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COMPARISON OF DESIGN AND ANALYSIS OF TUBE SHEET THICKNESS BY USING UHX CODE OF ASME AND TEMA STANDARD

Kalpesh D. Shirode[1], Dr. S. B. Rane[2], Mr. Yashwant Naik[3]

[1]Post Graduate Student, Sardar Patel College of Engineering, Andheri –West, Mumbai -400058, India
[2]Associate Professor, Sardar Patel College of Engineering, Andheri –West, Mumbai -400058, India
[3]Toyo Engineering India Ltd., H.T.A.T. Dept., Kanjur Marg, Mumbai, India

ABSTRACT

In order to investigate the optimized tube sheet thickness different methodologies are used. For the mechanical design of existing fixed tube sheet heat exchanger of a waste heat Boiler various code solutions are compared with each other. Solutions of Finite Element Analysis are used to optimize the design parameters. The purpose of this paper is to compare and analyse tube sheet design code UHX of ASME section VIII Div. 1 with TEMA standards. From the design methodology it is found that both standards are based on different theory of design. It is also found that FE analysis results are closed to exact solution and these results can be accepted with a reasonable degree of accuracy. Thus FEA can be used as an optimization tool for tube sheet thickness.

Keywords: Finite Element Analysis, Heat Exchanger Design, TEMA, ASME, UHX

I. INTRODUCTION

Heat exchangers are frequently called as the workhorses in process and petrochemical plants and more than 65% of these are tubular heat exchangers. Tubular heat exchangers exemplify many aspects of the challenges in the mechanical design of pressure vessels. Their design requires a thorough grounding in several disciplines of mechanics and a broad understanding of the interrelationships between the thermal and the mechanical performance of the heat exchanger [1].

There are many codes and standards available to design the heat exchanger components. Widely known codes are ASME Sect. VIII Div.1, 2, EN13445, TEMA, CODAP etc. Large heat exchangers are made of expensive materials which are cost effective components in industrial plants. For these, a thorough understanding of code differences is of paramount importance. Results of code comparisons exist and a few are published [12].

Design and analysis is very critical in refinery and heavy equipment industries. The optimized designs parameters are not only reduce the material cost but also help to define scope of research. In shell and tube heat exchanger tube sheet acts as the main pressure boundaries between shell side and tube side chambers.

It is therefore exposed to the operating transients of both fluids of heat exchanger.

Tube sheet is a key component of heat exchanger since it is directly connected to three major components of heat exchanger. This subjects the tube sheet to reactive loads in addition to pressure and thermal loads. The magnitude of the reactive loads is a result of complex interaction between the tube sheet and corresponding connected parts. Theoretically evaluation and analysis of tube sheet is one of the important and challenging tasks for designer.

The possibility of optimizing the thickness of the tube sheet with better knowledge of its state of stress has fuelled the researchers and engineers towards refinement in design and analysis procedure. The thickness of the tube sheet affects the cost of the heat exchangers in many ways. Increased thickness necessitates procurement of heavy and costly forging plate with difficult to achieve uniform acceptable mechanical properties. Thicker tube sheet results in longer tube length inside the tube sheet that do not take part in heat transfer. This unused tube length adds to the procurement length and cost.

The primary aim of tube sheet design is to determine and optimize the pitch pattern of the tube holes, the diameter and the thickness for known mechanical and thermal loads for efficient and safe performance of the heat exchanger. To obtain optimum tube sheet thickness, codes and standards are to be compared which makes the tube sheet design as an iterative process.

In these work the codes and standards used in the investigation are UHX part rules for design of tube sheet from ASME section VIII div. 1 and Appendix A from TEMA standards which was then analysed by FEA software ANSYS 13.

II. LITERATURE REVIEW

Structural integrity of pressure vessels and heat The exchangers depends on proper mechanical design arrived at after detailed stress analysis keeping in view all the static, dynamic, steady, and transient loads[8].

Therefore, an optimum mechanical design of various components of heat exchangers is of paramount importance. Mechanical design involves the design of pressure-retaining, non-pressure-retaining components and equipments to withstand the design loads, the deterioration in service.

It is also possible that formulae developed by some standards have higher factor of safety, which leads to some times over design. Over the course of time, finite element models have gained significant importance, and research has been ongoing to establish a supportive results to hand or software calculations. Computer models (CAE), have been developed to provide timely and economical simulations for results of a component under extremely sever loading conditions [3].

Many manufacturing industries nowadays, prefer finite element analysis of pressure vessel & heat exchanger component, because the simulations can be used to target sensitive parameters that affect the overall design, cost and safety of equipment.

