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## Analysis of Heads of Pressure Vessel

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**ABSTRACT:** Head design in pressure vessels is a challenging task. For the pressure vessels, different types of heads or ends can be provided. In this work, a comparative study of different types of pressure vessel heads is discussed. A finite element method based software ANSYS is used to observe the stresses in these heads. Axi-symmetric behaviour of elements is used to reduce the modelling & also analysis time. Quadrilateral elements with mid-side nodes are used for meshing the models. Comparison of stresses in these types of heads is done to study the differences in stresses and considering the forming cost and the stresses developed, torispherical head is found better than elliptical head & hemispherical heads.

**KEYWORDS:** Pressure Vessel, types of heads, stresses comparison

**SYMBOLS:** P = Pressure exerted, Do = Outside diameter of domed end, K = Shape factor, f = Design Stress

### I. INTRODUCTION

Need of large capacity deaerated water storage tanks: Nowadays instead of making use of number of boilers of small capacity, a single boiler having large capacity is used. This will be more economical than the previous method of using number of small capacity boilers. It is seen that the efficiency and life of the boiler increases if deaerated water is used for the boilers resulting in reduced corrosion rate. Large sized deaerated water storage tank is hence required to fulfil the requirement of large capacity boiler. Hence need revealed to use greater capacity deaerated water storage tank. Head/end of the vessel is critical zone and an analysis can provide guidelines in selecting proper head/end. The available types of different heads are mentioned in brief as follows.

**Hemispherical Heads:** A hemispherical head is the strongest shape; capable of resisting about twice the pressure of a torispherical head of the same thickness. The cost of forming a hemispherical head will, however, be higher than that for a shallow torispherical head [10]. 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. [1]

**Ellipsoidal Heads:** For pressures over 10bar, ellipsoidal heads are often used. In cross-section, the head resembles an ellipse, its radius varying continuously. This results in a smooth transition between the dome and the cylindrical part of the vessel. Ellipsoidal heads are deeper than comparable torispherical heads. 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. This will have a depth of head which is a quarter of the vessel's internal diameter D. 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. These are formed from part of a torus and part of a sphere. 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 would lead to a rapid change in geometry, resulting in excessive local stresses. To avoid this, a transition section (the "knuckle") is used between the dish and the cylinder. Normally, torispherical heads with pressure ratings much above 10bar are uneconomic. The torispherical head is actually very

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similar to the ellipsoid in shape and benefits. But it is easier to manufacture because of availability regular circular curves on the edges than a larger curve as it heads. [10]

Hemispherical and semielliptical heads are used for tall vertical towers because they are practically free from discontinuities. In such cases the cost of the top end closure is only a small part of the total cost of the pressure vessel. Also the space is not a limiting factor for vertical pressure vessels. Torispherical heads are more economical than other types of domed heads. Owing to their compact construction they are used for horizontal pressure vessels. [1] Complexities involved in analysis can be easily taken into account using FEA packages. In this current work, the analysis is carried out using ANSYS.

ANSYS Meshed Model with load & boundary conditions: Here for meshing of the model quadrilateral element with mid-side nodes (PLANE82) is selected as these are capable of giving good results for the present type of problems. PLANE82: It is a higher order version of the 2-D, four-node element PLANE42. It provides more accurate results for mixed (quadrilateral-triangular) automatic meshes and can tolerate irregular shapes without as much loss of accuracy. The 8-node elements have compatible displacement shapes and are well suited to model curved boundaries. Following figure shows the structure of PLANE82 element.

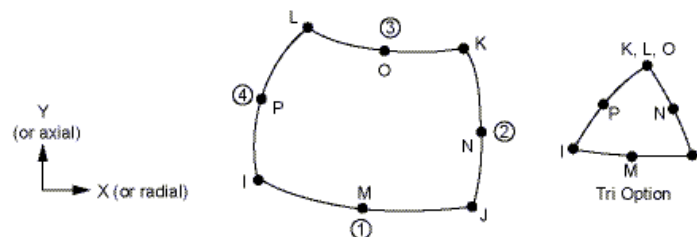


Fig.1 Structure of PLANE82 element [9]

The 8-node element is defined by eight nodes having two degrees of freedom at each node: translations in the nodal x and y directions. The element may be used as a plane element or as an axi-symmetric element. The element has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities.

