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Design Modification and Fatigue Life Analysis of Pressure Vessel Filter Tube Sheet

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Abstract*— tubesheet in pressure vessel use to filter the natural gas during mining process for many petroleum industrial applications. During this process the natural gas contains many contaminating elements with sulphur as main ingredient, which can combines with sand or other carbon elements to create harmful effects of particulate impurities like slogging, clogging, fouling on the surface of the tubesheet. These impurities creates chemical reaction with tubesheet surface material which are normally made up of steel or ceramics. During working condition, the layer of clog is deposited on the filter tubes sheet surface and tubes. This clog layer creates increase in pressure inside the vessel. Once this pressure level exceeds the acceptable value, the filter tube sheet are cleaned either weekly or monthly basis. But this cleaning process needs to stop the entire plant working till the end of complete removal of clog, this creates reduction in efficiency parameters in terms of cost. In the present work design of pressure vessel filter tubesheet is performed on the basis of working conditions. Further it has been modified as per the corrections and suggestions given by end user. Number of holes for filtration and its pattern have been calculated on basis of modified design to get effective filtration with maximum efficiency. Another solution in terms of replacing filter unit has been proposed with which is divided into two sections and after every 4 to 5 seconds other section of tubesheet receives a back pressure of one seconds and washes out the other part of filter tubes. This modification in cleaning process gives efficient results without shutting down the plant production. Since it is a regular cycle so its needs to be shut down the plant once a year for full clean-up. This modification in working cycle creates cycling loadings on the tubesheet i.e. reverse pressure for cleaning and forwards pressure for working of pressure vessel. This compressive and tensile forces creates fatigue on the tubesheet and reduction in its fatigue strength. Therefore this tubesheet needs to analyse with modified concept for reduction in stresses and improved fatigue life. Dynamic analysis has been performed to evaluate fatigue life with modified thickness with dense meshing to get effective solution with respect to change in thickness of tubesheet.

***Keywords*— FEA Analysis, filter tube sheet, transient analysis, Fatigue life evaluation, fouling.**

I. Introduction

This project deals with the analysis and determination of the fatigue life of the tube sheets which are widely used in the filters as main supporting elements of the filter tubes with variation in thickness. The application of the filters which is considered in this project is of petro chemical industries. The specific application analysed deals with the natural gas filtering immediately after it is mined. A tube sheet is a plate, sheet, or bulkhead which is perforated with a pattern of holes designed to accept pipes or tubes, 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 and 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. Perhaps the best known use of tube sheets is as supporting elements in heat exchangers and boilers. These devices consist of a dense arrangement of thin walled tubes situated inside an enclosed, tubular shell.

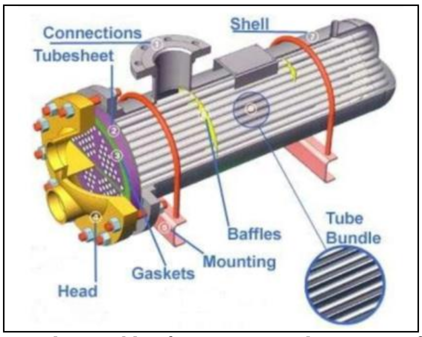

Figure1: General Assembly of Pressure Vessel & Pattern of tubesheet

Tubes are supported on either end by sheets which are drilled in a predetermined pattern to allow the tube ends to pass through the sheet. The ends of the tubes which penetrate the tube sheet are expanded to lock them in place and form a seal. The tube arrangement forms a contained unit between the tube sheets. The tube sheets are then bolted to flanges inside the shell. The shell extends beyond each tube sheet and is sealed, thereby forming two closed chambers on the non-tube ends of the tube sheets. This creates an arrangement where the exchanger consists of two separate end chambers joined by tubes which pass through an isolated space between the tube sheets. Heated fluid is then passed from one end chamber to the other through the tubes where cold fluid in the cavity between the tube sheets absorbs the heat energy. The design of tube sheets is a fairly precise and complex process; the exact number of tubes needs to be established and a pattern of holes calculated to spreads them evenly over the tube sheet surface. Large exchangers may have several thousand tubes running through them arranged into precisely calculated groups or bundles. Sheet design and production is largely automated these days with computer-aided design software performing the calculations and the tube sheet drilling done on computer numerical control machines. Tube plates or tube sheets have rows of holes with diameter of ‘D’ and pitch ‘P’. The material remaining between these holes are called ligament and the cross-sectional area of the ligament compared to the area in a normal unpierced cross section of width ‘P’ is called ligament efficiency. In other words, Stress Concentration Factor (SCF) is defined as the ratio of maximum principal stress □1 in the stressed model to the nominal stress applied at the boundary of the plate (□nom). As tubesheet plays a vital role in design and analysis of the pressure vessel it should be carefully studied for various loads and working conditions. The thickness of the tubesheet varies directly to the costing and procurement of various component of pressure vessel. Thicker tubesheet results in longer tube length inside the tubesheet that do not take part during working operations. The primary aim of this project is to evaluate the fatigue life design of tubesheet by determining and analyzing the effects of instant back pressure for cyclic loadings using Finite Element Analysis, the diameter, thickness and other design parameters are studied for given mechanical and working parameters for efficient and safe performance of the pressure vessel. This project work includes various design calculations using standard ASME codes for pressure vessel. A mathematical modeling has been prepared by considering tubesheet as a flat plate with center hole, for verifying the designed and FEA solution. Further dynamic and transient analysis has been done with FEA software ANSYS for evaluating the fatigue life of the tube sheet.

