FEA ANALYSIS OF PRESSURE VESSEL WITHDIFFERENT TYPE OF END CONNECTIONS

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Abstract— Design of head in pressure vessels is a challenging task. Different types of heads or ends can be provided for a pressure vessel. This paper deals with the Finite element analysis of Pressure vessels with different type of end closures(head) keeping the same cylindrical volume and thickness. The desired pressure vessel is designed as per ASME standard section VIII, division I for 120 bar pressure. In this work, a comparative study of different types of pressure vessel heads is discussed. The purpose of the work is to find out the best possible end closure out of Torispherical head, Elliptical head, Hemispherical head and Conical head. A finite element method based software ANSYS is used to observe the stresses in these heads.

Keywords: Pressure Vessel, end closures, finite element analysis, head, stress.

I. INTRODUCTION

Pressure vessels store large amounts of energy; the higher the operating pressure - and the bigger the vessel, the more the energy released which in the event of a rupture will lead to higher extent of damage or disaster or danger. To prevent stress related vessel rupture and catastrophic failure, main factors that contribute extensively to stress development must be identified and ways of how they can be mitigated must be recognized. Head of the vessel is critical zone and an analysis can provide guidelines in selecting proper head.

Different types of heads are discussed in brief below:

Flat Heads: Flat heads or plates are the simplest type of end closures used only for small vessels. They can be used as manhole covers in low pressure vessels and as covers for small openings.

Hemispherical Heads: A hemispherical head is the strongest shape and is capable of resisting nearly twice the pressure of a torispherical head of the same thickness. The cost of forming a hemispherical head will be higher than that for a shallow torispherical head. The amount of forming required to produce hemispherical shape is more, resulting in increased forming cost. As they are the expensive to form they are reserved for high pressure applications.

Ellipsoidal Heads: Ellipsoidal heads are often used for pressures over 10 bar. In cross-section, the head is like an ellipse with its radius varying continuously. This results in a smooth transition between the dome and the cylindrical part of the vessel. The shape of the ellipsoidal head is defined by the ratio of the major and minor axis. A standard arrangement on vessels is the 2:1 elliptical head. Due to shallow dished shape the forming cost is reduced.

Torispherical Heads: A torispherical shape, which is extensively used as the end closure for a large variety of cylindrical pressure vessels. The shape is close to that of an ellipse but is easier and cheaper to fabricate. Torispherical heads are made of a dish, with a constant radius. Joining the dish directly to the cylindrical section of the vessel leads to a rapid change in geometry, resulting in excessive local stresses. To avoid this, a transition section (knuckle) is used between the dish and the cylinder. They are generally used for very high pressure applications.

Conical Heads: The conical heads are widely used as bottom heads to facilitate the removal or draining of fluid. The semi-cone angle is usually taken as 30°.

II. LITERATURE REVIEW

When modelled correctly, FEA proves to be a very useful tool to find out the stress interactions between the vessel shell and the end closure but the operator needs to interpret the results correctly. For the validation of the FEA result, calculation of stresses by experimental methods is also necessary. The analyst must be able to obtain an approximate solution of stresses by using a classical analytical method to verify the FEA results. The paper deals with finite element analysis of different types of end closures and their interaction with the vessel shell keeping the thickness and volume of shell constant. Approximation of stresses was done for the horizontal pressure vessel supported on two saddle supports. Structural analysis was done to calculate the stresses in pressure vessel. [1] For the pressure vessels, different types of heads or ends can be provided. A comparative study of different types of pressure vessel heads is discussed in this work. A finite element method based software ANSYS is used to observe the stresses in these heads. Comparison of stresses in these types of heads is to be done to study the differences in stresses and to consider the forming cost and the stresses developed. [2] This work is concerned with design of different pressure vessel elements such as shell, torispherical head, operating nozzle, its reinforcement, on standards and codes and evolution of all components analysed by ANSYS and Experimental setup. The aim of the study was to address the problem of pressure vessel using both experimental and Finite Element Analysis (FEA) approach. The results obtained from both FEA models and experimental tests are compared which shows a close agreement. [3]

III. MATERIAL PROPERTIES AND DESIGN CALCULATIONS

The design of pressure vessel has been made considering various parameters internal pressure, volume etc. based on ASME codes. The length and diameter of the vessel have been chosen according to the codes based on the quantity of fluid to be stored.

