FEA BASED ANALYSIS & OPTIMIZATION OF SPACED SEQUENTIAL TUBE SHEET

Mihir K. Panchal[1], Bhumik B. Patel[2], Hardik Parmar[3]

[1]PG Student, [2]Assistant Professor, Mechanical Department, [3]Assistant Professor, Mechanical Department

Kalol Institute of Technology & Research Centre, Kalol, Gujarat Technological University, (India)

Silver Oak College of Engineering & Technology,Ahmedabad.

Abstract–**Tube sheetare used as for multiple purpose, either they connecting tubes for Heat Exchanger or act as support for filter element. As design of tube sheet is very complex, as it interactswith the pressure vessel and the stresses it generates. The location where the tube sheet is attached, radial expansion of the vessel is halted; this creates bending stresses in the vicinity of the tube sheet, in the new design that is proposed there are 3 tube sheets spaced at equal intervals. The resulting stress profile will be increasingly complex. In this research the analysis of sequential tube sheet will fall under ASME code, which recommends usage of FEA. Analysis and study the effect of tube sheet spacing on stress profile and optimize the structure with Spacing distance between tube sheets and Thickness of the tube sheet.**

Keyword–Tubesheet, Sequential Spaced Tubesheet, FE Analysis of Sequential Spaced Tubesheet

I. INTRODUCTION

A tube sheet is a plate, sheet, or bulkhead which is perforated with a pattern of holes designed to accept pipes or tubes. These sheets are used to support and isolate tubes in heat exchangers and boilers or to support filter elements. Depending on the application, a tube sheet may be made of various metals or of resin composites or plastic. A tube sheet may be covered in a cladding material which serves as a corrosion barrier and insulator and may also be fitted with a galvanic anode. Tube sheets may be used in pairs in heat exchange applications or singularly when supporting elements in a filter. Tube sheets are also used on cartridge-type filter devices to support the individual filter elements. They are similar in design to the high heat boiler varieties except they are typically made of resin composites or plastic and are generally used as single units. There are usually fewer tubes involved in a filter application although the tube sheet design still has to be carefully calculated to ensure optimal performance. However tube sheet design is very complex, because of its interaction with the Pressure Vessel & the stresses it generates. The location where the tube sheet is attached, radial expansion of the vessel is halted; this creates bending stress in the vicinity of the tube sheet.

II. RELATED STUDIES ONTUBESHEET

R. D. Patil at al.(2015) [1]works deal with the stress analysis of plates perforated by holes in square pitch pattern by using finite element method.

Sui Rongjuan at al.(2015) [2]conduct for Root cause analysis of stress corrosion at tube-to-tubesheet joints of a waste heat boiler. Leakage at the tube-to-tubesheet joints occurred in a waste heat boiler.

Ravivarma.R at al. (2015)[3]conduct Finite Element Analysis of a Tubesheet with considering effective geometry properties through design methodology validated by Experiment.

Shugen Xu at al.(2013)[4]works on the stress corrosion cracking in a weld of the tube to tube–sheet region of heat exchangers using thermo-mechanical stress in tube to tube–sheet joints including welding effect and determined it for failure analysis.

Shugen Xu at al.(2013)[5]conduct Numerical investigation on weld residual stresses in tube to tube sheet joint of a heat exchanger.

Dr. Enrique Gomez at al. (2013)[6] works on ASME section III stress analysis of a heat exchanger tubesheet with a misdrilled hole and irregular or thin ligaments. A stress analysis is described for a nuclear steam generator tubesheetwith a thin or irregular ligament associated with a misdrilled hole using the rules of ASME B&PV Section III and Non-Mandatory Appendix A.

III. OBJECTIVE

The literature survey carried out during the present course of work clearly shows that there is scope for analysis and optimization of spaced sequential tube-sheet using Finite element analysis. Hence the objectives of the present work are decided as under:

- Mechanical Design of Tube-sheet using ASME code.
- To create analysis SOP (Sequential Operating Procedure) in WB.
- To study the effect of tube sheet spacing on stress profile.
- To optimize the structure with the following criteria

I. Spacing Distance between tube sheets
II. Thickness of the tube sheet.

IV. METHODOLOGY

Referring the guidelines provided by the client, the dimensions of the tubesheet were finalized. The parameters provided by the client for design of tubesheet are as follows.