A. Problem Definition

Tube Sheet filters is cleaned by applying back pressure, and the pollutants are then collected at the opposite end of the vessel. Industrial filters do this operation once a month. However, in a Coal gas plant, the level of impurities is high, and this results in dense clogging of the filters within 5 days, and severe damage is caused to the filter and assembly due to the heavy built up of pressure as the tube get clogged. To tackle this problem, an instantaneous back pressure mechanism has been developed, which delivers 5 seconds of back pressure after 14 seconds of front pressure. This de-clogs the filters and reduces chances of pressure built up. However, due to back pressure, the stress profile in the filter changes from tensile to compressive, creating possibility of fatigue.

B. Objectives of the Project:

- Design of filter tubes heat and other related component on basis of working parameters.
- Design validation and modification as per end user.
- Mathematical modeling for validation of FEA methodology for the project.
- Dynamic Analysis with TET and HEX elements of FEA to evaluate efficient option for further transient analysis.
- Fatigue life analysis using various possible boundary conditions with respect to variation in tubesheet thickness.
- Evaluation of optimized thickness of tubesheet considering stresses, deformation and applied working pressure.

C. Methodology:

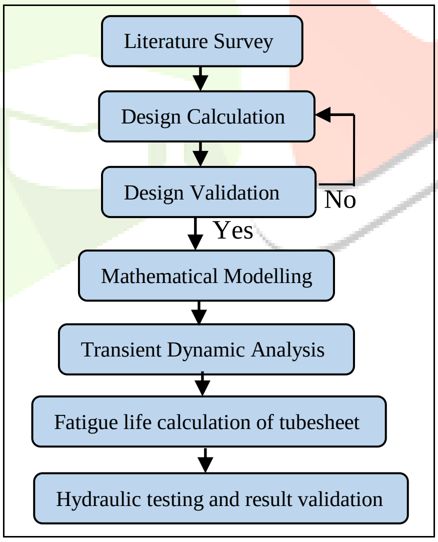

Figure 2: Methodology of the project work

II. LITERATURE SURVEY

W.J. O'Donnell [1] has described the method for calculating the stresses and deflection in the perforated plates with a triangular penetration pattern. Many different sets of effective elastic constants for perforated materials having a triangular penetration pattern have been proposed. The Paper concluded with Effective Elastic constants for both plane stress and bending loads for any plate thickness (H/R > 4) and preposition of complete structural design criteria for perforated plates. **D.L. Kaap, M.A. Sprague, et.all. [2]** describes a finite element benchmark for the dynamic analysis of perforated plates with a square penetration pattern using finite element dynamic analysis which agrees that Experimental and theoretical effective stiffness values for tube sheets with stiffness values determined from FE deflection analysis of statically loaded perforated plates. **Ming-Jia Li, Song-Zhen et.all. [3]** Summarized the development of the simulations and experimental studies for the fouling, erosion and corrosion of heat exchangers. The prediction models and methods, the simulations with these models and relevant experiments of fouling, erosion and corrosion were introduced. **Kalepesh D. Shirode, Dr. S.B. Rane et.all. [4]** investigated the optimized tube sheet thickness with different methodologies by comparisen of design and analysis of tubesheet thickness by using UHX code of ASME and TEMA standerds. From the design methodolgies it is found that both standards are based on different theroy of design. It is also found that FEA analysis results are closed to exact solution and these results can be accepted with a resonable degree of accuracy. **Kotcherla Sriharsha, Venkata Ramesh et.all. [5]** Elaborated the strength analysis of a typical tube to tube sheet joint in shell and tube heat exchanger. In the work the joint between tube and tube sheet joint in shell and tube heat exchanger is designed and analysed using ANSYS, for the combination of admiralty brass and steel as tube and tube sheet materials respectively. **Ravivarma.R, Azhagiri. Pon [6]** analysed required to assess integrity of Tubesheet are analysis for operating pressure loads and transient thermal analyses together with mechanical loads, for static and dynamic analysis. **R.D. Patil 2013[7]** has worked on the stress analysis of plate perforated by holes in square inch pattern. In this paper, for in plane loading a 4 x 4 pattern of hole i.e. 16 holes arranged in square pattern and subjected to uniaxial tension is considered. The stress distribution changes with the change in ligament efficiency for any given type of loading. Therefore effect of ligament efficiency on stress concentration factor was studied for uniaxial loading condition. **Naik Shweta [8]** has worked on the shape optimization and designing an optimal thickness for filter sheet assembly components for maximum economy. This paper describes a method for calculating stresses and deflections in perforated plates with a triangular penetration pattern. Average ligament stresses are obtained from purely theoretical Considerations but effective elastic constants and peak stresses are derived from strain measurements and photo elastic tests. Hydro test was taken