Design & Analysis of Vertical Pressure Vessel by using ASME Codes

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Abstract— The pressure vessel is designed for internal pressure using ASME Codes. The components of the pressure vessel are designed by calculating the factors like thickness of the shell, head, stress analysis etc. To validate the design result the pressure vessel is modeled and analyzed in ANSYS. The preferred method to conduct the analysis is FEA.

Key words: ASME, FEA, Pressure Vessel Design, Ellipsoidal, Analysis

I. INTRODUCTION

Pressure Vessels are the reservoir of fluids at pressure more or less than ambient, internal or external pressure. The pressure source can be pump, compressor, fluid head etc. Pressure vessels used in industrial applications such as in thermal and nuclear power plants, petrochemical refineries, process and chemical industry etc. The shapes of pressure vessels are mainly spherical or cylindrical with dished ends.

Designing is to calculate the dimensions of a component so that it can endure the applied loads and function. It also involves the process of estimating the stresses for the specified loads at different points of a component [1]. While designing the pressure vessel safety is the important concern because the rupture of pressure vessel or explosion may cause loss property& lives.

Further the analysis (finite element) which is a subpart of the design process includes the estimation of stresses and failure of the pressure vessel and its components. This research paper highlights the importance of ASME Code in designing of pressure vessel by validating the design using FEA.

Classification of pressure vessels are:

A. According to thickness

1) Thin walled cylinder – when t/d < 0.1
2) Thick walled cylinder- when t/d > 0.1

B. According to Position

1) Horizontal pressure vessel
2) Vertical pressure vessel
3) Inclined pressure vessel

C. According to end construction

1) Closed end
2) Open end

II. LITERATURE REVIEW

Apurva R. Pendbhaje, Mahesh Gaikwade, Nitin Deshmukh & Rajkumar Patil[5] present design and analysis of pressure vessel using ASME codes & standards to legalize the design. Pressure rise is developed in the pressure vessel. The aim of this design is the safety of pressure vessel due to the impact of potential. This avoids the possible accidents.

There have a few factors which are used to design the safe pressure vessel. These factors used for analyzing the safety parameter for allowable working pressure. These pressures are calculated using Pressure Vessel Design Manual by Dennis Moss, third edition.

Mayank Nirbhay, Orashant Tripathi & Vivek Kumar Gupta [3] present the design of a pressure vessel is carried out using ASME Codes. In this paper designed the various components of the pressure vessel by calculating the necessary design factors like thickness of the shell, head, stress analysis etc. To validate the design result the pressure vessel is modeled and analyzed in ABAQUS. This proposed method is to conduct the analysis is finite element method. Further the study in the variation of effective parameters in design of pressure vessel is done. To study the variation different graphs are plotted. internal pressure and diameter of shell. The applicability of various types of heads is also evaluated.

Shyam R. Gupta, &Chetan P. Vora[14] present some of the developments in the determination of factors in stress concentration in pressure vessels at openings, stress analysis of different types of end connections and minimization stress with the help of optimize location and angle of nozzle on shell and head. Pressure vessels are designed by the ASME pressure vessel code. The code gives for thickness and stress of basic components; from these values the designer can select appropriate analytical procedure for determining stress due to other loadings.

Shaik Abdul Lathuef & K. Chandra Sekhar [7] discusses some of the potential unintended consequences related to Governing Thickness of shell as per ASME. Here have scope to change the code values by take the minimum governing thickness of pressure vessel shell to requirements and also relocate of nozzle location to minimize the stresses in the shell. The value of the factor of safety results in economy of material this will lead to thinner and more flexible and economical vessels. The stress is evaluated in the vessel by Zick analysis approach.

III. THEORETICAL BASIS

A. Design Method / Procedure

The pressure vessels is designed using ASME Section VIII Division-I. The analytical method is followed for determining thickness and stress of components of pressure vessel. Here the component of pressure vessel refers to shell, head and nozzles, skirt support.

There are various factors [3] which must be considered while selection and designing of the pressure vessel such as

- Dimensions and geometry thickness diameter, length, and their limitations.
- Operating conditions
- Functions and location, corrosive nature, Nature of
fluid,
- Materials, its physical properties and cost.
- Type of failure
- Fabrication techniques
- Theories and type of failure
- Economic consideration

B. Design of Components of Pressure Vessel

Generally a pressure vessel consists of a shell with closed ends. Plates are used to manufacture the pressure vessel components. Parts or components are attached either by welds joints. Thus a joint efficiency factor is considered into account.

Design procedure as in ASME Code Section VIII Div-I [11] is followed to design a long vertical pressure vessel with Ellipsoidal heads.