Sr. No.	Parameter Description	Notations	Given Value
1	Internal Pressure	P	0.34 MPa
2	External Pressure	P_0	Atmospheric
3	Process Volume	V_p	286 cu m
4	Expected Stagnant Volume	V_s	Not Specified
5	Buffer Volume Requirement	V_b	Not Specified

6	Tube Porosity Volume	T_p	70
7	Tube Length	T_L	5.5m
8	Radius of tube sheet	r	3m
9	Tube Diameter	T_d	0.15m

Table -1: Input Parameters For Tube-sheet Design

Calculated dimensions were confirmed from the client and corrections suggested by the client were implemented in the design of tube-sheet.
The finalized dimensions of the tube-sheet were as follows:-

NTD=11000 mm
Thickness of Tube-sheet=409 mm
Ligament Efficiency = 0.1
Number of Holes on the tube-sheet=1131
Total length of vessel = 16000 mm
Thickness of Shell= 9 mm
Diameter of Nozzle = 300 mm
Thickness of Nozzle = 12 mm
No. of Nozzle= 2
Diameter of RF pad= 572 mm
Thickness of RF pad=12 mm
Diameter of Flange=600 mm
Thickness of Flange=12 mm

First to create solid model in Creo3.0 modeling software by using all above calculated parameters and ASME Code Section-VIII, Div-II. Three spaced sequential tube-sheets are mounted in vessel as shown in figure.

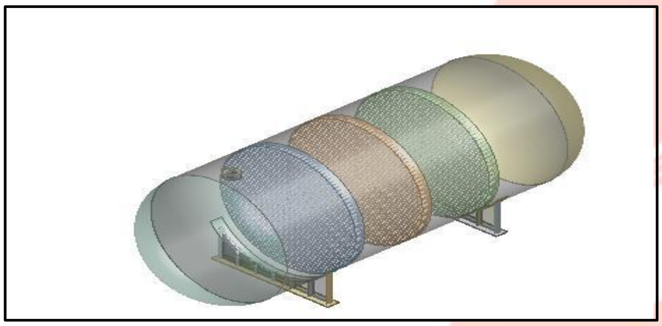

Figure-1 Solid model of pressure vessel

V. ANALYSIS

- Modal Analysis Input Parameters:

One saddle support is fixed and check the contact between face to face contacts, edge to edge contacts, edge to face contacts are properly detected or not.

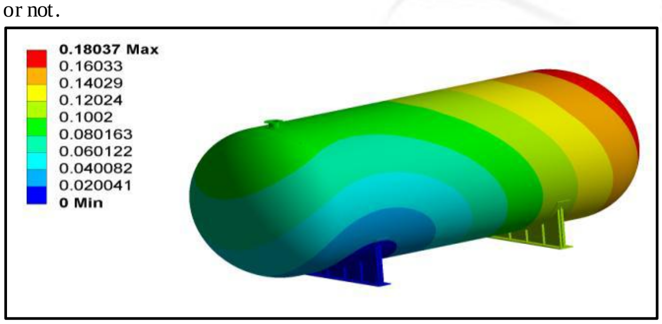

Figure-2 Maximum deformation- 0.18 mm

Above results shows maximum deformation is 0.18 mm and Frequency is 2.7476 Hz, so frequency is more than zero shows the all the contacts are properly detected.

- Static Structural Analysis Input Parameter:

1. Both saddle supports are fixed. 2. Gravity acting downward

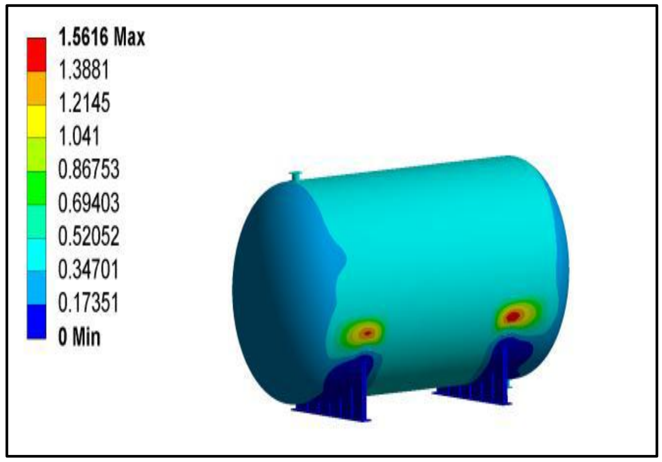

Figure-3 Maximum deformation-1.5616 mm

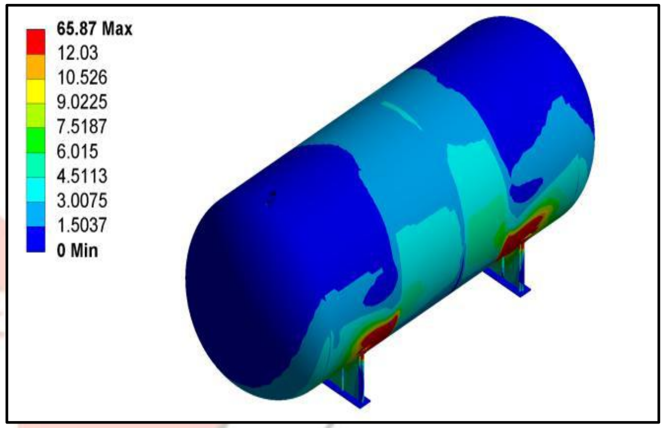

Figure-4 Maximum stress-65.87 MPa

Case-01: Input Parameters

1. Apply Internal Pressure=0.32

2. One saddle support is fixed and on second saddle Apply displacement.

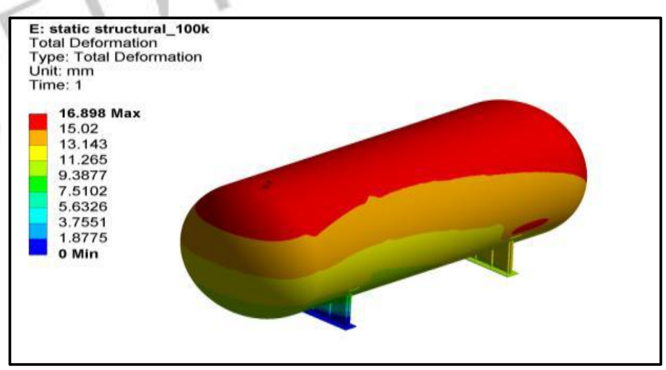

Figure-5 Maximum deformation= 16.89 mm

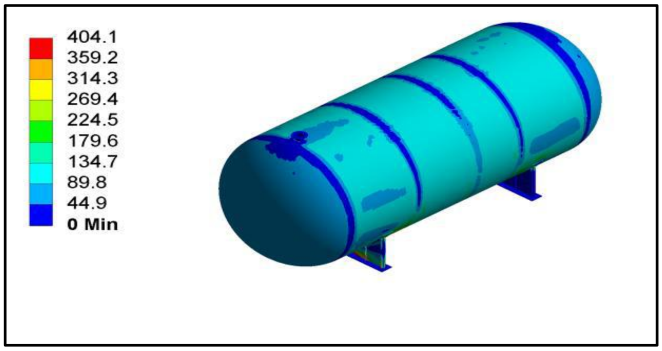

Figure-6 Maximum stress= 404.1 MPa

Case 02: Optimization of Tube-sheet at pressure 0.32 MPa
Input Parameters

1. Fixed support

2. Apply pressure = 0.32 MPa

Sr. NO.	Thickness (mm)	Stress (MPa)	Deformation (mm)
1	409	38.48	17.441
2	400	40.54	17.045
3	350	53.35	16.898
4	280	84.71	16.175
5	240	116.75	16.648
6	230	127.56	16.5

Table:-2: Maximum Stress & Maximum Deformation results for Different Thickness of tube-sheet

