Design and Experimental Validation of Composite Pressure Vessel

Mr. Jush Kumar. Siddani¹, Dr. C. Srinivas², Mr. L. Srinivas Naik³, Mr. T. Chandra Sekar⁴

¹,³,⁴ (Mechanical Engineering Department, Anurag Group Of Institutions-Hyderabad, India)
²(Mechanical Engineering Department, RVR & JC Engineering College-Guntur, India)
Corresponding author: Mr. Jush Kumar. Siddani

Abstract: The Cylindrical Composite Pressure Vessel (COPV) Become More Important In Transportation Of Fluids Like Petroleum Products Due To Increase In The Demand Of Daily Usage And For Vehicle Drive System. Light Weight And Low Cost Pressure Vessel Suitable For Oil Operated Vehicles Can Be Made Up Of Fully Metal, Hoop Wrapped With Metal Liner, Fully Wrapped With Metal Liner Or Made Of Fully Composite Materials. The Pressure Vessels Made Of Fully Metal, Will Not Prevent Catastrophic Failures And Besides Heavy Weight. These Limitations Can Easily Rectified/Reduced By The Pressure Vessel Made Of Composite Materials With The Help Of Netting Analysis. This Paper Deals With The Development Of Structural Design And Provides Experimental Validation Of COPV Made Of E-Glass Towpreg Fiber And Thin HDPE (High Density Poly Ethylene) Liner. This Experiment Revealed That The COPV Prevents Catastrophic Failures, Operated At High Pressures And Also Easy To Manufacture With Cost Effectiveness Compare To Metallic Pressure Vessels.

Objective: The Main Objective Of The Paper Is To Discuss The Design And Experimental Analysis Of A Composite Pressure Vessel And Its Advantages Over The Metallic Pressure Vessel.

Keywords - Composite Pressure Vessels, E-Glass Towpreg, HDPE Liner, Metallic Pressure Vessel And Netting Analysis, Submission

Date of Submission: 24-03-2018 Date of acceptance : 09-04-2018

I. INTRODUCTION


1. Reduction in Weight of Cylinder/Pressure Vessel.
2. Increasing the Safety of Cylinder with Reduced Accidents.
3. Less Maintenance.
4. Rust Free.

Due To These Reasons I Have Taken A Composite Material I.E. E-Glass Towpreg (Glass Fiber) Having A Chemical Composition 54.5%SiO₂, 14.5%Al₂O₃, 17%CaO, 4.5%Mgo, 8.5%B₂O₃, 0.5%Na₂O To Replace The Usage Of Metallic Pressure Vessels. The Principal Advantage Of E-Glass Fibres Are Available At Low Cost With The Superior Qualities Like Surface Resistivity, High Tensile Strength, High Chemical Resistance And Corrosion Resistance Along With The Insulating Properties.
II. PAPER CONCEPT


Typical Pressure Vessels Are Generally Designed With A Central Cylindrical Section And Two Spherical End Caps With Optional Polar Openings. The Relative Dimensions Of Different Sections Of The Vessel Are Designed According To The Corresponding Space And Weight Requirements And The Pressure Levels That The Vessel Is Expected To Withstand. Along With Thickness And Length Dimensions, The Shape Of The End Caps Also Plays A Vital Role In The Design. This Is Due To The Fact That The Dome Regions Undergo The Highest Stress Levels And Are The Most Critical Locations From The Viewpoint Of Structure Failure. The Design Concept Requires That The Pressure Vessels Provide Extremely High Efficiencies In Meeting The Overall Yielding And Buckling Failure Criteria. Moreover, The Slippage Trendency Of The Band At Its Edges Must Be Taken Into Account, Especially When Utilizing The In Plane Winding Technique.

Pressure Vessels Have Been Manufactured By Filament Winding For A Long Time. Although They Appear To Be Simple Structures, Pressure Vessels Are Difficult To Design. The Advantages Are Superior Specific Strength And Stiffness, Resulting In A Lighter Design. This Makes The Use Of Fiber Reinforced Composites Ideally Suited For Applications Where A Pressure Vessel Must Withstand High Internal Pressure Along With Axial, Bending, And Shear Loads. In Certain Applications, Significant Loads Are Imparted To Composite Pressure Vessels Due To Accelerations Caused By Transportation And Handling Operations.

III. EXPERIMENTAL DETAILS

A. Material Usage For The Composite Pressure Vessel

The Cylinder Made Up Of Composite Material Is Designed By Considering The Following Materials And Their Properties.

