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DESIGN AND STRUCTURAL ANALYSIS OF CNG COMPOSITE GAS CYLINDER

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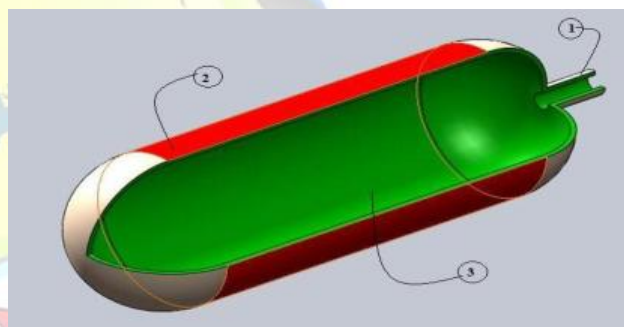
Abstract: Pressure vessels are essentially storage vessels, but they find a large variety of applications in assorted fields like in industrial processing equipment, where they are subjected to unusual conditions of pressure, temperature and environment. Pressure vessels were constructed from isotropic materials such as steel and aluminum. But now, with the advent of composites In the present study a 70 liters capacity CNG (compressed natural gas) gas cylinder is designed in accordance to ISO 11439:2000(E) standard. The composite gas cylinder is designed for burst pressure 730 bar (73MPa) using netting analysis of filament winding technology. The CNG gas cylinder comprises of cylinder and two end domes, out of one end dome being totally closed. The results indicate the gas cylinder under given loading and boundary condition is safe.

1. INRODUCTION

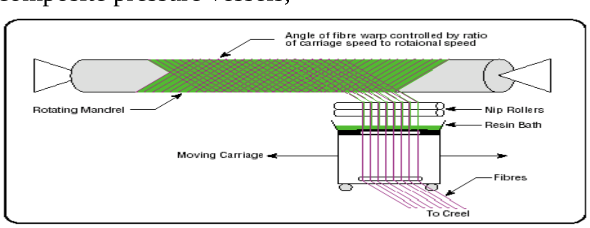
A CNG composite gas cylinder is developed on polymer mandrel using filament winding technology. The aim of the project is to design a 70 liter capacity CNG composite gas cylinder of 340mm diameter and 956mm length in accordance to ISO 11439:2000(E) specifications. Mathematical model is proposed for non-geodesic fiber trajectory on the polymer mandrel. For given geometric specification, ply wise layer design will be done using netting analysis of composite pressure vessel. Further structure analysis is carried out using finite element techniques required for computing failure analysis of composite gas cylinder.



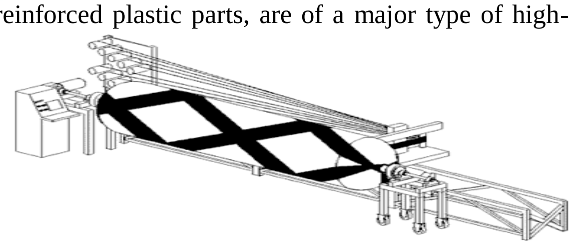
CNG composite Gas Cylinder (1. Metal pole opening, 2. Composite shell ,3. Polymerliner

II FILAMENT WINDING TECHNOLOGY

Filament winding is an automated process in which continuous filament is treated with resin and wound on a mandrel in a pattern designed to give strength in one direction shown in figure filament-wound composite pressure vessels,



which utilize a fabrication technique of filament winding form high strength and light weight reinforced plastic parts, are of a major type of high-



pressure vessel and are widely used in the

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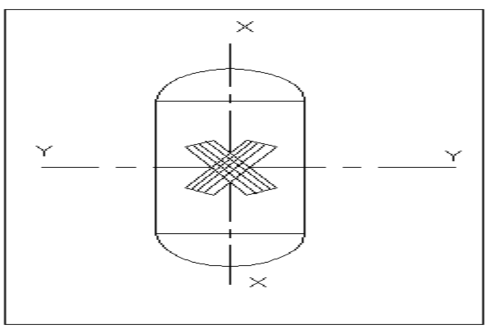
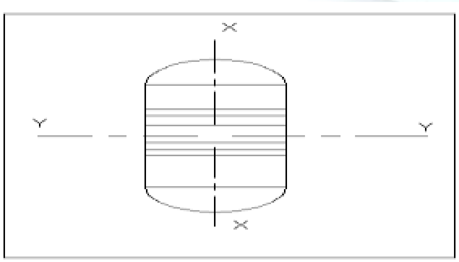
commercial .This kind of vessels consists of a cylindrical drum and two end dome parts with optional polar openings just like typical pressure vessels.

III NETTING ANALYSIS

Netting Analysis is used in predicting stresses in a fiber reinforced composite by neglecting the contribution of the resin system. The cylinder of the filament wound pressure vessel was basically composed of helical and hoop layers. Whereas the end domes comprises of helical and doilies. Doily is a planar reinforcement applied to local areas to provide additional strength, usually in hoop direction. Since it is not possible to wind hoop layers on the end domes directly by filament winding technique, an additional layer either a unidirectional fabric or drum wound hoop layers are developed and placed on the end domes. The preliminary design is performed using netting analysis methods to address the inner pressure loading.