Going through literature review, many authors presents their work by using different methodologies for design and analysis of tube sheet. K. Behseta, S. Schindler has present the work on the design of the tube sheet and the tube sheet-to-shell junction of a fixed tube sheet heat exchanger in which they compare the ASME Sect. VIII Div.1 and EN 1344-3 clause 13and Annex J for their investigation.

III. THE HEAT EXCHANGER

The heat exchanger considered in this paper is a Fixed Tube Sheet Shell-and-Tube heat exchanger of Waste Heat Boiler. In this heat exchanger the flue gases are flowing from tubes and the steam is from the shell. The geometrical dimensions and design data for the investigation are:

Shell Inner Diameter: 1984mm
Inlet channel Inner diameter: 3510mm
Tube outer diameter: 88.9mm
Tube hole Pitch: 124.5mm
Tube hole diameter: 89.3mm
Tube thickness: 7.62mm
Inner tube sheet to tube sheet distance: 6706mm
Shell thickness: 45mm
Channel thickness: 20mm
No. Of tubes: 148.
Baffle thickness: 20mm
Shell side pressure: 4.75 MPa
Tube side pressure: 0.35 MPa
Tube sheet design temperature: 343^{o}C
Shell design temperature: 343^{o}C
Channel design temperature: 343^{o}C
Tube design temperature: 343^{o}C
Tube inlet: 1416^{o}C
Tube outlet: 649^{o}C
Shell operating: 248^{o}C

As the flue gas inlet temperature is very high, to protect the welded tube-to-tube sheet joint from high temperature the ferrules are used. The channel and tube sheet are insulated from inside. The operating temperatures of tube sheet, channels are obtained from the thermal analysis. The material properties such as modulus of elasticity, allowable stresses, yield strength, coefficient of thermal expansion, thermal conductivity etc. for different materials are obtained from ASME Sect. 2 Part D. The geometrical details of fixed tube sheet heat exchanger are shown in Fig.1.

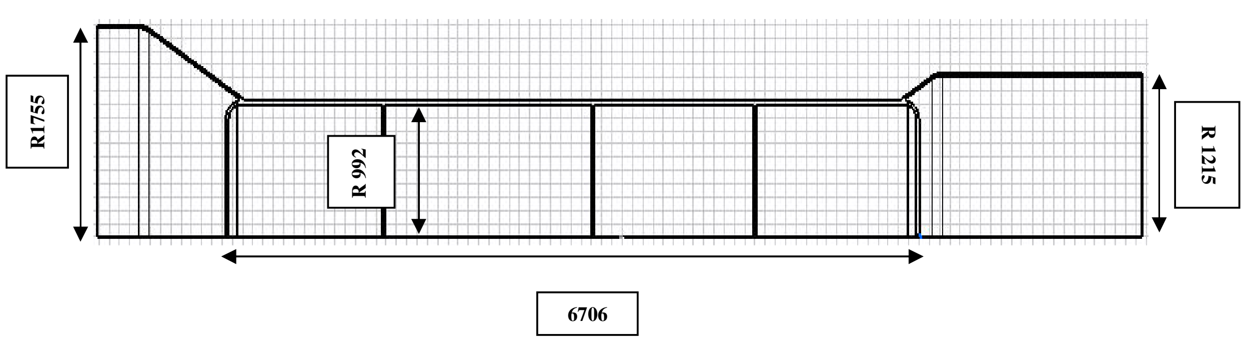

Figure 1 structure of heat exchanger

IV. CODE RESULTS COMPARISON

The results of the calculations according to ASME Sect. VIII Div. 1 of part UHX for load case 1,2,3,4,5,6 and 7 are given in Table I.

Table I

Load Case	Tube Sheet Thickness (mm)	Bending Stress In Tube Sheet (MPa)	Maximum Allowable Stress In Tube sheet (MPa)
1	20	88.95	200.62
2	60	177.56	200.62
3	60	196.22	200.62
4	45	347.6	427.46
5	60	167.05	427.46
6	60	401.65	427.46
7	60	385.05	427.46

As per TEMA code the tube sheet thickness at maximum effective pressure is 73.95mm and assumed thickness is 75mm which is within tolerance of ± 1.5.