<table>
<thead>
<tr>
<th>Component</th>
<th>Material</th>
<th>Manufacture Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polar Bosses</td>
<td>Ms En-24</td>
<td>Machining</td>
</tr>
<tr>
<td>Liner</td>
<td>Pig/Hdpe</td>
<td>Lay-Up &amp; Press Cured</td>
</tr>
<tr>
<td>End Plate</td>
<td>Medium Carbon Steel</td>
<td>Machining</td>
</tr>
<tr>
<td>Vessel</td>
<td>Glass-Epoxy Resin</td>
<td>Filament Winding</td>
</tr>
<tr>
<td>Mandrel</td>
<td>Pu Foam Steel</td>
<td>Machining</td>
</tr>
</tbody>
</table>

The Mean Effective Pressure Used In The Present Work Is 18 Bar, And The Design Pressure As 36 Bar.

B. Geometric Dimensions Of Composite Tanks:

<table>
<thead>
<tr>
<th>Details</th>
<th>Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter (Mm)</td>
<td>346</td>
</tr>
<tr>
<td>Length (Mm)</td>
<td>820</td>
</tr>
<tr>
<td>Water Capacity (Cum)</td>
<td>0.1</td>
</tr>
<tr>
<td>Liquid Capacity Kg</td>
<td>47</td>
</tr>
<tr>
<td>Dish Ends</td>
<td>Semi Ellipsoid</td>
</tr>
<tr>
<td>Manhole Openings</td>
<td>130 Mm –Nozzle End (Ne) 80 Mm- Drain End (De)</td>
</tr>
<tr>
<td>Dia Of Bolts (Mm)</td>
<td>6.0 Course</td>
</tr>
<tr>
<td>No. Of Bolts</td>
<td>24 Ne, 20 De</td>
</tr>
<tr>
<td>Thickness Of Flange (Mm)</td>
<td>15 Ne, 10 De</td>
</tr>
<tr>
<td>Liner</td>
<td>Pig</td>
</tr>
</tbody>
</table>
C. Netting Analysis

The calculation of thickness of the composite cylinder netting analysis is used for preliminary design. For convenience and speed, this analysis ignores the structural contribution of the resin by essentially treating all composite materials as if they were a net of fibers. In other words, tensile forces are carried only along the length of the filaments. The helical wind angle and the thickness of the filament wound layer changes continuously as measured from the tangent line to the turnaround point of the filament. Bending, bearing, and compressive stresses are not considered. This simplifying assumption is valid only if the casing wall stresses are dominated by internal pressure. The detail of netting analysis is shown below.

Simple cylinder-dome casing wall configuration consisting of single angle helical and hoop layers can be readily specified with the following closed form equations: Geodesic winding is followed in the end dome portion between the pole opening and the point inflection at either end. The angles of winding at various points in these portions of the end domes are obtained by using the well-known Clairut theorem, Rsinα = R0 where, R is radius at the point, α is angle of winding, R0 is radius at the pole opening and

Ne: \( \alpha_e = \sin^{-1}\left(\frac{89}{173}\right) = 31^\circ \)  
De: \( \alpha_d = \sin^{-1}\left(\frac{62}{173}\right) = 21^\circ \)

Certain technological constraints have to be considered while estimating the thickness requirements. Helical ply thickness is a function of both design as well as processing parameters such as local angle of winding, local cross sectional radius, volume fraction, number of spools, filament cross sectional area, etc. Helical thickness per ply for a given angle of winding and cross sectional radius can be experimentally estimated as:

\( R \times T_{hel} \times \cos\alpha = \text{Constant} \)
All Of The Above Technological Constraints Are Considered And Required Total Helical Thicknesses At Various Stations For The Design Loads” With The Material Allowable” Are Calculated. The Details Of Thickness Are As Follows:

<table>
<thead>
<tr>
<th>Nozzle End</th>
<th>Drain End</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{\text{hel}} = \frac{P r (2 \cos \alpha)}{2 \sigma_f \cos 2 \alpha} = 0.9 \text{mm}$</td>
<td>$T_{\text{hel}} = \frac{P r (2 \cos \alpha)}{2 \sigma_f \cos 2 \alpha} = 0.83 \text{Mm}$</td>
</tr>
<tr>
<td>$T_{\text{hoop}} = \frac{P r (2 - \tan^2 \alpha)}{2 \sigma_f} = 0.9 \text{Mm}$</td>
<td>$T_{\text{hoop}} = \frac{P r (2 - \tan^2 \alpha)}{2 \sigma_f} = 1.0 \text{Mm}$</td>
</tr>
</tbody>
</table>

Total Thickness = $T_{\text{hel}} + T_{\text{hoop}} = 1.8 \text{mm} = 2 \text{mm}$.