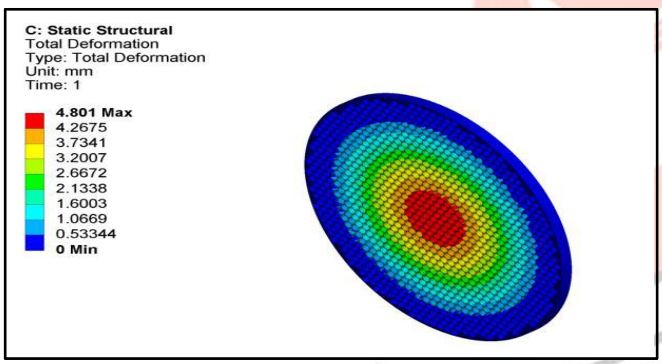

Figure-7 Maximum deformation= 4.801 mm

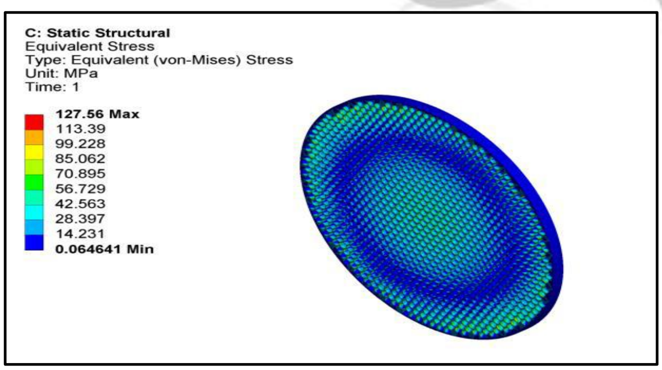

Figure-8 Maximum deformation= 4.801 mm

Tube-sheet is analyzed for pressure of 0.32MPa, decreasing the tube-sheet thickness from 409 mm to obtained the optimum thickness. The stress at 230mm thickness of tube-sheet is 127.56 MPa which is nearest and less than allowable stress. So the final Optimum thickness for tube-sheet at pressure of 0.32 MPa is decided at 230mm.

Case 03: Tube-sheet Optimization with Point Load and pressure of 0.01MPa

Optimized 230 mm thickness of tube-sheet with applying Gravity, point mass 2.5 kg of every tube on mid-point of tube length and pressure on tube-sheet 0.01 MPa ,various analysis are as follows. No. Tube-Sheet = 1 Total number of Tubes = 1131 Mass of each tube = 2.5 kg Total mass of all tubes on the tube-sheet =2.5*1131 = 2827.5 kg

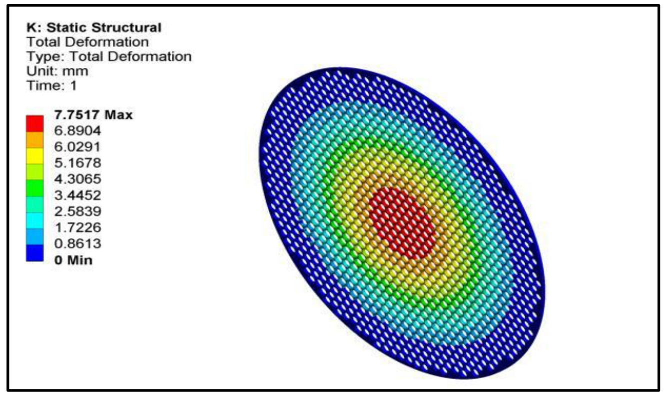

Figure-9 Deformation =7.7517 mm

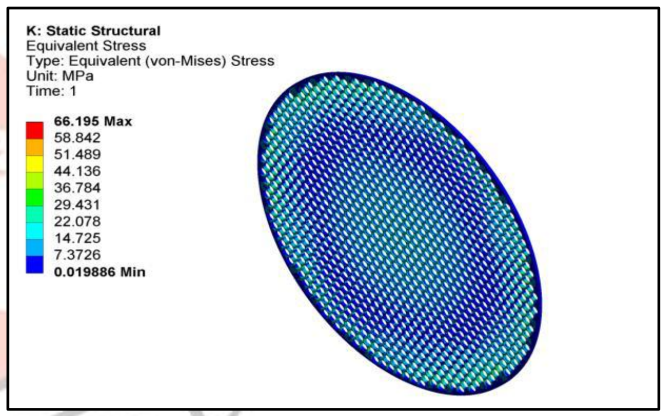

Figure-10 Maximum stress= 66.195 MPa

Sr. NO.	Thickness (mm)	Stress (MPa)	Deformation(mm)
1	230	4.6618	0.1501
2	200	5.8856	0.2268
3	180	7.3474	0.3094
4	160	9.0768	0.4379
5	140	11.612	0.6495
6	120	15.671	1.0215
7	100	22.37	1.7403
8	80	34.559	3.322
9	60	66.195	7.751

Table-3: Maximum Stress & Maximum Deformation results for Different Thickness of tube-sheet with mass of each tube at its C.G.