with and without the filter weights and results were taken. Finite Element Analysis Validation shows that efficiency of Filter sheet can be increased by increasing number of tubes and still maintaining Factor of Safety 5. **Dr. Enrique Gomez, Mr. Roberto Ruiz et.all. [9]** focused on stress analysis of heat exchanger tube sheet with a misdrilled hole or irregular or thin elements and A stress analysis is described for a nuclear steam generator tube sheet with a thin or irregular ligament associated with a misdrilled hole using the rules of ASME B&PV Section III and Non-Mandatory Appendix A, Article A-8000 for Stresses in Perforated Flat Plates. The analysis is applied to an actual, non-parallel misdrilled hole and compared to a parallel misdrilled hole. **L.K. Zhu, L.J. Qiao, X.Y. Li [10]** analysed the tube sheet cracking in slurry oil steam generators Tubesheet cracking is a severe problem in the oil refinery industry with consequences of shortened service life and increased costs. Analysis of the tube-sheet cracking shows that the cracks always occurred in the shortest tube-tube ligaments. The residual contact stresses concentrated near the oil-side expansion joints where the cracks initiated. **N. Merah,A.Al-Aboodi, A. N. Shuaib et.all. [11]**worked on a 3-D finite element (FE) model of a tube-tubesheet joint was used to determine displacement and stress distributions along the axial direction of roller expanded tube-tubesheet joint and to evaluate the combined effects of large initial clearance and strain hardening of tube material on interfacial pressure and tube deformation. An appreciable difference is observed at with over tolerances where the 3-D model predicts cut-off clearances (clearance at which the interfacial pressure starts to drastically drop) which are about 30% lower than those predicted by the axisymmetric models. **Minshan Liu, Qiwu Dong, XinGu, [12]** proposed that the waste heat boiler acts effectively to a kind of heat exchanger. The numerical analysis and experimental research are carried out to obtain the stress of the new type Ω-tubesheet in waste heat boiler and the stress distribution of Ω-tubesheet. It is indicated that the stress state of the Ω-tubesheet can be enhanced by changing the conventional whole-circle tubesheet into the composed structure to both the high and low temperature tubesheet. **R. A. Newby, G. J. Bruck et.all. [13]**Worked on Optimization of Advanced Filter Systems for hot gas particulate filter technology. Ceramic barrier filters have reached a near-commercial status for IGCC and PFBC applications, their reliability and maintainability is still a concern. This test experience has focused the issues and has helped to define advanced hot gas filter design concepts that offer higher reliability and availability. **Arthur P. Boresi and Richard J. Schmidt [14]** focused loading condition and its stress distribution for different shapes and location of applied forces with different boundary conditions. Work Results for large elastic deflections of circular plates, that is, for maximum deflections that are large compared to the plate thickness i.e. Stresses and Deflections in Flat Circular Plates with Central Holes. In the case of large deflections, direct tensile forces (tractions), though small for deflections less than half the plate thickness, become relatively large for deflections greater than the thickness.

III. DESIGN AND MATERIAL SELECTION

A. Conventional vs proposed filtration method:

During conventional processing of cleaning operation of tubesheet whole plant is shut down for a period of week or month time which creates lost in production and economical aspect.to avoid this proposed Method as shown in figure is comprises in four parts of time cycle. The newly designed compartments are divided into two compartments as shown in figure after every 5 seconds one of the compartments receives a back pressure of 1 second, and cleans the filter tubes. This ensures cleaning without stopping the plant, plus since this is in regular cycles, plant shutdowns for full clean-up are needed only once a year. During filtration process the compressed gas is passed through the gas inlet chamber to the Filter elements. This gas is collected at the top of the filter compartment. Blow pipes with nozzles are provided for providing the back pressure and clean the filter elements. A compressed air supply is provided for creating a high intensity back pressure. The process of creating back pressure is divided into 12 second of cycles for cleaning number of chambers. The process repeats itself over and over again. However one of the crucial components is the filter sheet itself. This sheet stress reversals from positive to negative and is susceptible to fatigue.