From calculation results according to UHX code the most critical load case is load case 6 that is shell side pressure acting along with differential thermal expansion. The net effective pressure acting on tube sheet as per UHX code is 2.28 MPa and 1.073 MPa as per TEMA. The net effective pressure acting on tube sheet in UHX design is more than the TEMA because UHX code provides formula for pressure acting on rim portion of tube sheet separately which was then included for calculating net effective pressure acting on tube sheet. This is one of the important factor which affects on bending stress (1) in tube sheet. Rim is the solid portion of the tube sheet on which both shell side and tube side pressures are acting and theses pressure contributes on bending of tube sheet.

$$\sigma = \frac{1.5*F_m}{\mu^*}\left(\frac{2*a_o}{h}\right)^2 * P_e \qquad (1)$$

Where,
μ^*= effective ligament efficiency
F_m= constant depends on besel function
a_o= radius of outer tube hole limit
h= assumed tube sheet thickness
P_e= effective pressure
There is no need to calculate the bending stress in tube sheet as per TEMA because in tube sheet thickness bending formula (2) using of maximum allowable stress the bending stress itself is within the allowable limits.

$$T = \frac{FG}{3}\sqrt{\frac{P}{\eta S}} \qquad (2)$$

Where,
T= tube sheet thickness
F= constant
P= effective pressure
η= average ligament efficiency
S= maximum allowable stress

In UHX code the value of factor X_a (3) depends on the ratio of stiffness offered by tube bundle to effective stiffness of tube sheet which controls the tube sheet thickness where as in TEMA factor F_q controls the tube sheet thickness.

$$X_a = \left[24(1-\vartheta^{*2})N_t \frac{E_t t_t (d_t - t_t) a_o^2}{E^* L h^3}\right] \quad (3)$$

Where,
E^*, ϑ^*= effective elastic constants of tube sheet.
N_t= number of tubes
E_t= modulus of elasticity of tube
t_t= thickness of tube
d_t= outside diameter of tube
L= length of tube between inner to inner face of tube sheet
X_a= tube sheet restraining factor

V. FE SOLID MODEL

Following Fig.1 and 2 illustrates solid model as per ASME and TEMA specifications respectively which were prepared in ANSYS for inlet and outlet tube sheet, inlet channel, shell, tubes, baffles, outlet channel, outlet tube sheet, insulations etc.

There is no geometrical difference in TEMA and ASME heat exchanger model except thickness of tube sheet which is our aim of analysis. The tube sheet is analysed for critical load case only i.e. for load case only. The model was simplified considering following factors:
- Considering that tube sheets, channels, number of tubes and its arrangement, baffles are symmetrical according to its geometry structure characteristic and load states.
- A quarter was cut off from the whole structure also in order to reduce size of FE model $1/4^{th}$ portion of equipment is modelled.

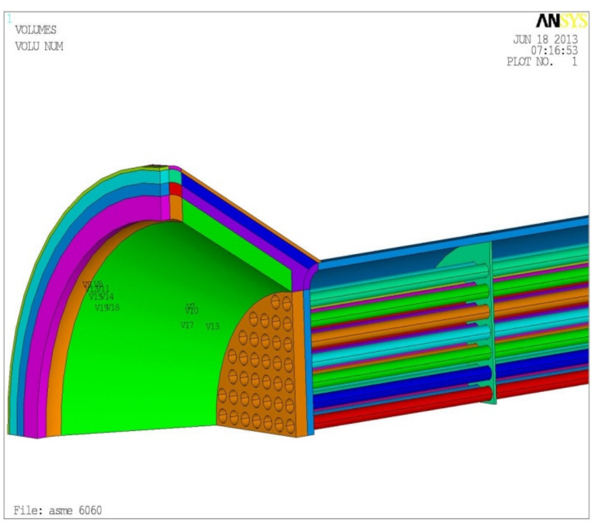

Figure 1 solid model of ASME heat exchanger

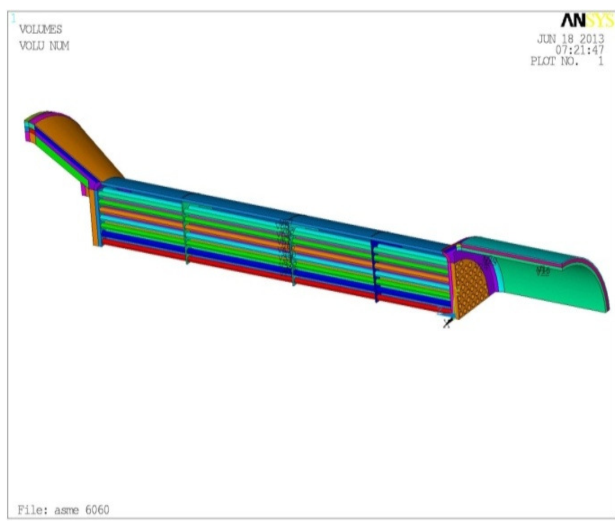

Figure 2 solid model of TEMA heat exchanger

VI. FE MESHED MODEL

There are many options of element types are available in ANSYS. The selection of element type is depending on the type of analysis. Higher order elements are better for non-linear analysis where the induced stresses exceed the elastic limit of material. For linear analysis where the induced stress are within yielding of material and for less memory usage of computation 8 node brick is the better than other type of element. The 8 node brick element was selected for such linear analysis. This type of element is used for static loading with small deformation which fulfils the requirement of analysis. The tube sheet, portion of shell, channel and tubes have been meshed with element type of 8 node brick SOLID 70 for thermal analysis and 8 node brick SOLID 185 for mechanical analysis.. Table II and III shows the details of number of elements and nodes used for ASME and TEMA model analysis.