Sr.No.	Properties	Value
1.	Density of material	7833Kg/m^3
2.	Modules of elasticity	2*10^{5}N/mm^2
3.	Operating pressure	120 Bar
4.	Inside diameter	1500 mm
5.	Cylinder length	2500 mm
6.	Ultimate tensile stress	483 N/mm^2
7.	Welding efficiency	1

Table 1 Material Property and Design Parameters

Design Calculations

1) Shell Calculation

Thickness (t) = $\frac{PR}{SE-0.6P} = \frac{12*750}{138*1-(0.6*12)}$

= 68.807 mm

2) Hemispherical Head Calculation

Thickness (t) = $\frac{PR}{2SE-0.2P} = \frac{12*750}{2*138*1-(0.2*12)}$

= 32.894 mm

3) Ellipsoidal Head Calculation

Thickness (t) = $\frac{PD}{2SE-0.2P} = \frac{12*1500}{2*138*1-(0.2*12)}$

= 65.789 mm

4) Torispherical Head Calculation

Thickness (t) = $\frac{0.885PL}{SE-0.1P} = \frac{0.885*12*1500}{138*1-(0.1*12)}$

= 116.44 mm

5) Conical Head Calculation

Thickness (t) = $\frac{\mathrm{PD}}{2\cos\alpha(\mathrm{SE}-0.6\mathrm{P})} = \frac{12*1500}{2\cos 30\,(138*1-(0.6*12))}$

= 79.45 mm

IV. FINITE ELEMENT ANALYSIS

The finite element analysis (FEA) is a numerical technique for finding the approximate solutions to boundary value problems for partial differential equations. Finite element analysis is a powerful tool in the field of engineering. Even though finite element analysis provides another way of analyzing structures, it requires proper understanding of the physics of the problem and the codes being used. To find out the stresses at the interaction between pressure vessel cylinder walls and end connectors, FEA proves to be very useful as this is not possible using standard design codes. FEA is a useful tool, but the operator needs to be able to interpret the results properly.

3D Cad Model of Vessel

Pressure vessel models of different condition are modelled with application of CATIA V5. The models are exported as STEP file with solid as option. Same models are imported into ANSYS Workbench Environment.

MESHING

ANSYS offers a complete set of tools for automatic mesh generation, including mapped mesh generation and free mesh generation.

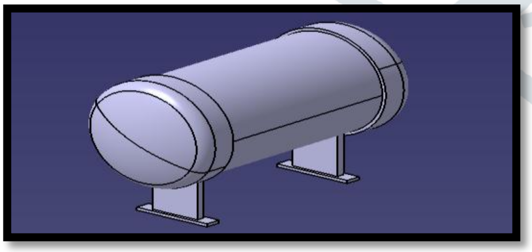

Fig.1 3D CAD model

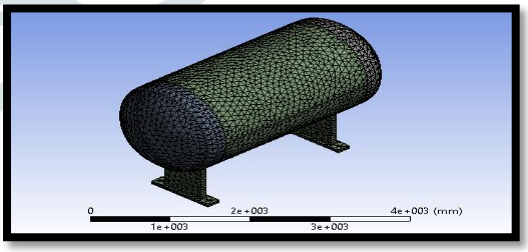

Fig.2 Meshing

BOUNDARY CONDITIONS

Boundary condition applied on the pressure vessel on fixed saddle support as shown by (C) keeping it as fixed support and pressure (A & B) of 12 MPa is applied on the all inner faces of the pressure vessel.

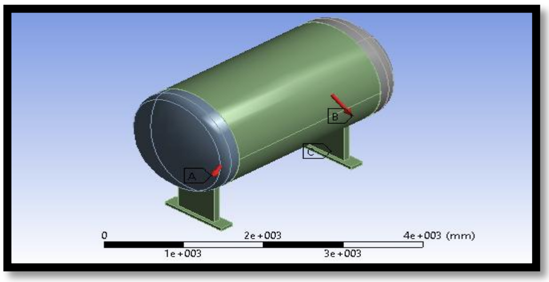

Fig.3 Boundary Conditions

STRESS & DEFORMATION CONTOURS FROM ANALYSIS

1) Flat Head

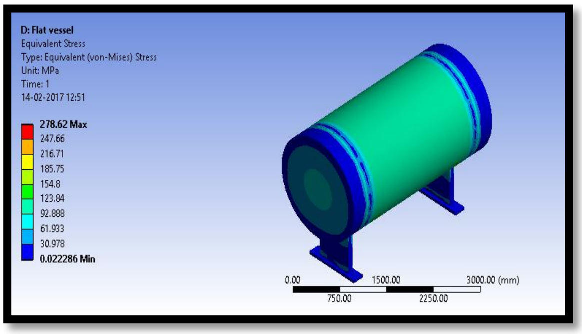

Fig.4 Stress in Flat Head Vessel

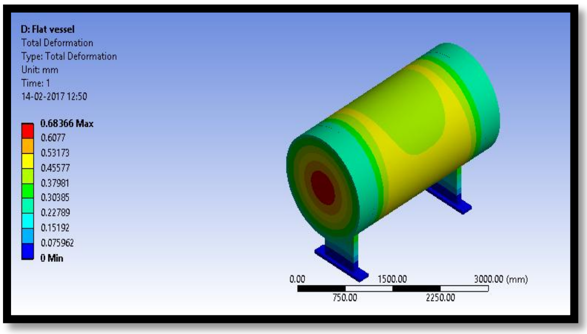

Fig.5 Deformation in Flat Head Vessel

From Fig.4 & 5, it is observed that the maximum equivalent stress of the pressure vessel is 278.62 N/mm^2 and is developed at the interaction between the shell and the head. The maximum deformation in the vessel of found to be 0.683 mm.

