Determination Of Stress And Deformations Analysis On Lpg Steel Cylinder

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ABSTRACT

This paper aims, Design and Analysis of Liquefied Petroleum Gas (LPG) cylinders made of Steel. LP-gas inside a container is in two states of matter, liquid and vapour. The liquid portion of container is in the bottom and the vapour is in the uppermost part of the vessel. Liquefied Petroleum (LP) Gas is stored and handled as a liquid when under pressure inside a LP-Gas container. When compressed moderately at normal temperature, it becomes liquid. When gas is withdrawn, the pressure drops and the liquid reverts to gas. This means that it can be transported and stored as liquid and burnt as gas.

A number of cases are considered to study the stresses and deformations due to pressure loading inside the cylinder. First, the results of stresses and deformation for steel cylinders are compared with the analytical solution available in literature in order to validate the model and the software. A variation of stresses and deformations throughout the cylinder made of steel is studied.

In this the cylinder is designed in Pro-E WILDFIRE to study the stresses and deformations of the cylinder. And it is converted to Pro-E model to ANSYS to know variations of the steel cylinder when it is under some conditions.

Keywords - LPG cylinder, Stress, Deformation, FEM modeling.

I. INTRODUCTION

LPG (propane or butane) is a colorless liquid which readily evaporates into a gas. It has no smell, although it will normally have an odour added to help detect leaks. When mixed with air, the gas can burn or explode when it meets a source of ignition. It is heavier than air, so it tends to sink towards the ground. Liquefied Petroleum (LP) Gas is composed predominantly a mixture of the following hydrocarbons: propane, propylene, butane or butylenes. Liquefied Petroleum (LP) Gas is stored and handled as a liquid when under pressure inside a LP-Gas container. When compressed moderately at normal temperature, it becomes liquid. When gas is withdrawn, the pressure drops and the liquid reverts to gas. This means that it can be transported and stored as liquid and burnt as gas. The expansion ratio of gas from liquid is 270:1 at atmospheric pressure. It is this expansion factor which makes LP-Gas more economical to transport and store large quantities of gaseous fuel in a small container in liquid state.

LP-gas inside a container is in two states of matter, liquid and vapour. The liquid portion of container is in the bottom and the vapour is in the uppermost part of the vessel, i.e. the space above the liquid level. Containers are normally filled 80-85% liquid, leaving a 15-20% vapour space for expansion due to temperature increase. The vapour pressure of propane increases as the liquid temperature increases. Propane at -42^{0}C inside a container would register zero pressure. At 0^{0}C, propane vapour pressure will increase to 380 kPa. At 38^{0}C, the vapour pressure of propane would be 1200 kPa [1].
LP-gas is odorless and non-toxic. A distinct smelling odourant such as ethyl mercaptan is added as a detection agent for all domestic, and for most commercial and industrial LP-gas. The purpose is to introduce sufficient odourant so that the presence of unburnt gas can be readily detected before it reaches a mixture that is flammable and comes in contact with a source of ignition.

II. LIQUEFIED PETROLEUM GAS (LPG) CYLINDERS

Fig. 1.1 Conventional Steel LPG cylinders

LPG is supplied in pressurised cylinders to keep it liquefied. The LPG (Liquefied Petroleum Gas) Cylinders (fig.1.1), from past many years, are being manufactured in our country from the very conventional metallic material such as steel. The weight of the cylinder becomes more as density of steel is higher compared to other light weight materials. In household applications, thrust should be given towards use of low density materials so that the weight will come down. With the advancement of low-density materials like FRP [2] (Fiber Reinforced Plastic) Composites, we can think of producing LPG cylinders with FRP to reduce its weight in future.

The present work deals with the Finite Element Analysis of LPG cylinders made of conventional material (such as steel).