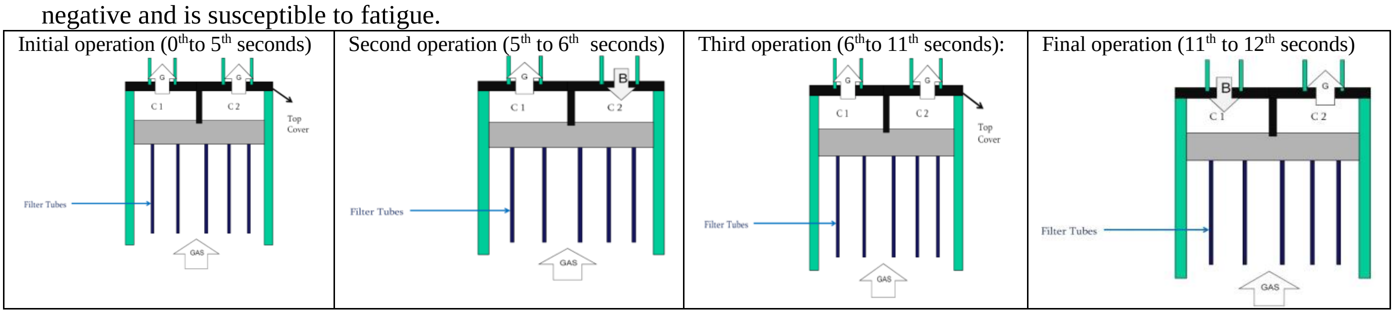

Figure 3: Proposed Methodology

B. Material Selection

Materials are selected according to the following criteria.

1) Corrosive or noncorrosive service
2) Contents and its special chemical/physical effects
3) Design condition (temperature)
4) Design life and fatigue affected during the plant life
5) Referenced codes and standards
6) Low temperature service
7) Wear and abrasion resistance
8) Welding and other fabrication processes

The material taken for tubesheet is SGR 590, as per the specifications of ASME codes. During analysis and testing of tubesheet of pressure vessel in this case the material used is SA 516 GR70 having following properties,

TABLE I

Properties of the tubesheet material

Carbon, max 0.5" and under	Manganese 0.5"	Tensile strength in ksi	Yield strength in ksi
0.27%	0.85-1.20%	70-90	38

C. Design parameters:

TABLE III

Tubesheet Parameters for Design Calculations (Instant Back Pressure)

Sr. No.	Parameter Description	Notations	Given Value
1	Internal Pressure	P	0.14 MPa
2	External Pressure	P_0	Atmospheric
3	Process Volume	V_p	126 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	2m
9	Tube Diameter	d	0.15m

A 5% Gap will be maintained on the Tube Sheet radius to allow for welding. Tubes arrange to form a 60^0 Equilateral Triangle.

TABLE IIIII

Designed values of various parameters for tubesheet

Tube sheet volume	11.945×10^6	Area pertaining to material removed	993.31 mm^2	Tube volume	15393.804 mm^3
Tubesheet thickness	150mm	Thickness of Shell and head	2mm	No of holes	544
Nozzle thickness	306mm	ligament efficiency	0.16	Load on bolt	417745.99
Reinforcement pad	478 mm.	Length of hub	0.12"	Length of shell	355.6mm
No of bolts	24	Bolt area required	20.887in^2		

IV. Experimental Analysis

A. FEA ANALYSIS (Transient Dynamic Analysis)

1) The final modified dimensions are as follows:-
   - Thickness of Tubesheet – 150 mm
   - Ligament Efficiency – 0.16
   - Number of Holes on the tubesheet - 490
2) Boundary Conditions for Convergence in tubesheet analysis:
   - Case 1: self-weight and gravity acting downwards.
   - Case 2: gravity acting downwards and design load (0.16 Mpa) acting in opposite direction of gravity.
   - Case 3: gravity acting downwards and back pressure (0.16 Mpa) acting in the direction of gravity.
   - Case 4: both positive and negative pressures acting on it.

Tubesheet was analysed for above mentioned cases by changing the element types. Tetrahedron Elements and Hexdominent Elements were used to get the maximum deflections and maximum stresses. Analyses were carried out varying the number of nodes and the size of elements. Rise of 50000 nodes was kept in every proceeding analysis. Highest number of nodes for analysis was selected as 3, 50,000 nodes. The maximum deflection and maximum stresses with respect to the number of nodes were plotted on the graphs. From these graphs the element size for which the stress values were highest was selected for the further Transient Dynamic Analysis.