## II. LITERATURE REVIEW

X. Charles (2014) carried out Stress Analysis of Pressure Vessel Due to Load and Temperature. The stresses induced within the vessel at numerous components area unit compared with their material allowable stresses and located to be within the limits. The deflection of the highest dish is 0.52 mm. The utmost stress happens at the change of integrity of torispherical half and main rim and also the minimum stress happen at high of the nozzle.[6]

Edin Sunje (2010) analysed stresses in torispherical head of pressure vessels. Experimental analysis of stress at torispherical head of pressure vessels was compared with results gathered from standard expressions. Also, the results were compared with evaluated results obtained using finite element method. For experimental analysis use multiple strain gages was done in order to obtain real stress in observed area. ANSYS software was used for FEM analysis. Significant deviations between results were obtained. Imperfection in material and shape, corrosion and other similar factor can be reason for such deviations in stress values obtained using mentioned three methods. Standard expressions as also as FEM analyses do not take into account mentioned factors that significantly influence on stress value in pressure vessels and could only be used as reference values for over viewing stress condition in pressure vessels. Nonexperimental methods are quite appropriate to use in design process as contiguous tools. [7]

Bandarupalli Praneeth (2012) performed finite element analysis of pressure vessel and piping design. Various parameters of Solid Pressure Vessel & Multilayer Pressure vessels are designed and checked according to the principles of A.S.M.E. The stresses developed in Solid wall pressure vessel and Multilayer pressure vessel are analysed by using ANSYS. The theoretical values and ANSYS values are compared for both solid wall and multilayer pressure vessels. It was found that multi layered pressure vessels are superior for high pressures and high temperature operating conditions. [5]

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Dr. M. M. Patil (2014) carried out experimental investigations using hydrostatic pressure tests with water. In the case of numerical investigations, the FEA models are constructed using material SA240 Gr 316. The results obtained from both FEA models and experimental tests were compared which shows close agreement. Comparing the flat flange and hub flange model on the ANSYS with the same loading and operating condition, he found 15 to 20 % reduction in stress. [8]

Findings of literature survey: It was observed that a little work is carried out on comparative analysis of different heads of pressure vessels. “BS 1113” codes for design of large sizes pressure vessels have not been communicated. In this work, analysis of different heads for large capacity deaerated water storage tank is carried out using “BS 1113” and validated using ANSYS.

### III. SPECIFICATIONS OF DESIGNED DEAREATED WATER STORAGE TANK

Specifications for a typical case of which Deaerated Water Storage Tank are communicated as follows.

- Pressure            3 Kg/cm<sup>2</sup> (or 0.2943 N/mm<sup>2</sup>)
- Temperature       1100C
- Capacity            30,000 kg
- Diameter            3 m
- Length              6 m

### IV. DETERMINATION OF THICKNESS OF SHELL ENDS:

Here two different types of heads/ends are taken into account.

a) Type1- (Torispherical, Hemispherical and Elliptical Head):

In “BS 1113” the formulae used for determination of thickness of torispherical head are applicable to semielliptical and hemispherical heads, hence analytical solution of only torispherical is shown.

Using the notations in the figure,

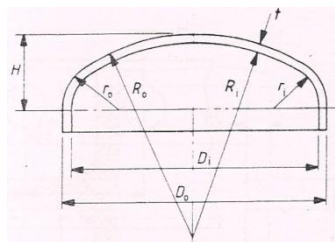


Fig.2 Torispherical shell End [2]

- i)  $R_i$  shall not be greater than  $D_o$
- ii) The internal corner radius “ $r_i$ ” shall neither be less than 10% of  $D_o$  nor less than 3 times thickness of shell end
- iii) The external height  $H$  shall not be less than 0.18  $D_o$

$$\text{Thickness of shell end} = t_{se} = \frac{P D_o K}{2 f}$$

$$\text{Let } H = 0.18 \times D_o$$

But as the minimum thickness  $t_{se}$  shall in no circumstances be less than 9.5 mm,

$$\text{Let } t_{se} = 10 \text{ mm}$$

$$\text{Hence, } H = 0.18 \times [3000 + (2 \times 10)] = 543.6 \text{ mm} \approx 600 \text{ mm}$$

$$\text{For, } H/ D_o = 600/3020 = 0.1986$$

As the value of  $K$  depends on  $\frac{d}{\sqrt{(D_o \times t)}}$  along with  $H/D_o$ , the value of  $\frac{d}{\sqrt{(D_o \times t)}}$  is determined first.