2) Hemispherical Head

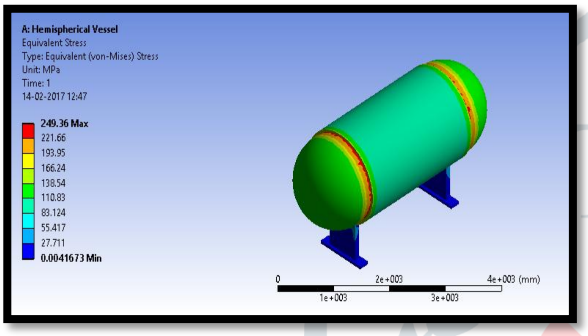

Fig.6 Stress in Hemispherical Head Vessel

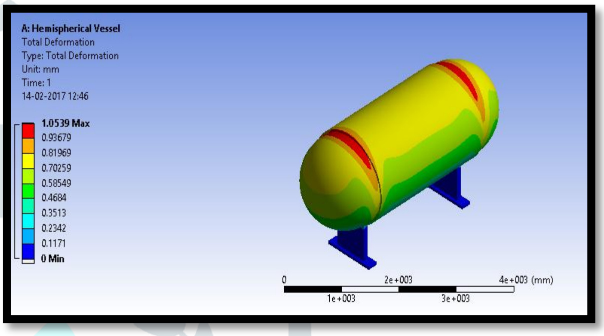

Fig.7 Deformation in Hemispherical Head Vessel

From Fig.6 & 7, it is observed that the maximum equivalent stress of the pressure vessel is 249.36 N/mm^2 and is developed at the interaction between the shell and the head. The maximum deformation in the vessel of found to be 1.053 mm.

3) Ellipsoidal Head

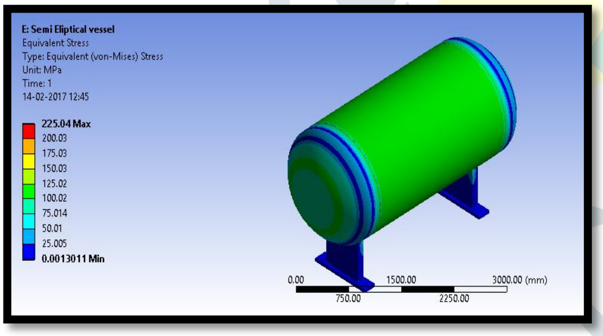

Fig.8 Stress in Ellipsoidal Head Vessel

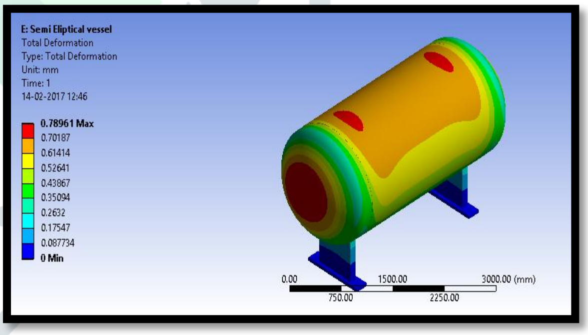

Fig.9 Deformation in Ellipsoidal Head Vessel

From Fig.4, it is observed that the maximum equivalent stress of the pressure vessel is 225.04 N/mm^2 and is developed on the ellipsoidal head. The maximum deformation in the vessel of found to be 0.789 mm.