The step involved in designing the vessel is shown in the flowchart shown in “Figure-1”

![Design procedure flowchart](image)

1) Selection of material of elements

The selection of material of pressure vessel as per ASME section II part A [12] is SA516 Grade 60 Carbon steel. Properties of material (SA516 Grade 60) for the shell and heads are shown in Table-1:

<table>
<thead>
<tr>
<th>Maximum allowable stress value (S)</th>
<th>1284.84kgf/cm² (126N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>7850 kg/m³</td>
</tr>
</tbody>
</table>

Table 1: Properties of Material

2) Design data input

<table>
<thead>
<tr>
<th>Code for design</th>
<th>ASME Sec-VIII Div-I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal design pressure (P)</td>
<td>28 Kg/cm²</td>
</tr>
<tr>
<td>External design pressure</td>
<td>Nil</td>
</tr>
<tr>
<td>Design temperature (°C)</td>
<td>200°C</td>
</tr>
<tr>
<td>Nominal inside diameter (Di)</td>
<td>1200 mm</td>
</tr>
<tr>
<td>Corrosion allowance (CA)</td>
<td>1.5 mm</td>
</tr>
<tr>
<td>Weld joint efficiency (E)</td>
<td>1</td>
</tr>
<tr>
<td>Shell length (L)</td>
<td>23950 mm</td>
</tr>
<tr>
<td>Type of head</td>
<td>Ellipsoidal</td>
</tr>
<tr>
<td>Material of construction</td>
<td>SA 516 Gr. 60</td>
</tr>
</tbody>
</table>

Table 2: Design Specifications

3) Calculation of the shell thickness under internal pressure for vertical vessel

As per UG-27

a) Circumferential Stress

When thickness does not exceed one half of the inside radius of vessel or P does not exceed 0.385SE, the following formulas used:

\[
(tr) = \frac{PR_i}{(3.1)}
\]

Where,
\[
R_i = R + C.A. = 600+1.5 = 601.5\text{mm or 60.15cm}
\]
\[
tr = 28*60.15/(1284.84*1.06*28)= 13.28 \text{mm}
\]

Total shell thickness = tr + C.A. = 13.28+1.5 = 14.78 mm

b) Longitudinal Stress

When the thickness not to exceed one half of the inside radius or P does not exceed 1.25SE, the following formulas to be used:

\[
(tr) = \frac{PR_i}{(3.2)}
\]

Where,
\[
R_i = R + C.A. = 600+1.5 = 601.5\text{mm or 60.15cm}
\]
\[
tr = 28*60.15/(2*1284.84*1.04*28)= 6.58 \text{mm}
\]

Total shell thickness = tr + C.A. = 6.58+1.5 = 8.08mm

Therefore, Maximum thickness considered is 13.28 mm. Generally the next standard fabrication plate available is15 mm thick, so the shell thickness under internal pressure is 15 mm.

4) Design of head-as per UG 31

Ellipsoidal Heads withs/L≥0.002. The required thickness of a dished head of ellipsoidal, in which half the minor equals one-fourth of the inside diameter of skirt determined by

\[
tr = \frac{PD}{(3.3)}
\]

Where,
\[
D = ID + (CA*2) = 1200+3 = 1203\text{mm or 120.3 cm}
\]
\[
tr = 28*120.3/(2*1284.84*1.02*28)= 13.13 \text{mm}
\]

Total shell thickness =tr + C.A. = 13.13+1.5 = 14.63 mm

As per design inputs this vessel will never undergo vacuum condition either partially or fully in its service life. Hence design for external pressure is not carried out.

IV. FINITE ELEMENT ANALYSIS OF PRESSURE VESSEL

Objective of the analysis is to conduct FEA of a long vertical pressure vessel to determine the maximum stress induced for a safe design, the maximum induced stress is less than the maximum allowable stress.

A. Modeling and Analysis Software

The detailed 3D modeling done in Solid works 2016 and analysis of pressure vessel was done in ANSYS. It is a general purpose Modeling and Analysis package for numerically solving a variety of mechanical engineering problem.

1) Modeling

Since the main aim of the investigation is to determine the maximum induced stress. During modeling many small features of the vessel were not modeled because they will have only a local effect and will not play much significant role.

Shell and head of the vessel were formed as shell by revolve tool in the Solid works 2016 part module as shown in Figure-2. The part modeling is done on the basis of the dimensions which are calculated in designing procedure.
Fig. 2: Modeling the pressure vessel in Solid Works 2016.

2) Boundary and Loading Conditions:
The pressure vessel is fixed at bottom flange of skirt support & inside pressure vessel is set to 28 kg/cm² pressure as shown in figure-3.

Fig. 3: Fixed support at bottom skirt of column

B. Meshing
Cylindrical bodies are swapable & hence hex elements are preferred for meshing. For other body parts tetrahedron elements are used. Sizing of 30 mm to 150 mm. Instead of using a coarse mesh, fine mesh is used to produce accurate results, as shown in Figure-4.

Fig. 4: Fine meshing of the pressure vessel with Element size 30mm of 150mm.

V. ANALYSIS RESULTS
The stress distribution is as shown in Figure-5, 6&7 the maximum stress induced in the vessel is 117.75 N/mm² (or 1200.7 kg/cm²) which is less than the maximum allowable stress i.e. 125.99 N/mm² (or 1284.84 kg/cm²), shown in Table-1. Thus, Analysis results achieved concludes that the design is appropriate and safe.

VI. CONCLUSION
Pressure vessel is designed using ASME Code Sec. VIII Div-I and analysis to be done in ANSYS. The analysis results are so close to the analytical design, hence both the data validates. The result obtained is that the induced stress is less than the maximum allowable stress. The analysis result proved that the design procedure adopted is appropriate.

The FEA also helps to study the actual stress distributions in pressure vessel components.

REFERENCES