III. INDENTATIONS AND EQUATIONS

IV. LPG CYLINDER MADE CALCULATIONS [3]

Input Specifications

Empty gas cylinder weight= 15.9 kg (with frames and holders) ≅ 13.0 kg (without frames)
Gas weight =14.2kg
Volume of the Gas = 47.8 liters
Perimeter = 102cm

Assumptions: (1) End dome is hemispherical
(2) Cylinder has been modeled without end frames.
Thickness of the cylinder = 2.4mm~2.5mm

Analytical Calculation for LPG Steel cylinder

A. Cylindrical portion

HoopStress, $\sigma_H = \frac{pd}{2t} = \frac{1.2*320}{2*2.5} = 76.8 Mpa$ ..(1)

Longitudinal stress, $\sigma_L = \frac{pd}{4t} = \frac{1.2*320}{4*2.5} = 38.4 Mpa$ …(2)

Longitudinalstrain,

$$\varepsilon = \frac{\sigma_L}{E} = \frac{38.4}{207*E3} = 0.000185 \ldots (3)$$

Longitudinal Deformation, $\delta = \frac{\Pr^2(1-\nu)}{2Et} = 0.050\,mm$ …(4)

b. Hemispherical End dome portion

Hoop stress,

$$\sigma_L = \frac{pd}{4t} = \frac{1.2*320}{4*2.5} = 38.4 Mpa \ldots (5)$$

LPG Cylinder wall thickness calculation

Since the thickness of LPG cylinder is not provided by the manufacturer, it has been approximated using following approach.

Perimeter of Cylinder, P =102cm
Diameter of Cylinder, D = 102/π = 32.46 cm =324.6mm

D_O ≅ 325mm

Radius of Cylinder =162.5mm

Note: Here mean radius (160mm) has been taken for modeling.

Empty gas cylinder weight = 15.9kg (with frames and holders) ≅ 13.0kg (without frames)
Gas weight = 14.2kg
Assumption: End dome is hemispherical.

2.4 Cylindrical Portion

D_O =325mm D_i= (325-2t) mm
t= Thickness of the cylinder.
Volume =V_1= π/ 4(D_O^2-D_i^2) ×L …..(6)
= π /4 (325^2 - $(325\text{-}2t)^2$) × L = π/4 (1300t-$4t^2$) × 360

2.5 END PORTION [4]

Volume=V_2=4\3 × 8 πD^3 = π\6 (DO^3 – Di^3) … (7)
= π\6 {$(325)^3$ – $(325\text{-}2t)^3$)}
=π\6 {(325^3) – [(325^3) - ($2t^3$) - 3×325×2t (325-2t)]} =π\6 [$8t^3$+633750t-3900t^2]

Total Volume V=V_1+V_2 … (8)
=π\4 (468000t-1440t^2) +π \6 ($8t^3$+633750t-3900t^2)

Mass=volume×density ….(9)
Density=7.8gm\$cm^3$ = 7.8e-3 gm\$mm^3$

V = [$32t^3$-(15600+8640t^2) + (2535000+2808000) t] mm^3

$$= \frac{24*13000*1000}{7.8*\pi} mm^3$$

Or $32t^3$-24240t^2+5343000t =12732395.45
Or $32t^3$-24240t^2+5343000t-12732395.45 = 0

After solving above equation, Thickness of the cylinder = **2.4mm ~ 2.5 mm**

V. GEOMETRIC MODEL

The geometry of the gas cylinder [5] is shown in fig.2. It has been approximated by hemispherical ends of 160mm radius. Length of the cylindrical portion is 360mm. The total length of the cylinder is 680mm.

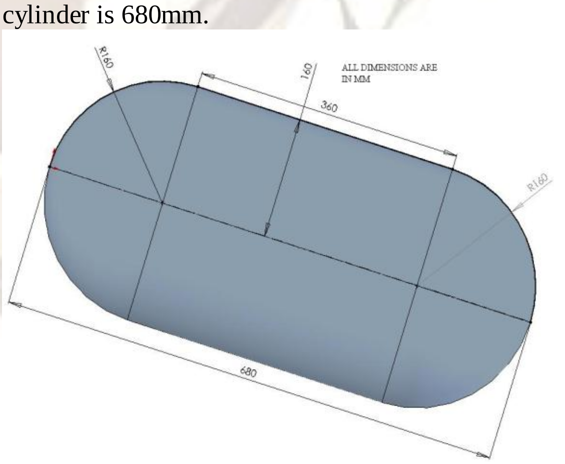

Fig 2:Geometric model of LPG cylinder without end frames

VI. MATERIAL PROPERTIES

The material used is steel for which material properties are listed below.