Where,

- $T_{\text{hel}}$: Required Total Helical Thickness,
- $T_{\text{hoop}}$: Required Total Hoop Thickness,
- $P$: Design Burst Pressure = 36bar
- $R$: Cross Sectional Radius Of The Cylinder
- $\Sigma_f$: Longitudinal Tensile Strength Of Filament Wound Composite
- $\alpha$: Angle Of Winding At Corresponding Station.

**IV. MANUFACTURING**

Pressure Vessels Have Been Manufactured By Filament Winding For A Long Time. Although They Appear To Be Simple Structures, Pressure Vessels Are Difficult To Design And Manufacture. The Present Article Or Object Is Manufactured With The Help Of E-Glass Towpreg Material.

The Filament Winding Along With Doily Lay-Up Is Carried Out On Mandrel Is Shown Below In Fig.3

![Fig. 3: Filament Winding Over Liner](image)

During The Pressure Test Only Those Strain Gauges Corresponding To Pressure Test Are Connected To The Data Acquisition System. The Test Article Along Strain Gauge Is Shown In Fig.4. Also The Lvdt Position (Bursted Vessel) AreShown In Fig.5

![Fig. 4: Test Article Along With Strain Gauges](image)  ![Fig. 5: Test Article Along With Lvdt Position](image)

**V. RESULTS & DISCUSSIONS**

The COPV Was Successfully Designed And Analysed By Using Filament Winding Technique. It Has Been Calculated That 2mm Was Chosen As Composite Layer Thickness By Using Netting Analysis. The Pressure And Strains Found In The Experiment Are Clearly Plotted.
A Comparison Is Between The Analysis (Fem) Data Where The Applied Pressure Was 36 Bar And Tested Data. It Is Found That The Results Were Similar Up To 36 Bars And As The Pressure Increased Strains Increased And At 52 Bars The Failure Occurred Which Are Called As First Ply Failure.

It Was Observed The Actual Burst Had Occurred At 50 Bars When There Was Sudden Drop Of Pressure Was Observed And Rupture Had Occurred At 52-54 Bars. This Indicates That There Is A Progressive Failure Of The Material Which Results In Ply By Ply Failure. This Will Not Result In Catastrophic Failure As In The Case Of Pressure Vessel Which Is Made Out Of Conventional Steel Material. The Actual Failure Occurred At Helical Winding Which Failed Due To Axial Stress And Pulling Due To Longitudinal Load Which Sheared The Helical Winding.

Even Though In Conventional Isotropic Material Pressure Vessels, The General Tendency Is Hoop Stress Is Twice The Longitudinal Stress. Even In Orthotropic Constructed Pressure Vessels The Same Holds Good As Long As There Is A Balanced Winding That Is 54° Winding. But In This Case The Angle Is Varying From 31° From Nozzle End To 21° At Drain End. Hence The Longitudinal Stress Is More Compared To Hoop Stress And Failure Occurred Due To Hoop Stress.

VI. CONCLUSION

A Cylinder Made Of Composite Material (E-Glass Towpreg Fiber)/Composite Pressure Vessel Has Been Designed And Analyzed To Meet The Purpose Of Making Fluid Storage Vessel With High Strength And Low Weight Compared To Existing Metallic Tanks. The Design Is Cost Effective Also. The Netting Analysis Is Used For Design Has Been Verified For The Railway Application For Storage And Transportation Of Fluids. The Composite Cylinder Designed (L=820 Mm; D=346 Mm; T=2mm) And Analyzed Under The Scope Of This Investigation Is Capable Of Withstanding The Stipulated Effective Design Pressure Of 36bar. The Analysis Of Composite Pressure Vessel Will Be Performed To Predict The Behavior Of The Structure The Design Stresses Are Within Safe Limits. The E-Glass Tow-Preg fiber Composite Cylinder Is More Suitable For Storage Of Fluids/Petroleum Products For Different Usage Compare To Metallic Tanks.

REFERENCES