Tube-sheet analysis with Point Load 2.5 kg of each tube and pressure of 0.01MPa is done with decreasing the tube-sheet thickness to obtained the optimum thickness. The stress at 60mm thickness of tube-sheet is 66.195MPa which is nearest and less than allowable stress. So the final

Optimum thickness for tube-sheet with Point Load of each tube and Pressure of 0.01MPa is decided at 60mm.

Case 04: Complete Vessel Analysis considering all tubes masses, pressure on tube-sheets 0.01MPa and internal Pressure on all other components as 0.32 MPa

Total number of Tubes = 1131 Total number of tube sheets = 3 Mass of each tube = 2.5 kg Total mass of all tubes on the three tube sheets = 2.5*1131*3 = 8482.5 kg

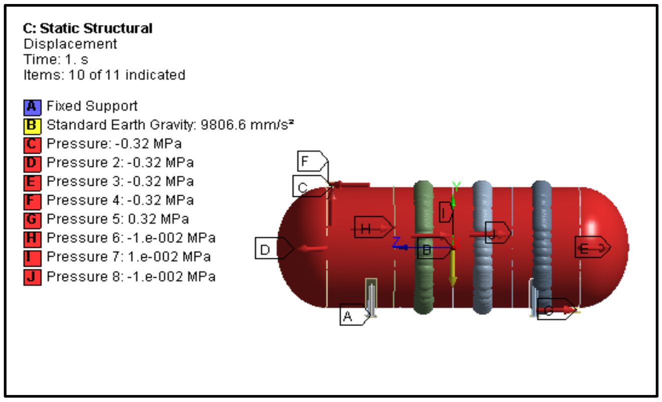

Figure-11: showing Boundary Condition and all point masses on all tube-sheets

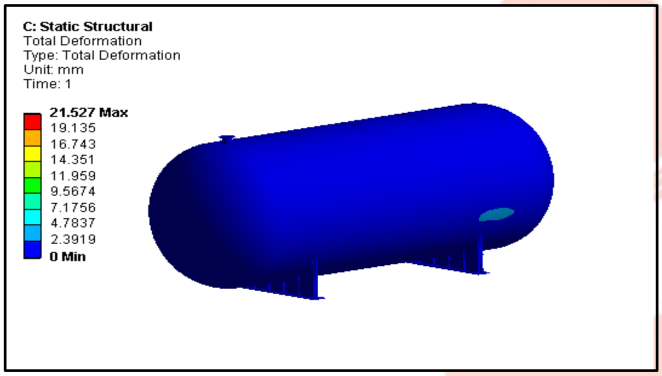

Figure-12: Deformation=21.52 mm

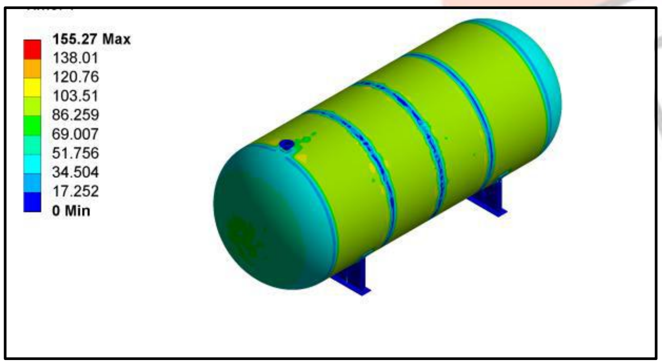

Figure-13: Stress=155.27 MPa

Case 05: Complete Vessel Analysis considering all tubes masses, pressure on tube-sheets 0.01MPa and internal Pressure on all other components as 0.32 MPa with 3 saddle supports.