Here  $d$  = diameter of manhole = 400 mm

$$\frac{d}{\sqrt{(D_o \times t)}} = \frac{400}{\sqrt{(3020 \times 10)}} = 2.3$$

Now, using the curves for shape factor, the value of  $K$  is decided.....[2]

$$\text{For } H/D_o = 0.19 \text{ \& } \frac{d}{\sqrt{(D_o \times t)}} = 2.3$$

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$$K = 2.2, \text{ Hence } t = \frac{P D_o K}{2 f} = \frac{0.2943 \times 3020 \times 2.2}{2 \times 174.66} = 5.59 \text{ mm}$$

Applying 2.5 mm corrosion allowance to the thickness of torispherical dish end,

Thickness of torispherical dish end = 5.59 + 2.5 = 8.09 mm  $\approx$  10 mm

As the thickness of torispherical dish end is 10mm the same is considered for the finite element analysis.

b) Type- 2 (Flat end):

Thickness of flat end is obtained [2] as mentioned below

$$\text{Thickness of flat end} = c \times d_i \times \sqrt{\frac{P}{f}}$$

Where, C = constant (not less than 0.41)  $\approx$  0.5

$$\text{Thickness of flat end} = 0.5 \times 3000 \times \sqrt{\frac{0.2943}{115.872}} = 75.595 \text{ mm}$$

As thickness of flat end is much greater than torispherical end, flat end is rejected. The torispherical dish end (Type-1) is considered for the finite element analysis.

Before performing the finite element analysis, analytical solutions are determined as below.

## V. ANALYTICAL SOLUTION

Here analytical solutions of the dish ends are considered for comparison with the stresses obtained by Finite Element method.

Hemispherical head:

$$\text{Stress in 'X' Direction (Radial Stress)} = \text{Stress in 'Z' Direction (Tangential Stress)} \dots \dots \dots [10]$$

$$= \frac{P \times D}{4xt} = \frac{0.2943 \times 2998}{4 \times 10} = 22.05 \text{ MPa}$$

Elliptical head:

$$\text{Stress in 'X' Direction (Radial Stress)} = \text{Stress in 'Z' Direction (Tangential Stress)} \dots \dots \dots [10]$$

$$= \frac{P \times a^2}{2 \times t \times b} = \frac{0.2943 \times 1499^2}{2 \times 10 \times 600} = 55.1 \text{ MPa}$$

In the above equation 'a' & 'b' are half of the major & minor axes of the elliptical head.

Torispherical Head:

$$\text{Stress in 'X' Direction (Radial Stress)} = \text{Stress in 'Z' Direction (Tangential Stress)} \dots \dots \dots [10]$$

$$= \frac{P \times R_c}{2 \times t} = \frac{0.2943 \times 2859.05}{2 \times 10} = 42 \text{ MPa}$$

Here Rc is radius of crown (Spherical portion of the head)

## VI. FINITE ELEMENT ANALYSIS

In this work, analysis is done using Finite Element Method based software ANSYS. During the work symmetry is defined at the upper vertical edge. At the lower edge, motion of points is restricted in vertical direction.

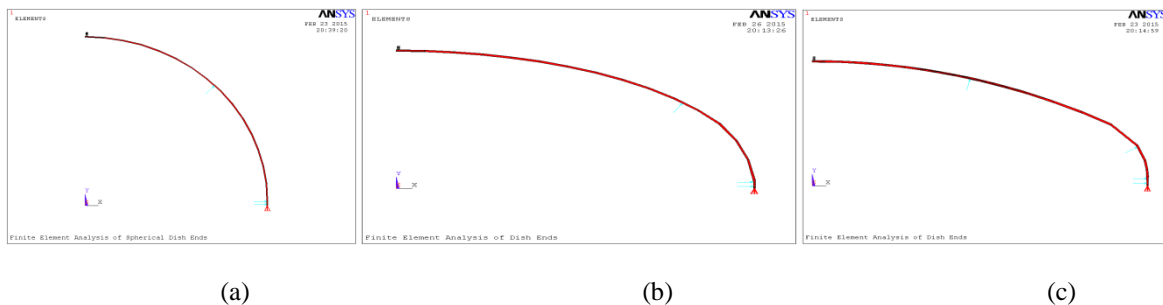


Fig. 3 Meshed model with load & boundary condition (a) Spherical dish end (b) Semielliptical dish end (c) Torispherical dish end

**VII. RESULTS & DISCUSSIONS:**

During the post processing, deformed shape along with the original shape & Von Mises Stresses are observed. For the validation of FEA results the nodes laying on the vertical axis of the pressure vessel head are noted and stresses in X & Z direction corresponding to these nodes are noted & are tabulated as below.