TABLE IV

Comparative Analysis of HEX and TET element

Boundary conditions	TET element		HEX element	
	Max Deformation	Max stress	Max Deformation	Max stress
Tubesheet analysis with self-weight and gravity acting downwards	38.074	0.8212	45.794	0.8290
Tubesheet analysis with gravity acting downwards and design load (0.16 Mpa) acting in opposite direction of gravity.	35.272	0.7150	122.23	2.3752
Tubesheet analysis with gravity acting downwards and back pressure (0.16 Mpa) acting in the direction of gravity	100.4	2.1186	106.13	2.1186
Tubesheet analysis with both positive and negative pressures acting on it.	61.76	1.0276	74.207	1.0381

As shown in above table TET element gives more accurate results compared to HEX element.

B. Transient Dynamic Analysis of Filter Tube Sheet for Multiple Cycles

The transient analysis of tubesheet was performed using 1, 00,000 nodes value for multiple cycles. Below figure shows the boundary conditions for single cycle under which the tube sheet was dynamically analysed with respect to time.

The top and bottom faces of Tube sheet were divided into two parts from centre and were named as Top A, Top B, Bottom A, Bottom A, Bottom B respectively. The circular plate was fixed at the circumference.

1) Boundary Conditions

- **0 – 5 Seconds: -** Pressure of 0.14 Mpa was applied on the left bottom half face whereas 0.145 Mpa was applied on the right top half face of the tubesheet.
- **5 – 6 Seconds: -** No pressure was applied on any of the surface.
- **6 – 11Seconds: -** Pressure of 0.14 Mpa was applied on the right bottom half face whereas 0.145 Mpa was applied on the left top half face of the tubesheet.
- **11 – 12Seconds: -** No pressure was applied on any of the surface.

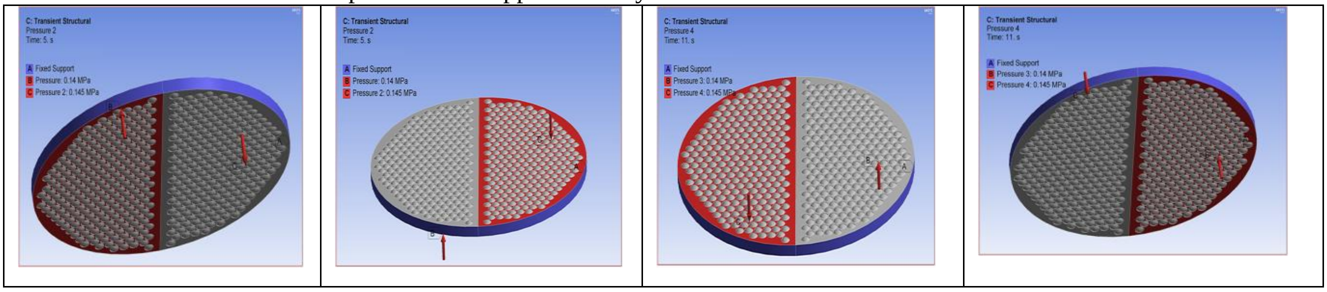

Figure 4: Time Cycle analysis using FEA

2) Results of Transient analysis:

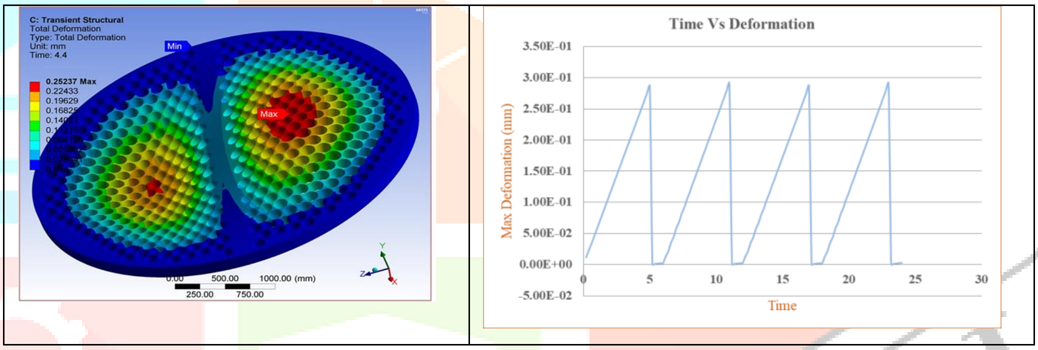

Figure 5: Transient Analysis Results with 100000 nodes for multiple cycles,

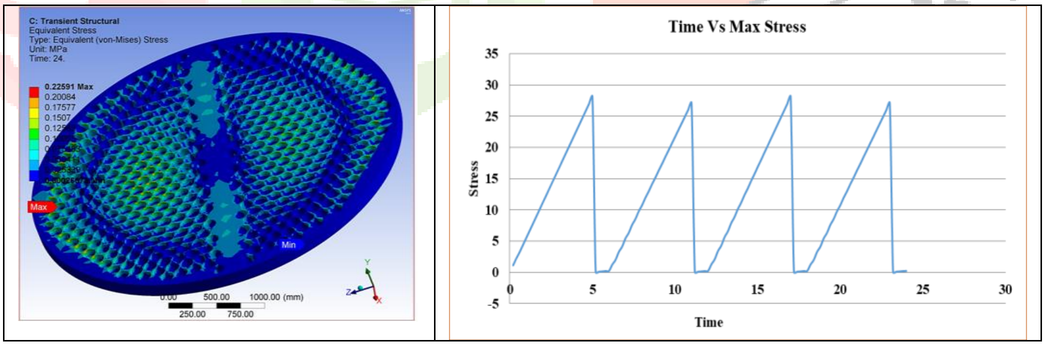

Figure6: Transient Analysis Results with 250000 nodes for multiple cycles,

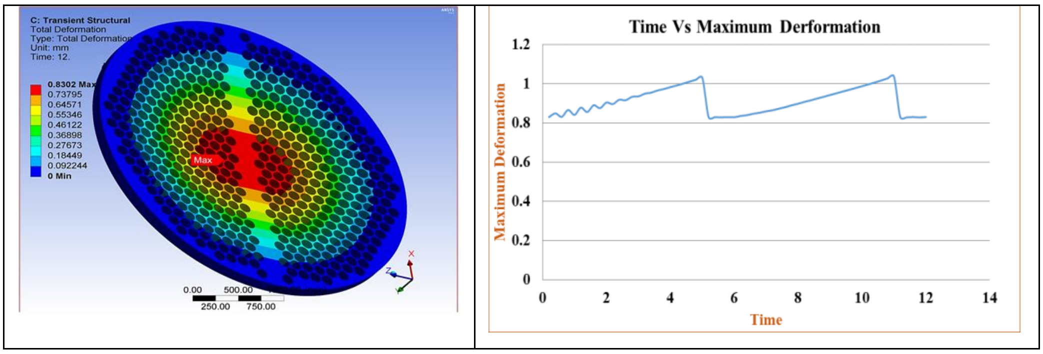

Figure7: Transient Analysis Results with 250000 nodes for single cycles,

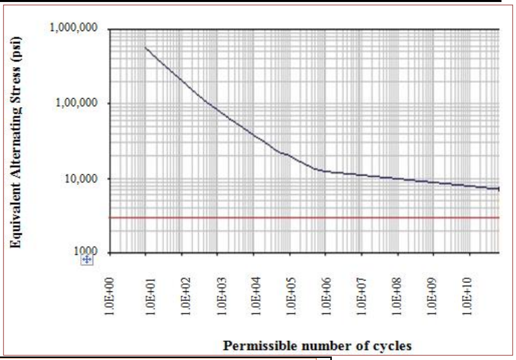

Figure9: Fatigue life cycle graph for 150 mm thickness tubesheet

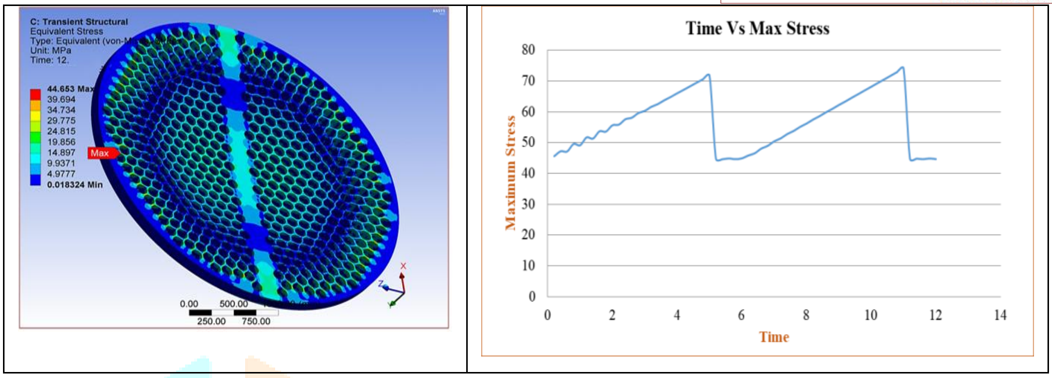

Figure8: Transient Analysis Results with 250000 nodes for every half cycles,

C. Fatigue Life Calculations For Tube Sheet

Cyclic Data

dS_{pk}– Range of Primary + Secondary + Peak = 27 N/mm^2 = 3916.30899 Psi

K_f – Fatigue Strength reduction factor = 2.50

m – Material constant used for the fatigue knock down factor = 3.00

n – Material constant used for the fatigue knock down factor = 0.20

S – Material Allowable Stress = 20015.207 Psi

S_y – Material yield Strength = 38426.29823 Psi

T_{av}– Average Cycle temperature = 150

E_t – Modulus of Elasticity at T_{av} = 29030000

Fatigue Penalty Factor

S_{ps} = 3* S or 2* S_y……………(Whichever is maximum)

S_{ps}= 76852.59646

K_{ek} 1 = 1

K_{ek} 2 = 1+ (1-n) / (n (m-1)) (dS_{pk} / S_{ps} – 1) = -0.89808

K_{ek} 3 = 1 / n = 5

K_{ek} = if ($dS_{pk} < S_{ps}$) then K_{ek} 1

Therefore, K_{ek} = 1

Permissible cycle life

$S_{alt}K$ = (K_f * K_{ek} * dS_{pk}) / 2

$S_{alt}K$ = 4895.386 Psi ……………………… Alternating stress in Tube sheet

$S_{alt}K$ = 33.7525 N/mm^2

It can be observed that for the calculated value of alternating stress i.e. 4895.386 psi, the model can sustain for more than E^{11} number of load cycles. Hence the tube sheet can sustain the alternating stress for infinite life. In this case the transient dynamic analysis of tubesheet was carried out for different loading conditions and for different thickness of tubesheet. Below are the results of the analysis in terms of fatigue life of the Tubesheet.

- **Tubesheet with 150mm thickness and 1,00,000 nodes:-**
  Maximum deformation – 0.252 mm
- **Tubesheet with 150mm thickness and 2,50,000 nodes:-**
  Maximum deformation – 1.0372 mm
  Fatigue Life – 1.0E11 number of cycles

D. Experimental Validation

1) All new product equipment shall be tested at 2.5 times the operating pressure using Hydro test.
