International Journal of Engineering Science Invention (IJESI)
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org ||Volume 7 Issue 4 Ver. II || April 2018 || PP 15-19

Design and Experimental Validation of Composite Pressure Vessel

Mr. Jush Kumar. Siddani[1], Dr. C. Srinivas[2], Mr. L. Srinivas Naik[3], Mr. T. Chandra Sekar[4]

[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 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

Now-A-Days There Is A Huge Demand Of Conventional Materials Like Steel, Al And Iron Etc. For Production Of Various Products In Different Industries. With The Limited Resources Of Conventional Materials And Their Disadvantages/Defects In Various Applications There Is A Need Of Replacement Of These Materials With Some Other Nonconventional Materials Like Composite Materials (FRP). Technically Composite Material Can Be Define As “A Multiphase Material From A Combination Of Materials, Differing In Composition Or Form, Which Remain Bonded Together, But Retain Their Identities And Properties, Without Going Into Any Chemical Reactions”(GRP = Plastic+ Glass Fiber).Composite Materials Are Used Widely For Different Applications Like In Aerospace Structures, Railway Transportation, Defense And Marines Etc. Due To Their Superior Mechanical Properties: High Strength, Stiffness, Large Damping, Superior Fatigue And Corrosion Resistance And So On. They Are Also Used Widely For Pressure Vessels For Storage Of Natural Gas And Fuels. Composite Overwrapped Pressure Vessels (COPV) Have Lower Weight, High Strength, Fatigue, Corrosion Resistance And A Long Span Of Life Compared To Conventional (Metallic) Pressure Vessels. In The Current Study Have Been Taken To Search the Alternative Material for the Cylinder With The Following

Advantages:-
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%Sio_2, 14.5%Al_2o_3, 17%Cao, 4.5%Mgo, 8.5%B_2o_3, 0.5%Na_2o 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

This Project Is Proposed To Design And Analyze Of A Cylindrical Pressure Vessel Made Up Of Composite Material. The New Composite Material Considered Is E-Glass Towpreg Fiber. It Is The Advanced Research To Replace The Metallic Cylindrical Pressure Vessels. The Process For Producing A Composite Pressure Vessel Is Termed Filament Winding. The Techniques For Filament-Wound Composite Pressure Vessel Can Be Classified Into Two Main Types: Geodesic Winding And In-Plane Winding, Which Consist Of Three Basic Steps. First, The Fibers (E-Glass Towpreg) Are Impregnated With A Resin. To Obtain Good Results, The Impregnation Must Be Done In A Carefully Controlled Manner, By Pulling The Fibers Through A Basin Filled With The Resin. Then, By The Use Of A Winding Machine, The Fibers Are Positioned Onto A Mandrel, Which Has The Shape Of The Pressure Vessel Required. Finally, The Wet Fibers Are Removed From The Winding Machine And Placed In An Oven, Where The Resin Is Cured Under Well-Defined Conditions Of Temperature And Time.

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 Tendency 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: 1

Component	Material	Manufacture Mode
Polar Bosses	Ms En-24	Machining
Liner	Pfg/Hdpe	Lay-Up & Press Cured
End Plate	Medium Carbon Steel	Machining
Vessel	Glass-Epoxy Resin	Filament Winding
Mandrel	Pu Foam Steel	Machining

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:2

Details	Dimensions
Diameter (Mm)	346
Length (Mm)	820
Water Capacity (Cum)	0.1
Liquid Capacity Kg	47
Dish Ends	Semi Ellipsoid
Manhole Openings	130 Mm –Nozzle End(Ne) 80 Mm- Drain End(De)
Dia Of Bolts (Mm)	6.0 Course
No. Of Bolts	24 Ne, 20 De
Thickness Of Flange (Mm)	15 Ne, 10 De
Liner	Pfg

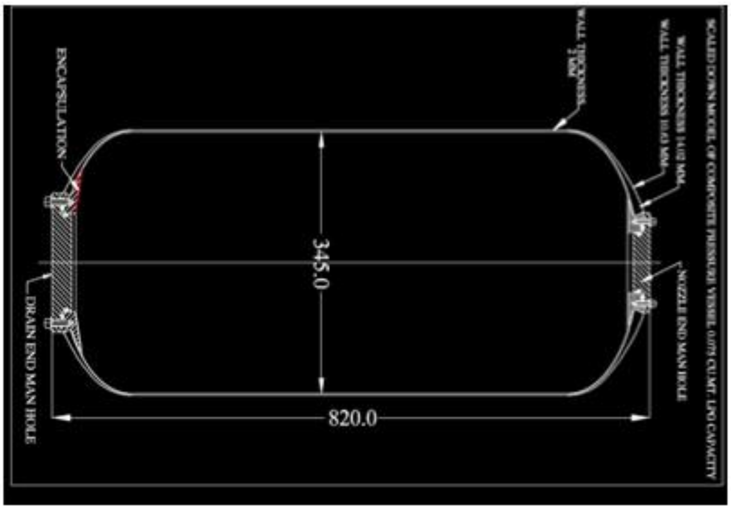


Fig. 1: Composite Pressure Vessel With Actual Geometry

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.