Density, ρ	= 7.8 gm/cc
Young's modulus, E	= 207Gpa
Poisson ratio, ν	= 0.3
UTS, σ	= 800 MPa
Yield strength	= 480 MPa

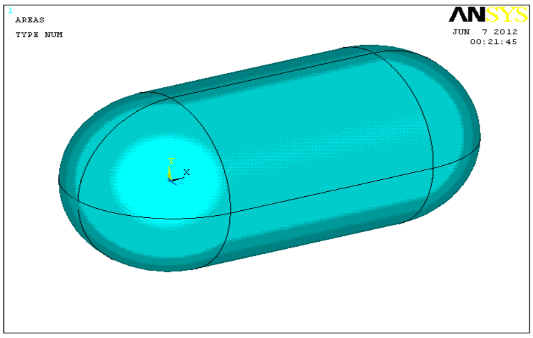

Fig 3: 3-D View of the geometric model

VII. Loads and Boundary Conditions

The figure 4 is the finite element model of the steel cylinder. Mapped mesh has been done for this model taking size control as 28 X 4 along the circumference of hemisphere and size control 40 along the longitudinal length of the cylinder.[7]

An internal pressure load of 1.2 MPa has been applied as shown in fig.6. To simulate a proper boundary condition, the mid symmetrical nodes of the cylinder are fixed in X-degree of freedom (Ux = 0) as shown in fig.5. Here it has been assumed that the mid plane deformation along x-direction is zero.

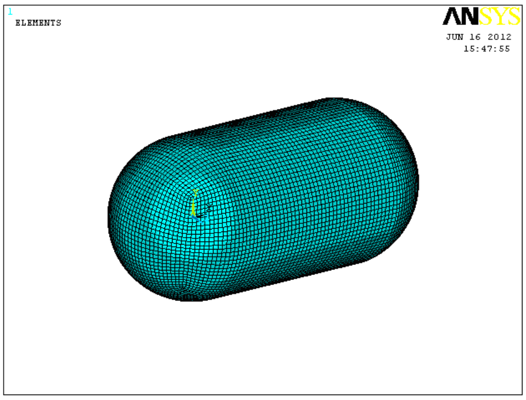

Fig 4: FE Mesh Model for Steel cylinder

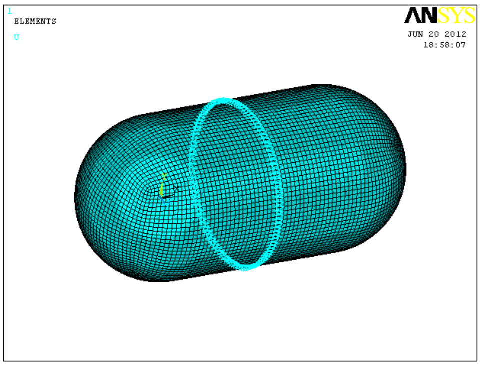

Fig 5 Boundary condition applied on cylinder

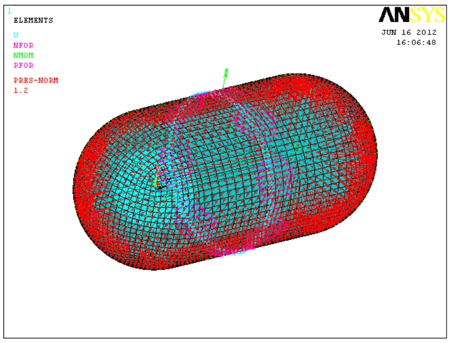

Fig 6 Internal pressure applied on Steel cylinder

VIII. Results and Discussions

The longitudinal (X-component) Displacement contour plot is shown in fig.7. For which the maximum displacement is occurring at the extreme points in the x-direction. Maximum Longitudinal displacement = 0.0332 mm