Table II

Analysis Type	Component	No. Of Elements	No. Of Nodes
Thermal And Mechanical	Tube Sheet Inlet And Outlet	2,25,690	2,84,940
Thermal And Mechanical	Inlet Channel	15,599	80,402
Thermal And Mechanical	Outlet Channel	23,599	48,172
Thermal And Mechanical	Shell	2,55,999	3,55,905
Thermal And Mechanical	Tubes	5,77,199	18,51,878
Thermal	Insulation Inside Inlet Channel And Tube Sheet	2,64,187	5,58,202
Thermal	Insulation Inside Outlet Channel And Tube Sheet	8,55,753	12,50,372

Table III

Analysis Type	Component	No. of Elements	No. of Nodes
Thermal And Mechanical	Tube Sheet Inlet And Outlet	4,92,778	6,81,452
Thermal And Mechanical	Inlet Channel	29,758	53,122
Thermal And Mechanical	Outlet Channel	37,819	57,844
Thermal And Mechanical	Shell	1,56,549	2,25,604
Thermal And Mechanical	Tubes	2,81,199	5,16,614
Thermal	Insulation Inside Inlet Channel	4,27,018	5,07,833
Thermal	Insulation Inside Outlet Channel	5,10,133	7,00,264

Following Fig. 3 and 4 show meshed model of ASME and TEMA model of tube sheet and its adjacent components. Sweep meshing has been applied to tube sheets, baffles and tubes. The shell and both channels are meshed by using mapped meshing. As the tubes are welded to the tube sheet so the nodes of the tubes are merged with nodes of the tube sheet surface area.

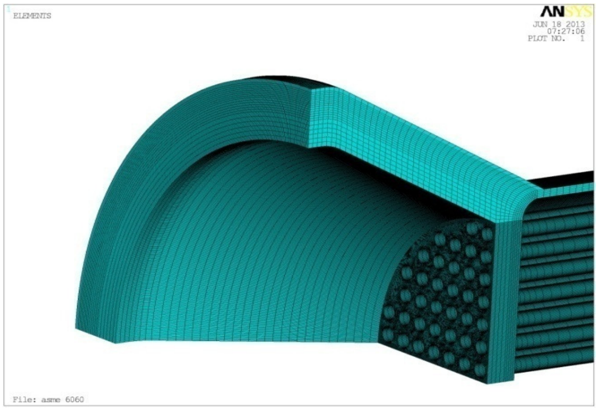

Figure 3 meshed model of ASME heat exchanger

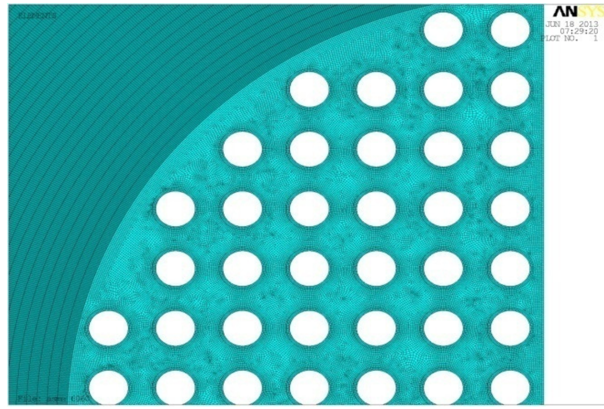

Figure 4 meshed model of TEMA heat exchanger

VII. THERMAL AND MECHANICAL BOUNDARY CONDITIONS

Following Fig. 5 and 6 indicates thermal boundary conditions applied to models for obtaining temperature distribution across the components of heat exchanger. Following Table IV shows details of applied temperature and heat transfer coefficient along the heat exchanger component.