Helical Winding.



Hoop winding.

Case I:

If the vessel is wound with only helical $\pm\phi$ fibers with an allowable fiber stress $\sigma_{f\phi}$. The helical fiber thickness ($t_{f\phi}$) & the wind angle ϕ is determined as follows:
forces acting on a two-ply helical layer with a cut of unit width in axial plane.
Force = stress X Area= $\sigma_{f\phi}$ (Band width x thickness)
Summing the forces in the axial direction,
N_x = force/unit length

$$N_x = \left(2\,(\sigma_{f\phi})\left(\frac{t_{f\phi}}{2}\cos\phi\right)\cos\phi\right) = \frac{Pi\,R}{2}$$

$$t_{f\phi} = \frac{P_i(R)}{(2)(\sigma_{f\phi})(cos^2(\phi))} \quad \text{---(1)}$$

$$N_y = (\sigma_{f\phi})(t_{f\phi})(sin^2(\phi)) = P_i\,R \text{---(2)}$$

From (1) & (2)

$$\frac{P_i(R)}{(2)(\sigma_{f\phi})(cos^2(\phi))} = \frac{P_i(R)}{(\sigma_{f\phi})(sin^2(\phi))}$$

$$tan^2(\phi) = 2$$

$(\phi) = \pm 54.7^0$ This is the wind angle required for a pressurized cylinder with helical windings only.

Case II:

If the vessel is wound with both helical ($\pm\phi$) fibers and hoop ($\phi=90^0$) fibers, determine the helical & hoop fiber thickness $t_{f\phi}$ & t_{90} respectively.

$$\frac{P_i(R)}{(2)(\sigma_{f\phi})(cos^2(\phi))}$$

$$2(\sigma_{f\phi})\frac{t_{f\phi}}{2}\,sin^2(\phi) + \sigma_{f\phi}\,t_{f90} = P_iR = N_y$$

But from (1),required total helical thickness

$$t_{f\phi} = \frac{(P_i)(R)}{(2)(\sigma_{f\phi})(cos^2(\phi))}$$

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$$(\sigma_{f\phi}) \frac{(P_i)(R)}{(2)(2)(\sigma_{f\phi})(cos^2(\phi))} \; sin^2(\phi) \; + \; \sigma_{f\phi}$$

$t_{f90} = P_i R$

Required total hoop thickness,

$$t_{f90} = \frac{(P_i)(R_i)\left(2 - tan^2(\phi)\right)}{(2)\sigma_{f90}}$$

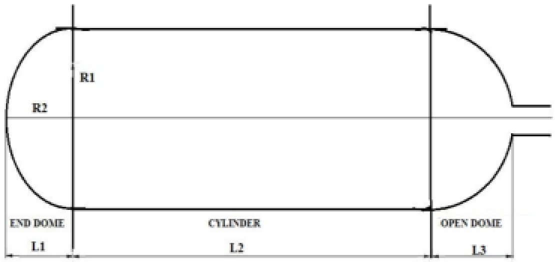
Where σ_{f90} = fiber stress in the hoop direction.
Wind angle to completely balance hoop & longitudinal stresses.

If $\sigma_{f90} = 0$ $2 - tan^2\phi = 0$
ϕ = angle of winding $= tan^{-1}\sqrt{2} = 54.74^0$

Note: It would be interesting to find out the value of wind angle at which one should wind the pressure vessel, so that the helical

IV.MATHEMATICAL MODELING FOR NON-GEODESIC FIBER TRAJECTORY ON MANDREL SURFACES

2D diagram for CNG composite gas cylinder



The geometric specifications are
L1=102mm, L2=706mm,L3=148mm,R1=168.5mm ,R2=102mm

Design requirements:

Working pressure = 200 bar

Minimum test pressure = 300bar
Burstpressure=73MPa

DESIGN AND ANALYSIS OF CNG COMPOSITE GAS CYLINDER

Design of CNG gas cylinder in accordance with ISO 11439: 2000(E).

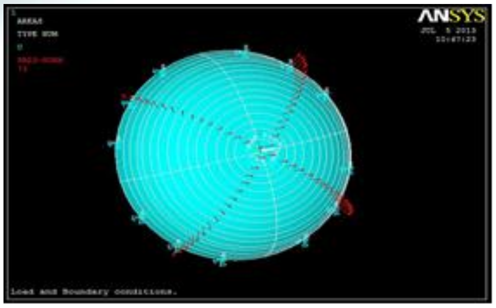
High pressure gas cylinders for Type CNG-4 are designed in accordance with ISO 11439 : (2000E)
CNG-4 : resin impregnated continuous filament with a non-metallic liner (liner composite)
The maximum service life shall be 20 years.