2) The Hydro test shall have slow built up of pressure, from base pressure to test pressure over a period of 120 min.
3) The equipment shall be maintained at test pressure for 30 min.
4) The pressure shall be gradually reduced to base pressure within a period of 45min.
5) After test, all components shall be subjected to NDT (Non Destructive Test), as below
   a) Visual Inspection-No surface irregularities must be present.
   b) Pre Dyed components should have no loss of dye due to leakage.
   c) Ultra Sonic Testing – Post Test, internal damage shall get amplified if any, and shall be recorded in an Ultra Sonic Test.

6) The test performance of the assembly should be completely elastic; this shall be verified by checking the dimensions of product for any permanent yield.

Hydro Test Condition

1) Working fluid: Water with Anti Scaling Additives
2) Test Pressure: 2.5 x 0.07 MPa
3) Leak Inspection: Sensors (LDR) on the top side of Filter Assembly.
4) Method: Visual Inspection on top side after completion of test.
5) Remark: Simultaneous testing of all 7 chambers was done.

Test Execution Details

1) Begin Time: 09.00 hrs
2) Base Pressure: 0 MPa (Empty vessel)
3) Peak Pressure Time: 11.00 hrs
4) Peak Pressure: 0.175 MPa
5) Pressure relief begins Time: 11.30 hrs

Visual Inspection Details

1) No leak observed on Top Side of Assembly
2) No visible damage observed after test.
3) Plug Adhesion intact after test.

Auditors Remarks:

1) Code requirements have been met by the analysis.
2) The Mesh is satisfactorily fine enough to generate accurate results.
3) The boundary conditions were inspected.
4) The maximum Stress in Filter sheet is 32 MPa, however nominal value if calculated is much lower, it satisfy FOS is 5.
5) Gasket plate shows peak pressure of 34 MPa. However it is observed to significant stress raiser due to vicinity of contact and relatively less thickness of the plate compared to the other components.
6) Material Non Linearity may not be modelled in future analysis as it will have negligible effect on accuracy and unnecessary increases solution time.
7) FEA processing has been done in line with requirements of SA 516 GR70, FEA and the component maintains a FOS greater than 5 for the current boundary conditions.