Table IV

Component	Temperature (^{O}C)	Convective Heat Transfer Coefficient (W/mm^{2}k)
Inside Channel	1416	Not applicable
Outlet Channel	649	Not applicable
Inside Shell	248	0.018701
Inside Of Inlet And Outlet Tube Sheet	248	0.018701
Outside Surface Of Tubes	248	0.018701
Outside Surface Of Heat Exchanger	40	0.00015119

The flue gases are in direct contact with the inlet and outlet channel from inside so there is no need to provide heat transfer coefficient. All the data of heat transfer coefficient are referred from “Heat Transfer and Heat Exchanger” Text Book

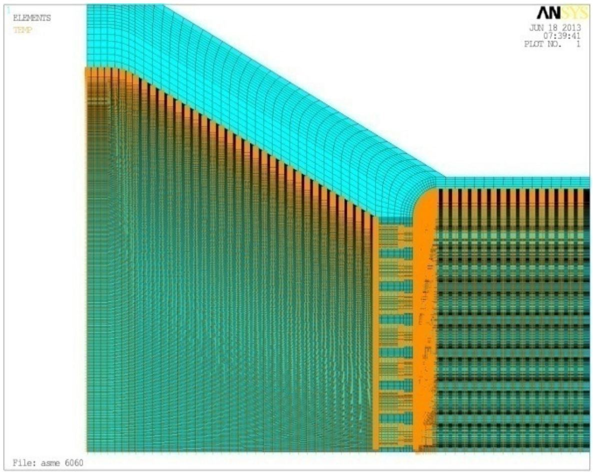

Figure 5 temperature applied at inner surface of heat exchanger

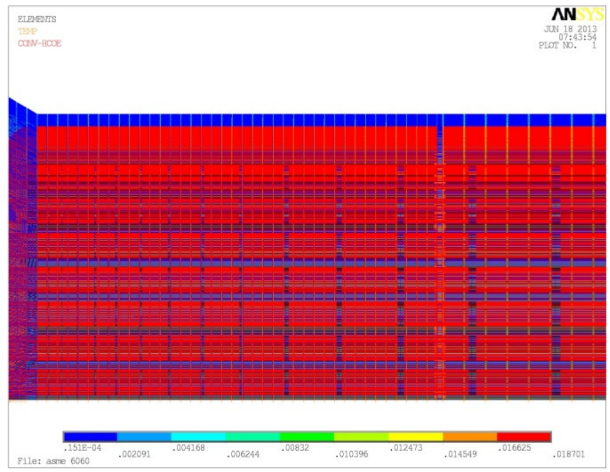

Figure 6 convective heat transfer coefficient applied at inner surface of shell

Following Fig. 7 indicates mechanical boundary conditions applied to models for obtaining solution. It is noted from design procedure that the most critical loading condition on tube sheet is shell side pressure acting with thermal expansion. So, heat exchanger model were analysed for this loading condition. Shell side pressure is applied at the inside of shell, across the baffles, outside surface of tubes, inside surface of tube sheet. The differential thermal expansion occurs between shell and tubes due to temperature difference between them. Since 1/4th portion of model is prepared, symmetrical boundary conditions have been applied at the symmetrical plane as shown below. Following Table V shows the mechanical loads and displacement applied on heat exchanger.

Table V

Component	**Type Boundary Condition**	**Pressure/ Displacement**
Inside Shell	Pressure	4.75 MPa
Inside Surface Of Tube Sheet (Inlet And Outlet)	Pressure	0.35 MPa
On XZ Plane Nodes	DOF	Symmetric about X axis
On YZ Plane Nodes	DOF	Symmetric about Y axis
At End Of The Inlet Channel Node	DOF	All Degree of Freedom
At End Of The Outlet Channel	DOF	All Degree of Freedom

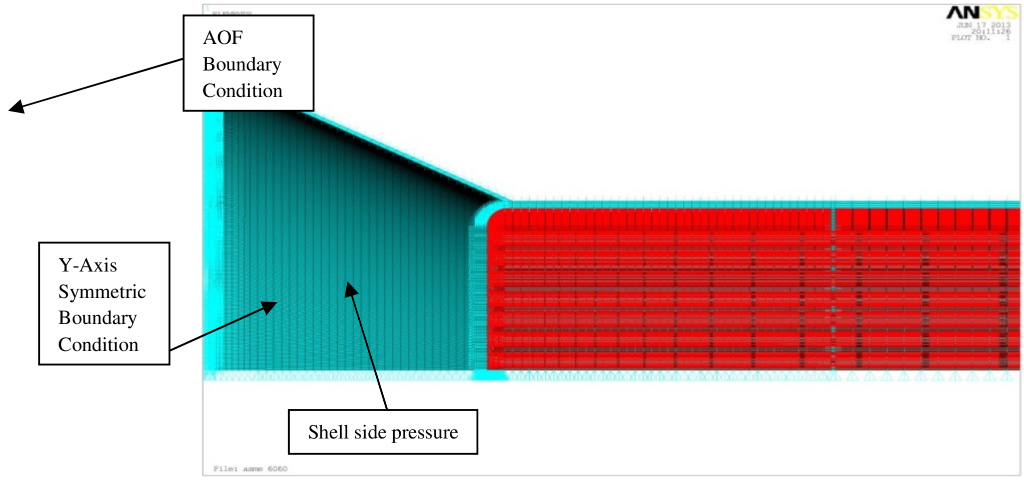

Figure 7 mechanical boundary condition applied on heat exchanger

VIII. RESULTS AND DISCUSSIONS

Fig. 8 and 9 show temperature distribution of heat exchanger models.