Table 1 Comparison of Stresses in different heads

Type of Head	Node Numbers		Stress (Analytical) In MPa		Stress (FEM) In MPa	
			SX	SZ	SX	SZ
Torispherical	Outer	32	42	42	43.148	43.178
	Middle	62			41.913	41.911
	Inner	60			40.626	40.638
Elliptical	Outer	56	55.1	55.1	57.785	57.828
	Middle	87			55.893	55.893
	Inner	02			53.952	54.002
Hemispherical	Outer	16	22.02	22.02	28.791	28.727
	Middle	48			22.135	21.139
	Inner	46			16.013	15.896

As the values obtained by finite element method are in close agreement with analytical values, the element type & mesh density found to be reasonably good. Hence other outputs like deformation & Von Mises stresses are taken into consideration for further study.

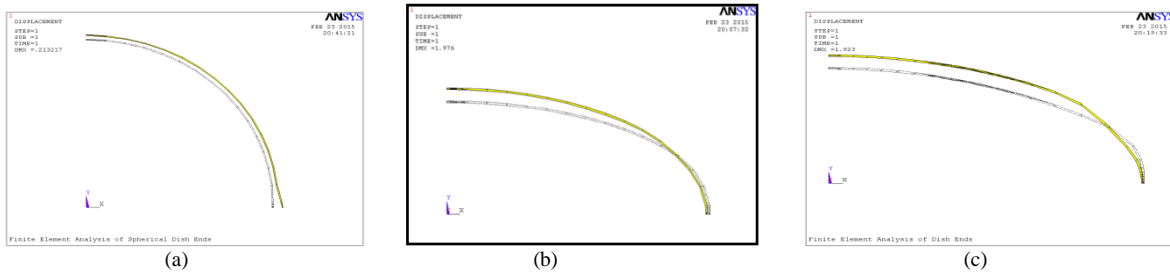


Fig. 4 Deformation of dish ends (a) Spherical dish end (b) Elliptical dish end (c) Torispherical dish end

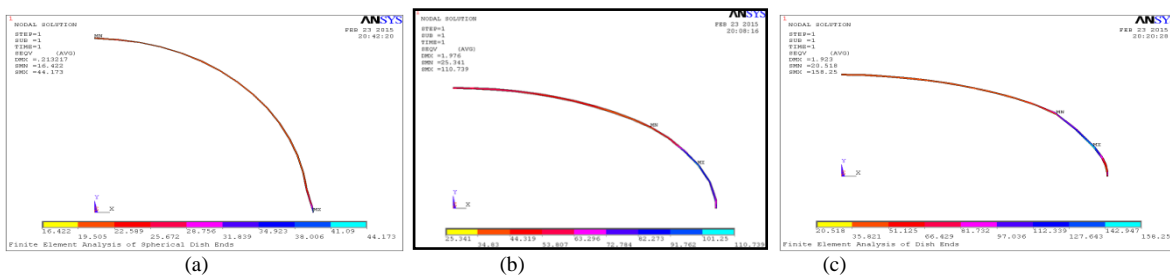


Fig. 5 Von Mises stresses in dish ends (a) Spherical dish end (b) Elliptical dish end (c) Torispherical dish end

Comparison of stresses & deformation in different types of heads:

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Table 2 Stresses & deformation for various heads of pressure vessel

Type of Head	Von Mises Stresses (Max.)	Deformation (Max.)
Torispherical	158.25	1.923
Spherical	44.176	0.2132
Elliptical	110.739	1.976

Thus considering the above data, torispherical head is selected as the pressure is less than 10 bar.

Analysis of Torispherical Dish End for different pressures: The effect of variation in pressure on the Von Mises stresses & deformation is studied. Following is the data regarding the response of the torispherical head for variation in pressure.

