Optimization of Concentric Pipe Heat Exchanger as Per Asme Code using Finite Element Analysis

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Abstract - The dissertation work describes the optimization & FEA of concentric pipe heat exchanger. It is proposed to study the abnormal behaviourof concentric pipe heat exchanger when hot & cold fluids are passed through pipes. The concentric pipe heat exchanger using material SA 516 Grade 70 which is discussed in this report has covered making the (thickness) optimization of inner pipe, tubesheets, and nozzlesas per ASME Code in order to reduce induced von-mises stress & deflection in the concentric pipe heat exchanger. Deflection & Von-mises stress inducedin concentric pipe heat exchangerat different stagesanalyzed in ANSYS 15.0. UHX 14 Case is solved with hot fluid 250° C & cold fluid 100° C are passed through pipe to know behaviour of heat exchanger in terms of von-mises stress & deformation. Finally at different temperature the behaviour of heat exchanger is analyzed & compared ANSYS results with experimental results for validation. It is observed that there is good agreement between ANSYS & experimental results.

Keywords – *FEA, Heat Exchanger, Inner Pipe, Nozzle, Saddle, Tubesheet.*

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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]

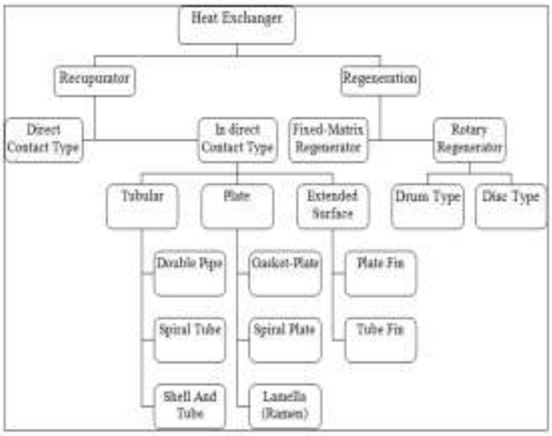

Fig. 1 Classification of Heat Exchanger [3]

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].

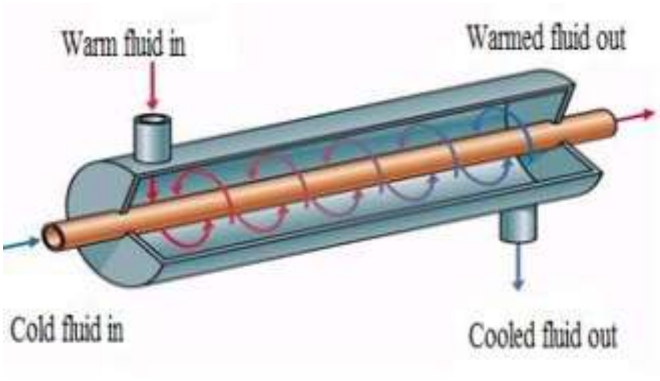

Fig.2Concentric Pipe Heat Exchanger [3]

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 [4]

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: This study 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^2k &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, LaithNajim 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	$L_{0\ (Exterior\ \ Proj\ )}$	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	$T_{req\ (Tube\ \ Sheet\ )}$	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	13861 mm

B. Material Properties of Concentric Pipe Heat Exchanger

Material = SA 516 Grade 70
Maximum allowable Stress = 20000 psi
= 137.8951 MPa
Modulus of Elasticity (E) = 200GPa
Poisson's Ratio (μ) = 0.29
Density = 7850 kg/m3 [7] [11].

C. Optimization of Concentric Pipe Heat Exchanger in ANSYS

1) Modeling:

Fig. 3: Concentric Pipe Heat Exchanger

a. Meshing:

Element Size : 150 mm
Element Type : Quadrilateral.

Optimization for thickness is carried by using,

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

Where,

Treq = Shell wall thickness (mm)
P = Internal Pressure (MPa).
R = Radius of Shell (mm).
S = Allowable Strength of Material (MPa).
E = Welding Efficiency [9].

2) Both Saddles Fixed:

Table 2: Shell Thickness vs Stress & Deformation

Sr. No.	Shell Thickness in (mm)	Von-Mises Stress (MPa)	Deformation (mm)
1	12	1155.4	28.202

The above table 2 shows that when both saddles are fixed & 0.195 MPainternal shell pressure is applied then the maximum von-mises stress (more than 414 MPa as per ASME code) & deformation are induced in the shell. Now, by making one saddle fixed & other free von-mises stress& deformation will be analyzed.

3) One Saddle Fixed & Other Saddle Free:

Table 3: Shell Thickness vs Stress & Deformation

Sr. No.	Shell Thickness in (mm)	Von-Mises Stress (MPa)	Deformation (mm)
1	12	1034.3	33.719

The above table 3 shows that von-mises stress induced in the heat exchanger is reduced, considering shell thickness as 12 mm as per availability of material is concerned. For 12 mm shell thickness von-mises stress induced is quite less in one saddle fixed & other free as compare with both saddle fixed.

4) Optimization of Inner Pipe:

In order to reduce further amount of stress it's necessery to optimize the inner pipe & tubesheet.

