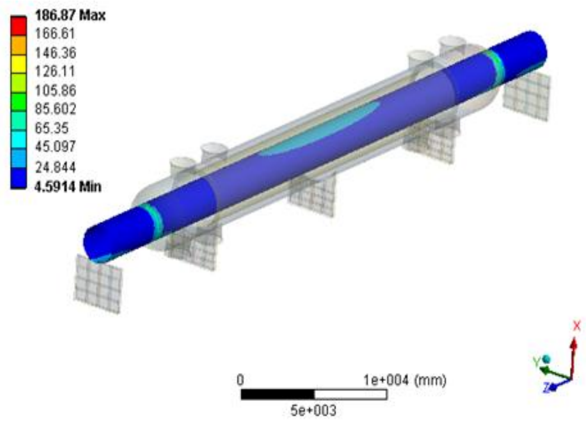

Fig. 17 Von-Mises Stress of Inner Pipe heat Exchanger (t=12mm)

Table 4 ANSYS Inner Pipe Results under Self Weight + 0.2 MPa Pressure + Temp 250 Deg (Extra Saddle)

ANSYS Inner Pipe Results Under Self Weight + 0.2 MPa Pressure + 250 Deg Temperature + Extra Saddles				
Sr No	Thickness	Deflection Upper Side (mm)	Deflection Lower Side (mm)	Stress (MPa)
1	12 mm	4.424	-7.955	186.87
2	18 mm	4.186	-8.294	185.56
3	24 mm	4.046	-8.726	184.27
4	30 mm	3.923	-9.186	182.88

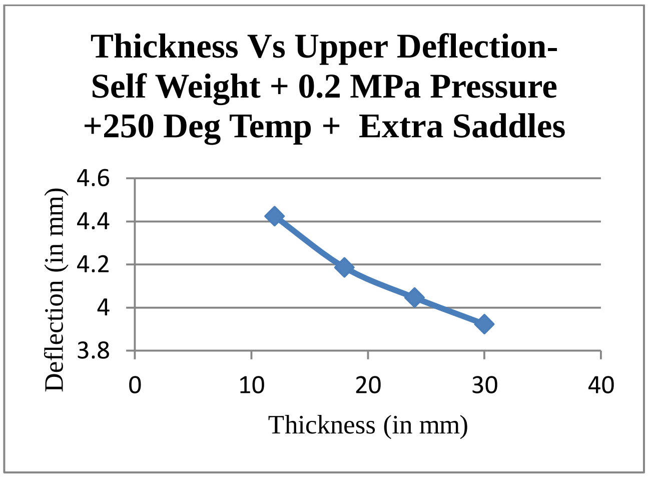

Fig. 18 Thickness vs. DeflectionUpperSelf Weight+0.2 MPa Pressure+Temp250 Deg (Extra Saddle)

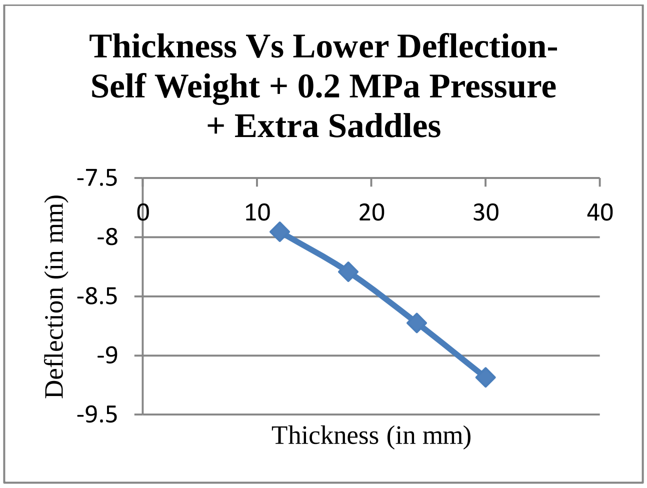

Fig. 19Thickness vs. Deflection LowerSelf Weight+0.2 MPa Pressure+Temp250 Deg (Extra Saddle)

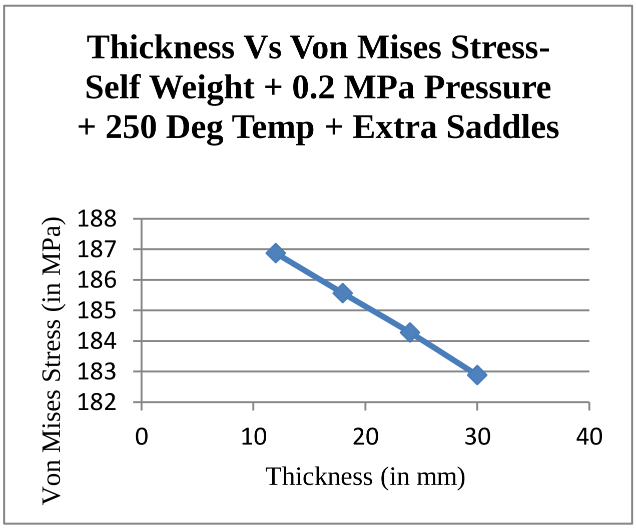

Fig. 20Thickness vs. Von-Mises StressSelf Weight+0.2 MPa Pressure+Temp 250 Deg(Extra Saddle)

VI. CONCLUSION.

The static structural analysis is carried out for inner pipe thickness optimization for 12mm, 18 mm, 24mm & 30 mm. It is observed that the deflection of inner pipe in the upper side (i.e. upward) is getting slightly decreases from 12 mm to 30 mm (4.567 mm to 3.114 mm) whereas deflection of inner pipe in the lower side (i.e. downward) is getting increases from 12 mm to 30 mm (-7.385mm to -9.364mm). The von mises stress induced in inner pipe from 12 mm to 30 mm thickness as (582.358 mm to 471.807 mm).

Considering different thicknesses ANSYS results, the minimum deflection induced in inner pipe for 12 mm thickness is defined as optimized inner pipe even though; comparing its stress induced in inner pipe for 12 mm thickness is (582.358 MPa) is slightly higher than the other thickness. In order to reduce the stress induced in the inner pipe for 12 mm, it is time to make addition of extra saddles to the extreme end of inner pipe & verified their results in ANSYS in terms of deflection & von-mises stress.

At last we found that, the stress induced in the inner pipe with different thickness slight get changes leads to decrease the induced stresses compare to previous results (i.e. induced stress for 12 mm thickness is 186.87 MPa) so considering optimized inner pipe thickness as 12 mm carrying extra saddles has less deflection & stress.

For concentric pipe heat exchanger inner pipe 12 mm thickness can be considered as the best optimized thickness of inner pipe among the others.

VII. SCOPE FOR FUTURE WORK

Concentric pipe heat exchangers inner pipe having changes in the geometry can be investigated using similar procedure. It is important because it is observed that having more heat transfer rate can leads to less deflection & stresses induced in the inner pipe.

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