The tubesheet was checked for the maximum deformation under the fluid pressure of 0.173 Mpa, and working at 27^0C. The holes of tubes were blocked with the help of GR 3084 Plugs. To measure the deformation (LC 4C1 X) HBM type of Strain gauge was located at the centre of the Filter Tubesheet. The table below shows the values of deformation obtained analytically as well as experimentally and the percentage of error.

TABLE V
Experimental Vs FEA Analysis Results

Sr. No.	Test	Max Deformation in mm by FE Analysis	Max Deformation in mm by Measurement	% Error
1	Hydro Test at 0.173 Mpa Pressure	4.3903	4.9	10.4%
2	Under self-weight and gravity condition at 0 Mpa	0.82867	0.86	3.64%

Improvements in Design and Scope of Project

Following are the parameters where there is a scope of improvement.

a. Changing the material used for the Tubesheet
b. Reducing the number of filter holes in the tubesheet.
c. Changing the pattern of holes in the tubesheet.
d. Changing the cycle time of pressures and checking it for fatigue life.
e. Changing the thickness of the tubesheet and checking it for the required life.

Out of the above scopes only one was carried out for analysis purpose. In improvement the thickness of the tubesheet was reduced and checked for the fatigue life, following results were obtained in the transient analysis with varying thickness,

TABLE VI
Result analysis of transient FEA for variation in thickness.

Conditions of Analysis	Maximum Deformation (mm)	Fatigue Life
Tubesheet with 150mm thickness and 1,00,000 nodes	0.252	1.0E+10
Tubesheet with 150mm thickness and 2,50,000 nodes	1.0372	1.0E+11
75mm thick tubesheet with extreme loading conditions	7.3413	1.0E+08
75mm thick tubesheet with real load conditions	6.3733	1.0E+08

V. CONCLUSION AND FUTURE SCOPE

A. Conclusion

The project deals with the determination of the fatigue life of tubesheet which is one of the major components in industrial filter vessels. The tubesheet have to sustain the static load of the filter tubes as well as the self-weight due to gravity. In the current study a new system exerting back pressure was implemented due to which the tubesheet was under alternating stresses causing the tubesheet to undergo fatigue. To increase the accuracy of results the convergence analyses were performed with different boundary conditions to get the proper number of nodes and element size for further analysis. Convergence analysis gave the following conclusion:-

a) 2.5 Lakh nodes should be used for the further transient analysis as the value of stress is maximum for 2.5L nodes for different boundary conditions.
b) Hexdominent Element should be used as it shows quality meshing results.

Transient dynamic analyses were performed on the tubesheet to check the maximum deformation and stresses at various instant of time during the load cycle. A transient analysis performed on the tubesheet with 1 Lakh nodes concluded that the deformation at the end of every load cycle is reaching its initial value and only one complete load cycle is sufficient for further analyses. Further the transient dynamic analysis of tubesheet with 2.5 Lakh nodes was performed to get the maximum deformation and maximum stresses in the tubesheet. Using the maximum stress values the fatigue life of tubesheet was calculated which came out as infinite life. Further the improvement in project was suggested as the reduction of tubesheet thickness to 75mm form 150mm. The fatigue life under extreme condition for tubesheet came out as finite life but under real loading conditions the life was infinite which proved that the tubesheet with 75mm thickness can be used for the current application. The summarized conclusions are listed below,

1) Design calculations of pressure vessel has been verified by customer end and modified as per ASME section VIII.
2) Triangular (30°) and Rotated triangular (60°). A triangular (or rotated triangular) accommodates more tubes than square (or rotated square) pattern. Triangular layout produces high turbulence. A triangular layout pattern is limited to use in clean services on the shell side.
3) Square (90°) and Rotated square (45°). It is usual practice to use square layout pattern for dirty services on shellside.
4) Proposed mathematical model of circular plate with hole suggest that finite element procedure for the tubesheet of pressure vessel is acceptable.

B. Future Scope

Following are the parameters where there is a scope of improvement.

1) Finite element procedure is best suitable process for pressure vessel analysis; further this process can be applied using various different FEA elements with fine meshing and transient analysis.
2) Further analysis can be done for different components of the pressure vessel such as shell, flange, support etc for evaluating the results to improve efficiency and life of the pressure vessel.
3) Changing the material used for the Tubesheet – Comparatively stronger material can be used and analyzed for the fatigue life. The thickness of tubesheet required in this case will be comparatively less.
4) Reducing the number of filter holes in the tubesheet. – Reducing the number of holes may increase the ligament efficiency of the tubesheet.
5) Changing the pattern of holes in the tubesheet- Different patterns of holes may give different ligament efficiencies and the optimum pattern could be evaluated after analysis.
6) Changing the cycle time of pressures and checking it for fatigue life.

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