4) Torispherical Head

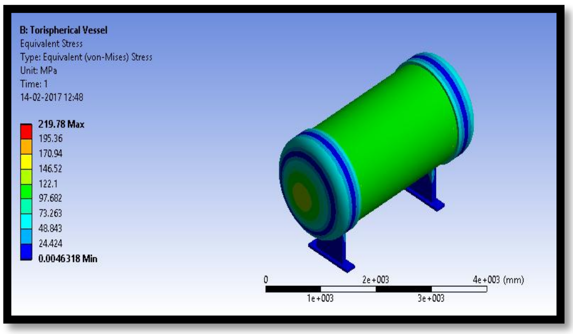

Fig.10 Stress in Torispherical Head Vessel

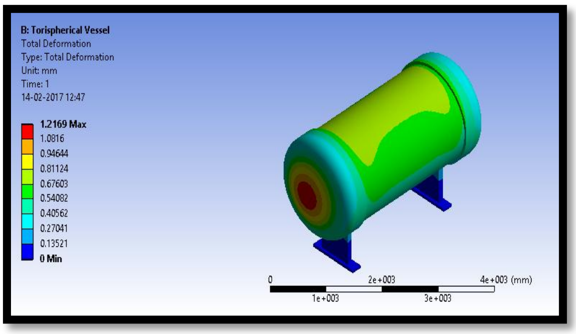

Fig.11 Deformation in Torispherical Head Vessel

From Fig.4, it is observed that the maximum equivalent stress of the pressure vessel is 219.78 N/mm^2 and is developed on the Torispherical head. The maximum deformation in the vessel of found to be 1.206 mm.

5) Conical Head

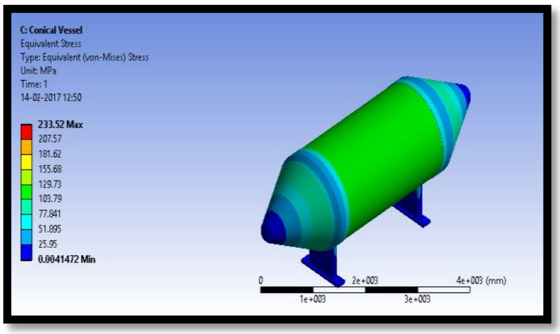

Fig.12 Stress in Conical Head Vessel

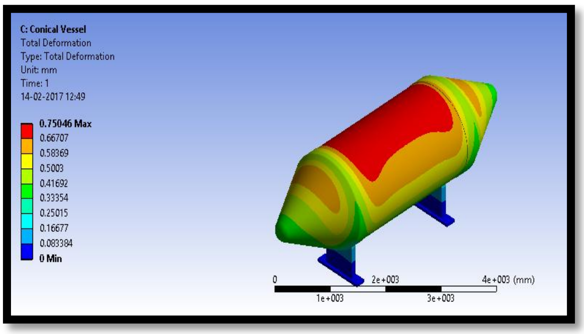

Fig.13 Deformation in Conical Head Vessel

From Fig.4, it is observed that the maximum equivalent stress of the pressure vessel is 233.52 N/mm^2 and is developed on the conical head. The maximum deformation in the vessel of found to be 0.750 mm.

V. RESULTS AND DISCUSSION

With the help of Finite element analysis, we have studied the actual stress distributions in the different components of pressure vessel and the actual behavior of pressure vessel.

1) STRESS & DEFORMATION RESULTS

Sr.No	Type of PV Head	Eq. Stress (MPa)	Deformation (mm)
1.	Flat Head	278.62	0.683
2.	Hemispherical Head	249.36	1.053
3.	Ellipsoidal Head	225.04	0.789
4.	Torispherical Head	219.78	1.206
5.	Conical Head	233.52	0.750

Table 2 Stress Results

Table 2 shows the variations in the von mises stresses in different type of pressure vessel heads. It is also observed that the location of maximum stress also changes for different types of pressure vessel heads. From the software results, maximum von mises stresses are induced flat head pressure vessel and is less in torispherical head pressure vessel.

2) CONVERGENCE RESULTS

Convergence is one of the main criteria for checking the accuracy and effectiveness of the analysis results. Generally, a finer mesh produces more accurate results than a coarser mesh. At some point, one reaches a point where the increased mesh density fails to produce a significant change in the results. At this point the mesh is said to be “converged.” In our case, convergence (Ellipsoidal Head Vessel) is clearly seen at about 336035 elements when the stress value does not change significantly.

Sr.No	No. of Elements	No. of Nodes	Eq. Stress (MPa)
1.	2460	5249	185.86
2.	5822	12263	213.19
3.	19789	40404	211.51
4.	109292	193761	222.43
5.	336035	577880	223.64

Table 3 Convergence results

Five different end connection models were analyzed with same internal pressure of 12 MPa and same volume and the results for end connection sub-structured models were analyzed in ANSYS.

VI. CONCLUSION & FUTURE SCOPE

Results shows that the end connection with torispherical shape is the least stressed when compared to other models. As the forming cost of torispherical head is less as compared to hemispherical head, it can also be used for high pressure applications. On the contrary, the thickness of torispherical head is the largest and hence the material cost increases considerably. The maximum value of stress is found in the flat head. Hence, these types of heads are not generally used for high pressure applications even though their forming cost is less. Thus, from the analysis, the interpretation that torispherical heads can be used for high pressure application is also validated.

For the future work, analysis of different types of heads can be done by varying the internal pressure. Different types of heads give different results for changes in internal pressure. Moreover, the analysis can only be done taking into consideration the external loads like wind load and weight of the vessel which has been neglected in this study.

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