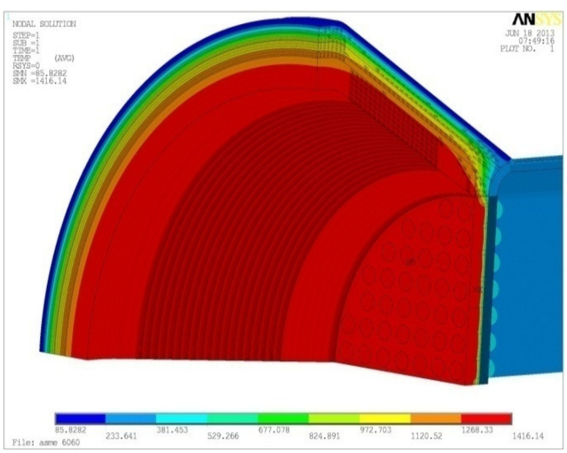

Figure 8 temperature distributions across inlet side of heat exchanger

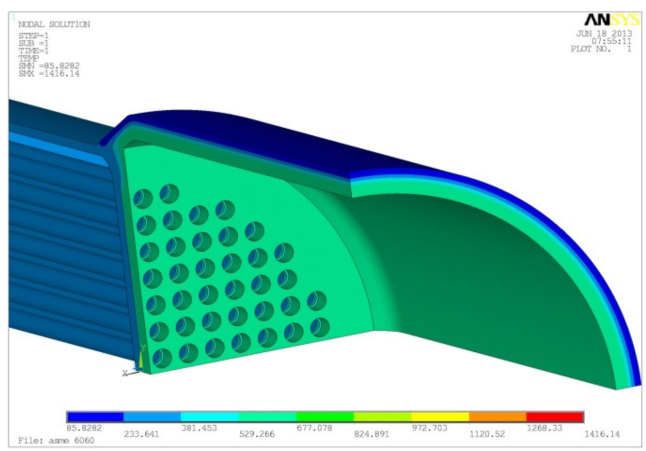

Figure 9 temperature distribution across outlet of heat exchanger

Following assumptions have been made while carrying out FE analysis.
- Structural deformations are proportional to the loads applied.
- All materials used in analysis shows linear elastic behaviour.
- The material is homogeneous and isotropic and the deformations are small.

After getting structural results stress linearization has been carried out across thickness of component as per "Von Misses Theory" at maximum SEQV stress location shown in Fig. 10 and 11

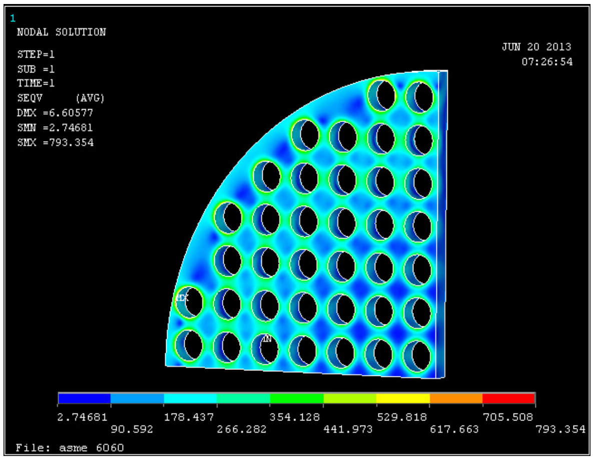

Figure 10 Von Misses Stress distributions across tube sheet of ASME heat exchanger

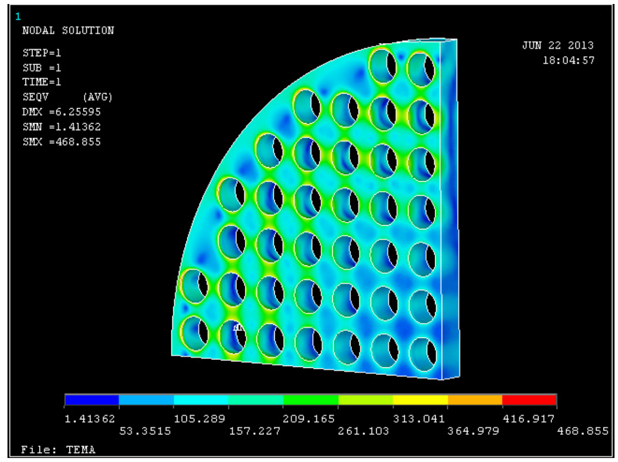

Figure 11 Von Misses Stress distribution across tube sheet of TEMA heat exchanger

From the Table VI the results of design calculations and analysis it is observed that analysis results are closed to that design value which is acceptable. It is also observed that the maximum stresses for tube sheet are occurring at outer periphery of tube holes. The bending stress in tube sheet as per UHX code is 401.5MPa at optimum tube sheet thickness of 60mm. The primary plus secondary stress as per analysis according to Von Misses Theory at maximum SEQV is 350.3 MPa. Both design and analysis bending stresses are within allowable stress limit. The maximum bending stress is observed to be at outer periphery of tube hole. Analysis result of TEMA model is 271.7MPa which is within allowable stress limit.