For all- composite cylinders with non-metallic, on-load bearing liners the service lift shall be demonstrated by appropriate design methods, design qualifications testing and manufacturing controls. A pressure that
would settle to 200 bar at a settled temperature of 15^0c

Material selection:

The plastic liner is compatible with the service conditions mentioned above.
High performance reinforcement glass Fiber/epoxy LY556-XY54
Fiber tensile strength (σ_f) = 3050-3400MPa
Fiber tensile modules = 89-91 GPa
Shear modules = 14 GPa

V. RESULT ANALYSIS CNG CYLINDER FOR DESIGN PRESSURE AT 73 Mpa



Loading and boundary conditions at end dome of CNG composite gas

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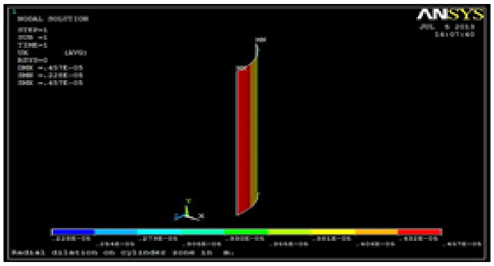
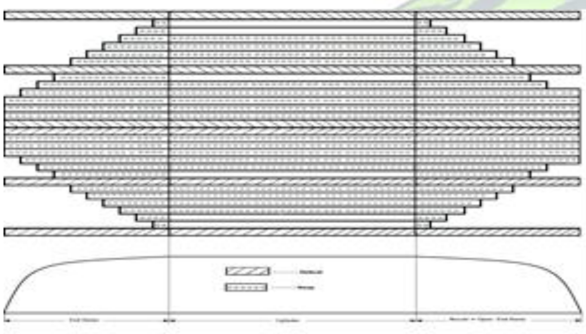
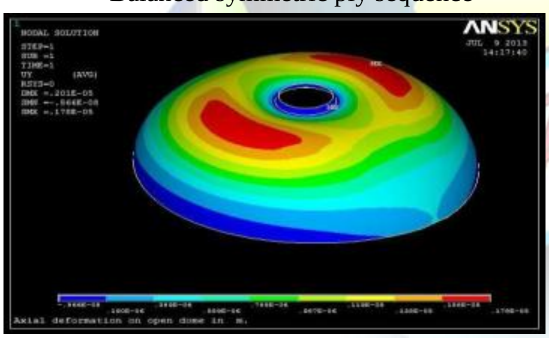


Radial dilation of CNG composite gas cylinder at cylinder zone,in m



Balanced symmetric ply sequence



Axial deformation of CNG composite gas cylinder at open dome, in m

STRUCTURAL PARAMETERS FOR DESIGN PRESSURE AT 73MPa

Results / Zones	Hoop stress in MPa	Longitudinal stress in MPa	Radial dilation in mm	Axial deformation in mm
End dome	909.7	88.05	$0.8x10^{-3}$	$0.197x10^{-3}$
Cylinder	1272	86.07	$0.397x10^{-2}$	$0.909x10^{-7}$
Open dome	1091	212.82	$0.170x10^{-2}$	$0.155x10^{-2}$

STRUCTURAL PARAMETERS FOR BURST PRESSURE AT 84MPa

Results / Zones	Hoop stress in MPa	Longitudinal stress in MPa	Radial dilation in mm	Axial deformation in mm
End dome	1047	101.319	$0.921x10^{-3}$	$0.226x10^{-3}$
Cylinder	1464	99.044	$0.457x10^{-2}$	$0.105x10^{-6}$
Open dome	1256	244.892	$0.195x10^{-2}$	$0.178x10^{-2}$

We obtain the deformation along radial and axial directions are computed. The hoop and circumferential stresses for the entire pressure vessel are also computed using ANSYS. The above results indicate the proposed design of CNG composite gas cylinder using netting analysis is safe at design pressure 73 MPa. However it is computed that the CNG composite gas cylinder can withstand up to 84 MPa(840bar).

VI. DISCUSSIONS

OPEN END DOME

The maximum radial dilation of 0.170×10^{-5} mm is noticed at cylinder open dome.

The maximum axial deformation of 0.155×10^{-5} mm noticed near the pole opening as a cumulative effect .

The maximum hoop stress of 1091 Mpa is observed at middle of the end dome.

The maximum longitudinal 212.82 Mpa is noticed near cylinder end dome junction

CYLINDER ZONE

The maximum radial dilation of 0.397×10^{-5} mm is noticed at cylinder zone.

The maximum axial deformation of 0.909×10^{-10} mm noticed cummilative effect at cylinder zone .

The maximum hoop stress of 1272 Mpa is observed at cylinder zone.

The maximum longitudinal 86.07 Mpa is noticed cylinder zone .

END DOME

The maximum radial dilation of 0.8×10^{-6} mm is noticed middle of the end dome.

The maximum axial deformation of -0.197×10^{-6} mm noticed as a cummilative effect at end dome .

The maximum hoop stress of 909.7 Mpa is observed at middle of the end dome.

The maximum longitudinal 88.05 Mpa is noticed near cylinder end dome junction .

VII .CONCLUSIONS

Results on deformation along radial and circumferential stresses for the entire pressure vessel are also computed using ANSYS. The results indicate the composite pressure vessel under the given loading and boundary condition is safe.

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