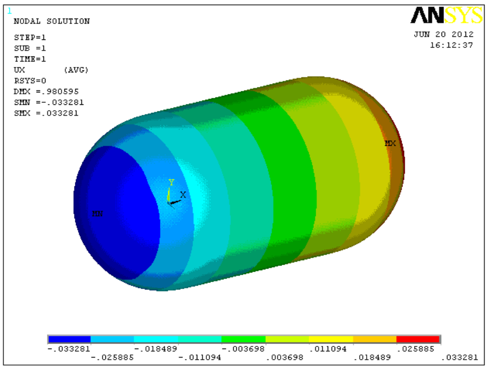

Fig 7 Longitudinal Displacement (in mm) plot for steel cylinder

The longitudinal (X-component) Stress contour plot is shown in fig.8. For which the maximum stress is occurring at the mid plane at which the cylinder is constrained along the longitudinal direction (x-direction).

Maximum Longitudinal stress = 43.48 MPa

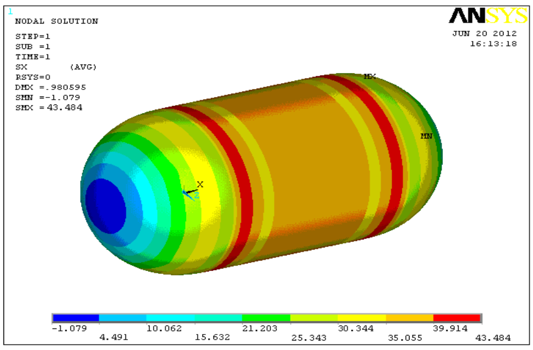

Fig 8 Longitudinal stress (in MPa) contour plot for steel cylinder

The Hoop (Y-component) Stress contour plot is shown in fig.9. Maximum Hoop stress = 79.30 MPa

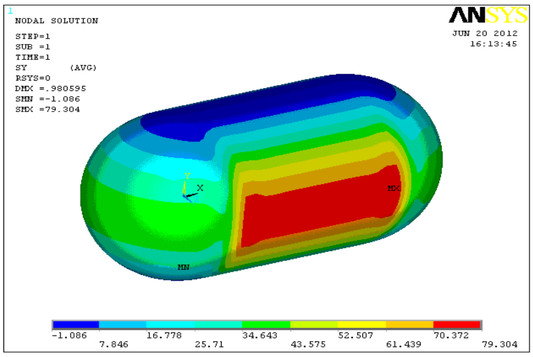

Fig 9 Hoop stress (MPa) contour plot for steel cylinder

The figure 10 is the figure showing the Vonmises stress plot for steel cylinder .For which the Maximum Vonmises stress =68.81 MPa and the yield strength of the steel is 480 MPa. So, the maximum stress occurring is within the limits and the design is safe. Maximum Vonmises stress =68.81 MPa

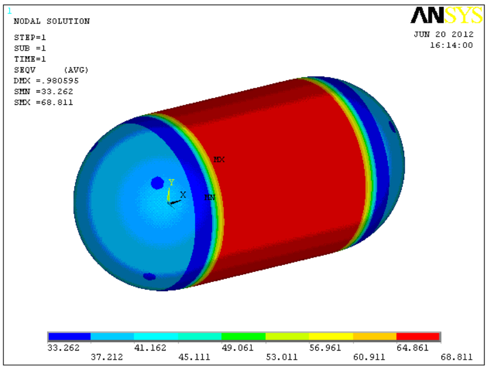

Fig 10 Von-mises stress contour plot for steel cylinder

The figure 11 shows the nodes which are selected to draw the Longitudinal Displacement variation graph (fig 12) and the Longitudinal Stress variation graph (fig 13) for Steel Cylinder.