Table VI

Load Case	Location Of SCL	Types of Stress	Design Results As Per Codes (MPa)	FEA Results (MPa)	Allowable Stress (MPa)	Tube sheet Thickness (mm)
Shell Side Pressure With Differential Thermal Expansion (ASME) Model	Perforated Region	P_m+P_b+Q	401.5	350.3	427.46	60
	Knuckle Region	P_m+P_b+Q		279.3	427.46	
Shell Side Pressure With Differential Thermal Expansion (TEMA) Model	Perforated Region	P_m+P_b+Q	-	271.7	427.46	75
	Knuckle Region	P_m+P_b+Q		350	427.46	
Optimum Tube sheet thickness obtained by FEA						45

The results obtained from analysis are much less than that obtained from code design. So the tube sheet thickness can be more optimized by FEA methods and FEA results can be used as an optimization tools for design. In both codes there is no provision of tube sheet with knuckle design. The stresses in tube sheet with knuckle are less than the flat circular plate placed on elastic

IX. CONCLUSION

For this special heat exchanger application of ASME Sect. VIII Div. 1 and TEMA design procedure have been successfully implemented which was then analysed by using FEA software package ANSYS 13.

The setting up FE model is time consuming, but the results may be worth the effort because from result Table VI the bending stress in tube sheet by finite element analysis are very less than stress calculated by both codes. The factor of safety used for designing the tube sheet in both standards are more which increases dimensions of the heat exchanger components. It is concluded that the tube sheet thickness of given heat exchanger is safe according to the codes and analysis.

From the result Table VI it is observed that the classical design procedure for calculating tube sheet thickness as per TEMA and ASME standards gives tube sheet thickness of 75mm and 60mm respectively but, FEA gives more optimised tube sheet thickness of 45mm. Based on above it is concluded that FE method for the tube sheet analysis saves 25% of material compare to TEMA design and 20% material compare to ASME design which further reduces the manufacturing cost and time. The induced stresses in the tube sheet for calculated thickness of tube sheet by both codes and analysis are below allowable limits which is acceptable. From design point of view ASME design method is more realistic than the TEMA methodology.

TEMA considers tube sheet as a solid plate without effective elastic constant due to perforate for the tube sheet design gives over thickness than ASME.

The best of the two design by formula approaches are discussed and all details of differences in design methodology are given in following Table VII

Table VII

	ASME Sect. VIII Div.1	**TEMA**
Types of Heat Exchangers	Covers All Three Types of Heat Exchangers.	Covers All Three Types of Heat Exchangers.
Simplicity of Formula	ASME Follows A Step Wise Procedure That Requires Calculation of Many Parameters.	Simple Formula For Applicable Requires Less Number of Parameters But Less Accurate Than ASME.
Ligament Efficiency	Based On Modified Minimum Ligament Efficiency	Based On Average Ligament Efficiency H Which Is Ratio of Perforated To Solid Area
Effect of Tube Expansion In Tube Sheet	Considered By Reduction In Tube Hole Diameter	Not Considered
Effect of Untubed Diametrical Lane	Taken By Increasing Pitch I.E. Effective Pitch	Not Considered
Effect of Solid Rim	By Use Of Effective Diameter Of Outer Tube Hole Limit	Not Considered
Effective Elastic Constant	Considers Tube Sheet As A Solid Plate With Effective Elastic Constants	Does Not Consider Tube Sheet With Effective Material Properties Due To Perforated. It Assumes Constant Value Of 0.178 For Deflection Efficiency.