Figure 4 : Inner Pipe

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 (mm)**	**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	549.7
3	24 mm	3.629	-8.798	506.121
4	30 mm	3.114	-9.364	471.807

The above table shows that optimization of inner pipe for deflection & von-mises stress for different thickness is calculated still there is large von-mises stress induced in the pipe So, by making addition of saddles at extreme ends of inner pipe the deflection & von-mises stresses in the inner pipe can be reduced.

4) Addition of Saddles at Extreme End:

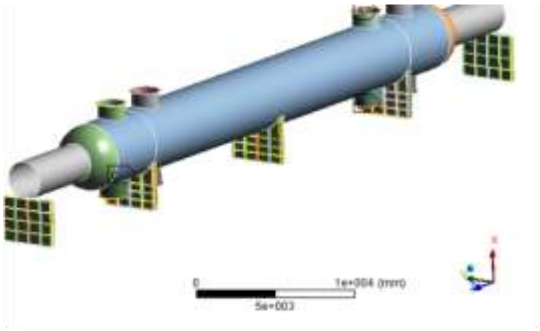

Fig. 5: Addition of Saddle (at Extreme End)

Table 5: 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

The above table 5 shows that the amount of stress & deflection are reduced by making addition of saddles to the inner pipe at extreme end.

5) Optimization of Tubesheet:

Fig. 6: Circular Plate with Hole (Tube Sheet)

Table 6: Tube sheet Thickness vs. Von-Mises Stress

Sr. No.	Tube Sheet Thickness (in mm)	Von-Mises Stress (in Mpa)	
		Tube Sheet (T_1)	Tube Sheet (T_2)
1	30	404.61	457.48
2	35	388.8	448.7
3	40	466.94	452.85
4	45	359.46	470.95
5	50	417.83	413.75
6	55	385.66	383.52
7	60	353.3	351.75

Optimization of intermediate pipe tubesheet is calculated in ANSYS for different thickness as shown in table.The optimum thickness for Tubesheet is as 55 mm.

6) Optimization of Nozzle Thickness:

Figure 7: Nozzles

Table 7: Nozzle Thickness vs Area

Sr. No.	Nozzle Thickness (mm2)	Required Area (mm2)	Actual Area (mm2)
1	9	10372.32	31305.18
2	12	10372.32	10725.18
3	18	10372.32	22230.18
4	24	10372.32	34455.18

Optimization of nozzle thickness is carried out with different thickness nominal thickness is taken as 12 mm against required thickness.

IV. RESULTS & DISCUSSION IN ANSYS & EXPERIMENTAL

A) Structural & Thermal Analysis

1) Modeling:

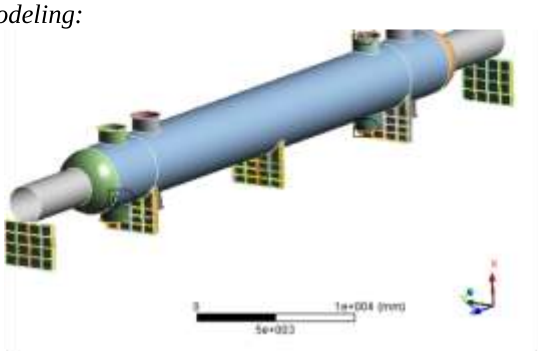

Fig.8: Concentric Pipe Heat Exchanger

a. Meshing
Element Size : 150 mm
Element Type : Quadrilateral.
Number of Elements: 103640.
Number of Nodes : 82821

2) Boundary Condition:

Boundary conditions are applied for concentric pipe heat exchanger before structural & thermal analysis.

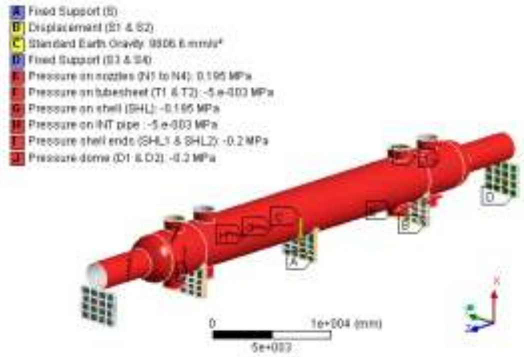

Fig.9: Boundary Condition_1

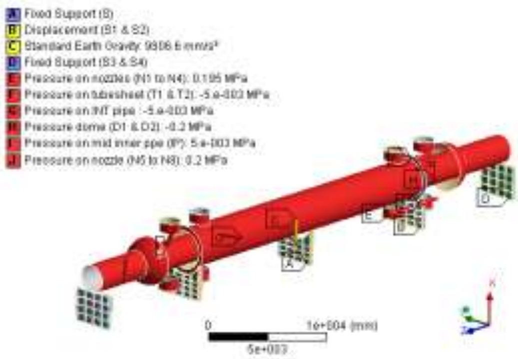

Fig. 10: Boundary Condition_2

In this UHX Case 14 pressure & temperature of hot & cold fluid (as shown in table 8) is applied in inner pipe, intermediate pipe & shell then, structural & thermal analysis is carried out in ANSYS workbench to know von-mises stress & deformation in the concentric pipe heat exchanger.