Table 3 Effect of variation in Pressure on Max. Deformation & Max. Von Mises stresses

Sr. No.	Pressure (MPa)	Max. Von Mises Stresses (MPa)	Max. Deformation (mm)
1	0.2	107.543	1.307
2	0.22	118.298	1.438
3	0.24	129.052	1.568
4	0.26	139.807	1.699
5	0.28	150.561	1.83
6	0.2943	158.25	1.923
7	0.3	161.315	1.96
8	0.32	172.07	2.091
9	0.34	182.824	2.222
10	0.36	193.578	2.352

Following are the graphs indicating the relation between the pressure applied & the corresponding maximum Von Mises stresses.

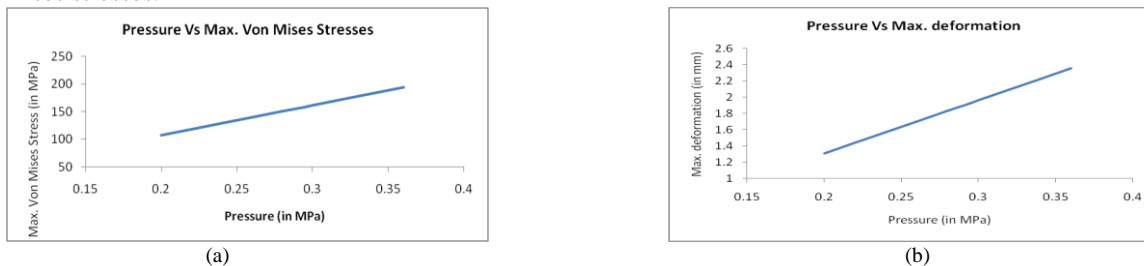


Fig. 6 Effect of pressure on (a) Max.Von Mises stress in Torispherical head (b) Max. Deformation in Torispherical head.

## VIII. CONCLUSIONS

From the present work, it is observed that stresses & deformation in hemispherical heads is the lowest. Maximum Von Mises Stresses in elliptical & torispherical heads are observed 2.5 times (150.67 % more) & 3.58 times (258.22 % more) respectively as compared to Maximum Von Mises stresses in hemispherical head. Maximum deformations observed in elliptical & torispherical heads are 9.26 times (826.83 % more) & 9 times (801.96 % more) respectively as compared to deformation in hemispherical head. Observed deformations in elliptical & torispherical dish ends are in close agreement. As forming cost of torispherical heads is less than elliptical heads & hemispherical heads, it is recommended for the present case ( $P < 10$ bar), though the stresses are slightly on higher side than elliptical head.

## REFERENCES

- [1] V.B. Bhandari, "Design of Machine Elements", Tata McGraw Hill Publishing Co. Ltd, New Delhi, 2005
- [2] British Standard Specification for Design & manufacture of water tubes, steam generating plants (including superheaters, reheaters & steel tube economizers) : BS 1113, 2011
- [3] Indian Standard- Hot Rolled Medium And High Tensile Structural Steel — Specification- BIS- 2011
- [4] D. Gandy, "Carbon Steel handbook", Electric Research Power Institute, California, 2007

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*(An ISO 3297: 2007 Certified Organization)*

**Vol. 4, Issue 2, February 2015**

- [5] Bandarupalli Praneeth, T.B.S.Rao, "Finite Element Analysis of Pressure Vessel and Piping Design", International Journal of Engineering Trends and Technology- Volume 3, Issue 5- 2012
- [6] X. Charles, "Stress Analysis of Pressure Vessel Due to Load and Temperature", Middle-East Journal of Scientific Research 20 (11): 1390-1395, 2014
- [7] Edin Šunje, Emir Nežirić, "Analysis of Stress in Torispherical Head of Pressure Vessels", 1st International Research/Expert Conference "Manufacturing and Advanced Technologies", MAT 2010, Mostar Bosnia and Herzegovina, 18-20 November 2010
- [8] Dr. M. M. Patil, Dr. Lokesh Bajpai, "Design, Analysis and Experimental Verification of Torispherical Head and Toriconical Bottom Pressure Vessel", International Journal of Innovative Science, Engineering & Technology, Vol. 1 Issue 10, December 2014
- [9] ANSYS, User Manual
- [10] Sinnott R.K, Engineering Design (4th Edition), Elsevier Publication, 2005.