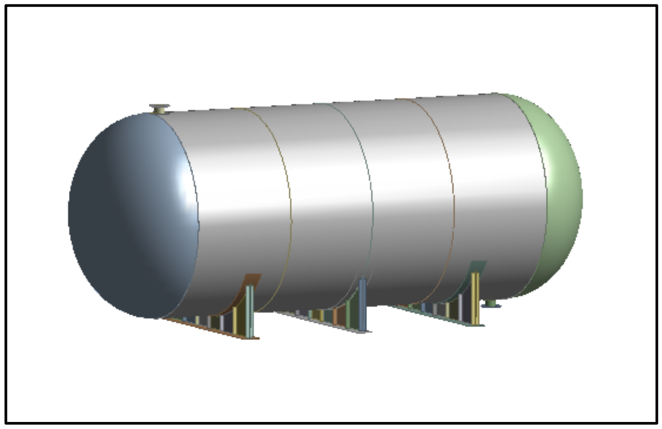

Figure-14: pressure vessel with 3 saddle supports

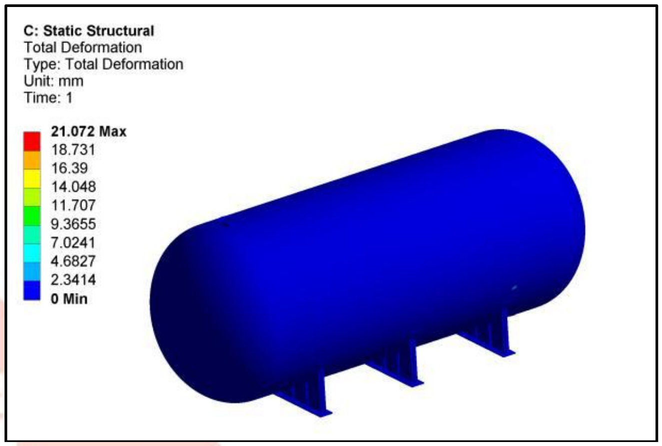

Figure-15: Deformation=21.072mm

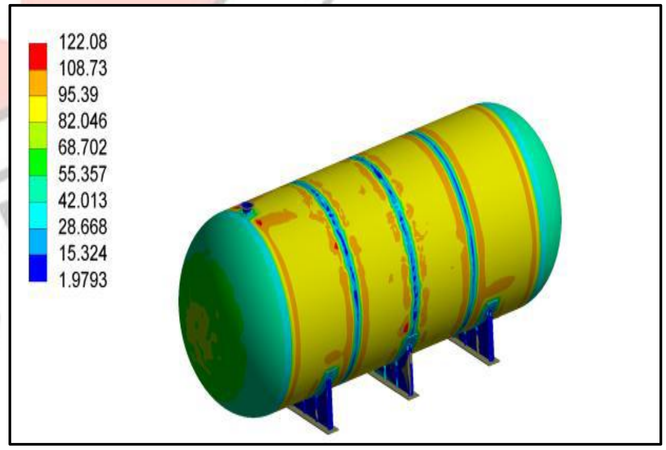

Figure-16: Stress=122.08 MPa

Stress Result for Complete Vessel Analysis considering all tubes masses, pressure on tube-sheets 0.01MPa and internal Pressure on all other components as 0.32 MPa with3 saddle supports stress is 122.08MPa which is within the limit of allowable stress.

VI. CONCLUSION

1. The project is basically focused on an Analysis and optimization of space sequential tube-sheet in pressure vessel. Designs of pressure vessel are done by ASME Code Section-8. Div-2.

2. The Analysis of pressure vessel model was done in ANSYS 15.0 workbench. The results were supported with an experimental validation for verifying the actual deformation and FEA results. Following are concluding remarks based on the analysis performed on vessel.

3. Firstly analysis of pressure vessel model is done to develop the standard operating procedure. From the comparison of results at different mesh size.it is concluded that variation in results is within acceptable limit, hence approximately 100000 nodes mesh size is fixed for further analysis.in that maximum stress is 404.1MPa and deformation is 16.89 mm.