	ASME Sect. VIII Div.1	TEMA
Stiffening Effect of Tube	ASME Considers Tube Bundle As Elastic Foundation For The Tube Sheet. Hence The Stiffening Effect Of Tubes Reduces The Bending Stress Of The Tube Sheet In Short It Supports The Tube Sheet Against Pressure And Bending Moment From The Shell And Channel. Which Was Considered In The Form Of Value F_m. This Value Of F_m Again Depends On X_a Which Is Nothing But Ratio Of Tube Sheet Stiffness To The Tube Bundle Stiffness	Assumes Stiffening Effect of Tube Which Is Counterbalanced By Weakening Effect Of Holes
Stresses in components	ASME calculates bending stress in tube sheet, tube axial stress in outer most tube row, axial stresses at junction of tube sheet to shell and tube sheet to channel	TEMA calculates shell longitudinal stress, periphery of tube bundle longitudinal stress, tub to tube sheet joint loads

X. REFERENCES

Journal Papers

1) W. Reinhardt R. Kizhatil G. H. McClellan, Analysis of a Tubesheet Undergoing Rapid Transient Thermal Loading, Transactions of the ASME, Vol. 122, November 2000,476-481
2) M.S. Liua, Q.W. Donga, D.B. Wanga, X. Ling, Numerical simulation of thermal stress in tube-sheet of heat transfer equipment, International Journal of Pressure Vessels and Piping 76 (1999) 671–675
3) Weiya Jin, Zengliang Gao, Lihua Liang, Jinsong Zheng, Kangda Zhang, Comparison of two FEA models for calculating stresses in shell-and-tube heat exchanger, International Journal of Pressure Vessels and Piping 81 (2004) 563–567
4) Li Guo, Zhao Jianping, Design by Finite Element Analysis on Tubesheet of Heat Excahnger with a Central Hole, International Journal of Pressure Vessels and Piping, 2011,57867,USA
5) C. F. Qian, H. J. Yu, L. Yao, Finite Element Analysis and Experimental Investigation of Tubesheet Structure, Journal of Pressure Vessel Technology, ASME, Vol. 131 (2009),1-4
6) Porter, M.A., Martens, D.H., Investigation of a Shell and Tube Exchanger in Process Gas Heating Service, ASME Pressure Vessel and Piping Conference, 2008, Chicago, Illinois, USA PVP 2008-61635.
7) Hongjie Yu, Caifu Qian, Ri Cao, On the Design Approach of Double-tubesheets, Advanced Materials Research Vols. 118-120 (2010) pp 650-654
8) Khosrow Behseta, Donald Mackenzie, Robert Hamilton, Plastic load evaluation for a fixed tube sheet heat exchanger subject to proportional loading, International Journal of Pressure Vessels and Piping 92 (2012) 11-18
9) Khosrow Behseta, Donald Mackenzie, Robert Hamilton, Ratcheting Assessment of a Fixed Tube Sheet Heat Exchanger Subject to In Phase Pressure and Temperature Cycles, Journal of Pressure Vessel Technology, ASME, 2011, Vol. 133 / 041201-1-5

10) Lin Zhou, Xiaohua He, Changyu Zhou, Xiaoping Zhang, the Simplified Method for Stress Analysis on Tubesheet of Fixed Tubular Heat Exchanger with Expansion Joint, ASME 2011 Proceedings of Pres. Ves. & Piping division, July 2001, pp 1-6
11) F. Osweiller, U-Tube Heat-Exchangers: New Common Design Rules for ASME, CODAP, and EN 13445 CODES, Journal of Pressure Vessel Technology, ASME, February 2006, Vol. 128 / 95-102
12) K. Behseta, S. Schindler, On the design of the tubesheet and the tubesheet-to-shell junction of a fixed tubesheet heat exchanger, International Journal of Pressure Vessels and Piping 83 (2006) 714–720
13) Prof.Alpesh V Mehta, Nimit M Patel, Dinesh K Tantia and Nilsh M Jha, "Mini Heat Exchanger using Al2o3-Water Based Nano Fluid", International Journal of Mechanical Engineering & Technology (IJMET), Volume 4, Issue 2, 2013, pp. 238 - 244, ISSN Print: 0976 – 6340, ISSN Online: 0976 – 6359.
14) Ajeet Kumar Rai and Mustafa S Mahdi, "A Practical Approach to Design and Optimization of Single Phase Liquid to Liquid Shell and Tube Heat Exchanger", International Journal of Mechanical Engineering & Technology (IJMET), Volume 3, Issue 3, 2012, pp. 378 - 386, ISSN Print: 0976 – 6340, ISSN Online: 0976 – 6359.
15) Sunil Jamra, Pravin Kumar Singh and Pankaj Dubey, "Experimental Analysis of Heat Transfer Enhancement in Circular Double Tube Heat Exchanger using Inserts", International Journal of Mechanical Engineering & Technology (IJMET), Volume 3, Issue 3, 2012, pp. 306 - 314, ISSN Print: 0976 – 6340, ISSN Online: 0976 – 6359.

Codes and Standards

1) ASME Section VIII Div. 1,Boiler and Pressure Vessel Code (2007)
2) ASME Section II Part D, Properties Materials (2007)
3) Standards of the Tubular Exchanger Manufacturers Association 9th Edition (2007)