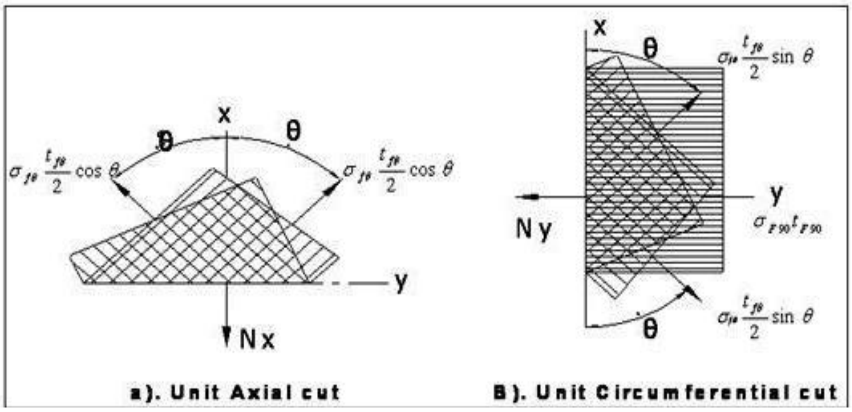


Fig. 2: Netting Analysis

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, $R\sin\alpha = R_o$ Where, R Is Radius At The Point, A Is Angle Of Winding, R_o Is Radius At The Pole Opening And

Ne: $A_v = Sin^{-1}(89/173) = 31^0$ De: $A_d = Sin^{-1}(62/173) = 21^o$

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:

Nozzle End	**Drain End**
$T_{hel} = Pr/(2\sigma_f \cos^2\alpha)$= 0.9mm	$T_{hel} = Pr/(2\sigma_f \cos^2 A)$= 0.83 Mm
$T_{hoop} = Pr(2-\tan^2\alpha)/(2\sigma_f)$= 0.9 Mm	$T_{hoop} = Pr(2-\tan^2 A)/(2\sigma_f)$= 1.0 Mm
Total Thickness = T_{hel}+ T_{hoop}=1.8mm=2mm.	Total Thickness = T_{hel}+ T_{hoop}=1.83mm=2mm.

Where,

T_{hel}: Required Total Helical Thickness, T_{hoop}: Required Total Hoop Thickness,

P: Design Burst Pressure =36bar R: Cross Sectional Radius Of The Cylinder

Σ_f: Longitudinal Tensile Strength Of Filament Wound Composite

A : 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

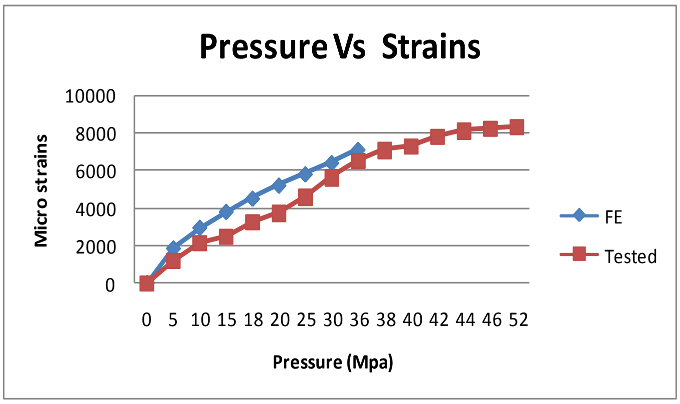
During The Pressure Test Only Those Strain Gauges Corresponding To Pressure Test Are Connected To The Data Acquisition System. The Test Article Along Strain Gauge Is Shown In Fig.4. Also The Lvdt Position (Bursted Vessel) Are Shown In Fig.5

Fig. 4: Test Article Along With Strain Gauges

Fig.5: Test Article Along With Lvdt Position

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

[1] "Lifshitz Jm, Dayan H. "Filament-Wound Pressure Vessel With Thick Metal Liner." *Compos Struct*, 32,Pp. 313-323, 1995

[2] "Filament Winding Simulation Of Composite Overwrapped Pressure Vessel" By

[3] "Optimization Of Pressure Vessel Using A Composite Material" By Deepak Thomos, Colin Johnson, Sarath Krishna- Volume 3, March 2014.

[4] "Design, Fabrication And Testing Of Composite Overwrapped Pressure Vessel For Cng Storage" By M. Radhika, K. Chandrasekhar, G.V Rao – December, 2014.

[5] "Experimental And Numerical Analysis Of A Ldpe/Hdpe Liner For A Composite Pressure Vessel", By E.S. Barbozaneto , M. Chludzinski , P.B. Roese , J.S.O -Vol 30 ,2011.

Mr. Jush Kumar. Siddani"Design and Experimental Validation of Composite Pressure Vessel" International Journal of Engineering Science Invention (IJESI), vol. 07, no. 04, 2018, pp 15-19