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Table 8: Geometrical Specifications

Sr. No.	Parameter	Inner Pipe (mm)	Intermediate Pipe (mm)	Shell (mm)
1	Diameter	2425	3430	4200
2	Thickness	12	6	12
3	Fluid	Hot Fluid	Cold Fluid	Hot Fluid
4	Pressure	0.2 MPa	0.195 MPa	0.2 MPa
5	Temperature (Inlet)	250° C	100° C	250° C
6	Temperature (Outlet)	100° C	250° C	100° C

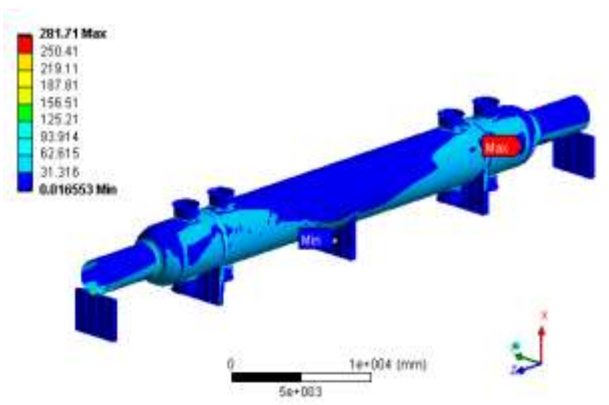

Fig. 11: Von-Mises Stress (Case 14)

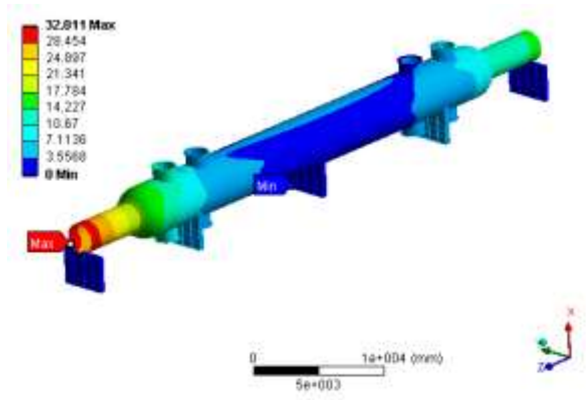

Fig. 12: Total Deformation (Case 14)

Similarly, at different temperature von-mises stress & deformation are tabulated in table 9 & 10.

3) Temperature Variation Trends:

Table 9: Temperature vs. Deformation

Sr. No.	Temp (°C)	Deformation (mm)	Experimental (mm)
1	230	28.931	25.6
2	240	30.644	27.1
3	250	32.011	29.3
4	260	34.079	31.4
5	270	36.798	32.0

Table 10: Temperature vs. Von-Mises Stress

Sr. No.	Temp (°C)	Von-Mises Stress (mm)	As Per ASME Code (mm)
1	230	265.85	414
2	240	273.78	414
3	250	281.71	414
4	260	289.64	414
5	270	297.57	414

As the temperature varies in the concentric pipe heat exchanger doesn't allow exceeding von-mises stress & deformation beyond specified limit. It indicates the optimized design model is safe.

B) Experimental Results

1) Comparison of ANSYS & Experimental Results:

Table 11: Comparison of ANSYS & Experimental Results

Case 14	Thermal Expansion of Heat Exchanger in mm (Deformation)		% Error
	ANSYS	Experimental	
Inner pipe, intermediate pipe & shell side acting pressure Simultaneously with thermal expansion	32.011	29.3	8.47

Case 14 shows that the Inner pipe, intermediate pipe & shell side are subjected to pressure simultaneously with thermal expansion. In ANSYS deformation induced in concentric pipe heat exchanger is 32.011mm at inner pipe extreme end

& it is experimentally validated, observed 29.3 mm. It is observed that there is good agreement between ANSYS results & experimental results & percentage error is 8.47.

V. CONCLUSION

1. The thickness optimization for inner pipe, intermediate pipe's tubesheet& nozzles are carried out to reduce the induced high von-mises stresses & deformation in the concentric pipe heat exchanger.
2. The optimized thickness itself indicates that it's von-mises stress & deformation getting reduces. Similarly, When hot & cold fluid enter into the pipe the von-mises stress is observed as within permissible stress value as per ASME code & deformation induced in the pipe in ANSYS also validated experimentally.
3. It is observed that there is good agreement between ANSYS resulta& experimental.
4. At 250° C temperature the induced von-mise stress in ANSYS is 281.71 against 414 MPa (required as per ASME code). & the deformation induced in the pipe in ANSYS is 32.011 mm against 29.3 (Experimental validated result). The percentage error is 8.47.

VI. SCOPE FOR FUTURE WORK

The applications of Computational Fluid Dynamics (CFD) in the field of heat exchanger plays an important role for studying in different areas such as fluid flow misdistribution, fouling, pressure drop & thermal analysis in the design & optimization.

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