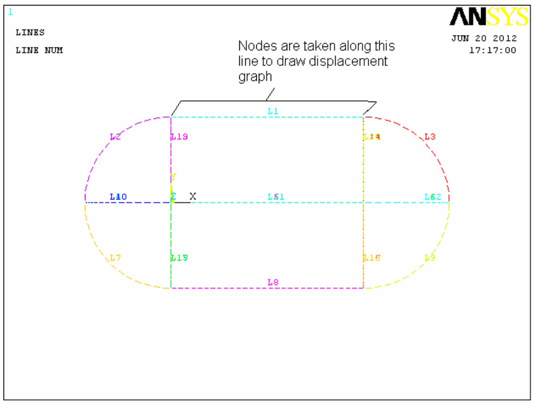

Fig 11: Nodes selected along the axis

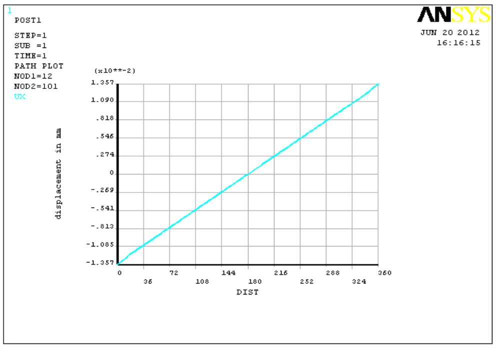

Fig 12: Graph for the Longitudinal Displacement

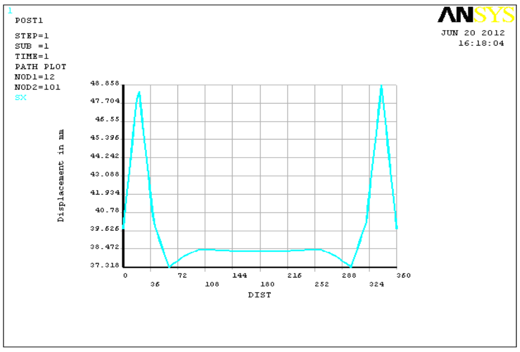

Fig: 13 Longitudinal Stress variations Graph for Steel Cylinder

The detailed results of FE analysis as well as classical method for the cylinder are listed below.

Table 1:Comparison of results for steel

Sl.No	RESULTS	FE METHOD	CLASSICAL METHOD
1	Longitudinal stress, MPa	43.48	38.4
2	Hoop stress, MPa	79.3	76.8
3	Von-mises stress, MPa	68.81	66.5
4	Longitudinal Deformation, mm	0.033	0.05

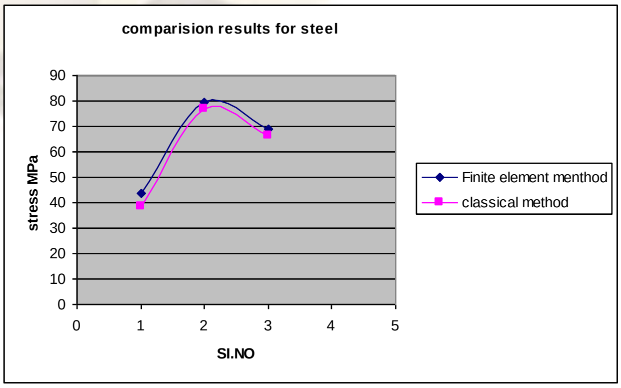

Fig: 14 Stress variations Graph comparison results for Steel Cylinder

IX. CONCLUSION

Based on the analysis of LPG cylinder made of steel, the following salient conclusions have emerged out from the present investigations:

By conducting analysis of LPG steel cylinder the stresses and deformations under pressure load of the cylinder are found. These results are compared with analytical solutions which are seen in the table above Table: 1.

Several stresses and deformations are studied and the solutions are given in the form of diagrams and graphs.

Some variations of results of the LPG steel cylinder is generated while studying FE method and Analytical method.

X. FEATURE SCOPE OF WORK

1. Material properties evaluation of FRP composite laminate by coupon level testing. The properties used for FE analysis are taken from available literatures, whereas the end properties of composites are highly dependent on process and laborer's skill.
2. Optimization of winding angle in CNC filament winding process.
3. Fiber orientation is the decisive factor in the strength of the composites.
4. Detailed design of FRP cylinders including end frames and its attachment with the cylinders.
5. Burst Test of the LPG cylinders for its qualification as per ASME.
6. Workout for the complete costing for FRP cylinders as well as existing steel cylinders, and to study its suitability in Indian scenario.

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