4. Tube-sheet optimization including point mass weight of 2.5 kg of each tube for reducing weight and material, 60 mm of tube-sheet is finalized.Optimizationresults shows 71% weight reduced of Tube-sheets.

5. Stress Result for Complete Vessel Analysis considering all tubes masses, pressure on tube-sheets 0.01MPa and internal Pressure on all other components as 0.32 MPa with 3 saddle supports is 122.08MPa which is within the limit of allowable stress (138MPa)

6. Experimental test shows that no leakage and damage in vessel.

Above all the conclusion shows the optimization of stress, weight and material is done. for this condition model is safe as per ASME Section-VIII, Div-II.

FEA results and Experimental results are in close resemblance and proved that FEA analysis is correct and is validated by experimental deformation results Manufactured tested values is 9.41mm. % error between FEA and experimental result's is 17% which is less than the allowable error (20%) in FEA for large pressure vessel. Hence our FEA results are reliable. No damaged is detected by using ultrasonic testing machine. Finalized vessel satisfies ASME Criteria and this has been validated through FEA.

ACKNOWLEDGMENT

I am humbly expressing thanks to my respected guide Mr. Bhaumik B. Patel And my external guide Mr. Manan P. Panchal for their valuable time, constant help, encouragement and useful suggestions, which helped us in completing the research in time.

REFERANCES

1. R. D. Patil, Dr. Bimlesh Kumar(2015) An Approach to Finite Element Analysis of Boiler Tube-Sheet. AJER e-ISSN: 2320-0847 p-ISSN: 2320-0936 Volume-02, Issue-08, pp-08-11.
2. Sui Rongjuan, W. W. (2014). Root cause analysis of stress corrosion at tube-to-tubesheet joints of a waste heat boiler. Engineering Failure Analysis 45, 398-405.
3. Ravivarma.R, A. P. (2014). Finite Element Analysis of a Tubesheet with considering effective geometry properties through design methodology validated by Experiment. International Journal of Computational Engineering Research (IJCER) ISSN (e): Vol, 04, Issue, 4, 2250-3005.
4. Shugen Xu, Weiqiang Wang (2013) Numerical investigation on weld residual stresses in tube to tube sheet joint of a heat exchanger. International Journal of Pressure Vessels and Piping 101, 37-44.
5. Shugen Xu, Y. Z. (2013). Using FEM to determine the thermo-mechanical stress in tube to tube–sheet joint for the SCC failure analysis. Engineering Failure Analysis 34, 24-34.
6. Dr. Enrique Gomez, D. E. (2013). ASME Section III Stress Analysis of a Heat Exchanger Tubesheet with a Misdrilled hole and irregular or thin ligaments. PVP 2013, 14-18.
7. Chi Bum Bahn, S. M. (2013). Leak behaviors of steam generator tube-to-tubesheet joints from room Temperature to 320 C. International Journal of Pressure Vessels and Piping 101, 45-54.
8. Chi Bum Bahn, S. M. (2013). Leak behavior of steam generator tube-to-tubesheet joints under creep condition:Experimental study. International Journal of Pressure Vessels and Piping 101, 55-63.
9. Kotcherla Sriharsha, V. R. (2012). Strength Analysis of Tube to Tube Sheet Joint inShell and Tube Heat Exchanger. International Journal of Science, Engineering and Technology Research (IJSETR),Volume 1, Issue 4, 2278-7798.
10. H.F. Li a, C. Q. (2010). Cracking simulation of a tubesheet under different loadings. Theoretical and Applied Fracture Mechanics, 27-36.
11. Haifeng Wang, Z. S. (2007). Connection strength and tightness of hydraulically expanded tube-to-tubesheet joints. Journal of Materials Processing Technology 194, 93-99.
12. K. Behseta, S. S. (2006). 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, 714-720.
13. Weiya Jin, Zengliang Gao, (2004) 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 81,563–567.
14. V. G. Ukadgaonker, P. A., & Babu, S. (1996). Review of analysis of tube sheets. Int. J. Pre Ves. & Piping 67, 279-297.
15. ASME Boiler and Pressure Vessel Codes Section VIII, Division I.
16. ASME Boiler and Pressure Vessel Codes Section-II, Part-D.