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Design and Optimization of an LPG Cylinder Constructed from FRP

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Abstract- Liquefied Petroleum Gas, LPG (propane or butane) is a colour less liquid which readily evaporates into a gas. It is used as a fuel in heating appliances and vehicles. It is now increasingly used as an aerosol propellant and a refrigerant, replacing chlorofluorocarbons in an effort to reduce damage to the ozone layer. Main purpose of research is to replace the conventional material used for cylinder with the new material MFRP which shows the similar properties to conventional material and weight can also be reduced for the cylinder with the similar strength.

Index Terms- Liquefied Petroleum Gas ,MFRP Cylinder, Optimization in weight.

1. INTRODUCTION

Liquefied Petroleum Gas, LPG (propane or butane) is a colour less liquid which readily evaporates into a gas. LPG is composed of the following hydrocarbons: propane, propylene, butane or butylene. LPG is stored and handled as a liquid when under pressure inside a LPG gas container. When gas is withdrawn, the pressure drops and the liquid reverts to gas.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.

It has no smell, although it will normally have an odour added to help detect leaks. It is heavier than air, so it tends to sink towards the ground. The expansion ratio of gas liquid is 270:1 at atmospheric pressure. It is expansion factor which makes LP-Gas more economical to transport and store large quantities of gaseous fuel in a small container .Containers are normally filled 80-85% liquid, leaving 15-20% vapour space for expansion due to temperature increase. The vapour pressure of propane increases as the liquid temperature increases. Propane at -420C inside a container would register zero pressure. At 00C, propane vapour pressure will increase to 380 kpa. At 380C, the vapour pressure of propane would be 1200 k pa.

2. PHYSICAL PROPERTIES AND CHARACTERISTIC OF LPG

2.1. *Density*

LPG at atmospheric pressure and temperature is a gas which is 1.5 to 2.0 times heavier than air. It is readily liquefied under moderate pressures. The density of the liquid is approximately half that of water and ranges from 0.525 to 0.580 @ 15 deg. C. Since LPG vapour is heavier than air, it would normally settle down at ground level/ low lying places, and accumulate in depressions.3.1.1. *Sub-subheadings*

2.2. *Vapour Pressure*

The pressure inside a LPG storage vessel/ cylinder will be equal to the vapour pressure corresponding to the temperature of LPG in the storage vessel. The vapour pressure is dependent on temperature as well as on the ratio of mixture of hydrocarbons. At liquid full condition any further expansion of the liquid, the cylinder pressure will rise by approx. 14 to 15 kg./sq.cm. for each degree centigrade. This clearly explains the hazardous situation that could arise due to overfilling of cylinders.

3. FLAMMABILITY

LPG has an explosive range of 1.8% to 9.5% volume of gas in air. This is considerably narrower than other common gaseous fuels. This gives an indication of hazard of LPG vapour accumulated in low lying area in the eventuality of the leakage or spillage. The auto-ignition temperature of LPG is around 410-580 deg. C and hence it will not ignite on its own at normal temperature. Entrapped air in the vapour is hazardous in an unpurged vessel/ cylinder during pumping/filling-in operation. In view of this it is not advisable to use air pressure to unload LPG cargoes or tankers.

COMBUSTION

The combustion reaction of LPG increases the volume of products in addition to the generation of heat. LPG requires upto 50 times its own volume of air for complete combustion. Thus it is essential that adequate ventilation is provided when LPG is burnt in enclosed spaces otherwise asphyxiation due to depletion of oxygen apart from the formation of carbon-dioxide can occur.

LPG cylinders are manufactured either in two piece or three piece construction as shown in Fig.1. Body parts of a cylinder are explained in this figure [1].

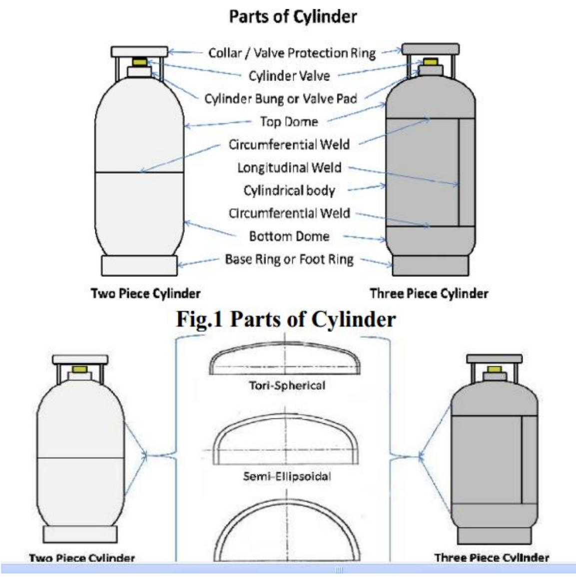

Fig.l Parts of the LPG Cylinder

DATA ANYALISIS:

An LPG cylinder is taken into consideration as it is made of steel which are heavy to carry. LPG is a safe, economical and convenient fuel as it has high calorific value (13.8 kWh/kg, which is equivalent to 13.8 units of electricity), it was evident that the existing steel LPG cylinders were heavy for easy handling and lack an accurate way of showing remaining level of the fuel.

MATERIAL PROPERTIES FOR COMPARISION AND FURTURE CALCULATIONS:

MATERIAL PROPERTIES	ELASTIC MODULUS N/m^2	POISSIONS RATIO	MASS DENSITY Kg/m^3	YIELD STRENGTH N/m^2
METAL	2×10^{11} N/m^2	0.3	7800	2.4×10^8
GFRP	1.9×10^{10} N/m^2	0.29	3400	1.315×10^8
FRP	8.47×10^8 N/m^2	0.28	1800	1.5×10^8

DESIGN CALCULATIONS OF FRP VESSEL:

FRP pressure vessel shall be designed in accordance with BS 4994. FRP pressure vessel designed for internal pressure 0.7 MPa and internal diameter is 320 mm. In case of cylindrical shell subjected to internal pressure maximum circumferential load (Qϕ) shall be determine by formula

$$Q\phi = \frac{pD1}{2}$$

Here p= Internal pressure
D1= Internal diameter

This gives

$$Q\phi = \frac{0.7*320}{2}$$

$$Q\phi = 112 \text{ N/mm}$$

If vessel construction is of CSM backing with filament winding layer the design unit loading per layer would be determine according clause 9.2 of BS4994

a) Design factor K
K=3XK1XK2XK3XK4XK5

Here K1: based on method of manufacturing
K2: based on chemical environment
K3: based on operating temperature
K4: based on level of cycling
K5: based on curing procedure

This gives

$$K = 3X1.5X1.2X1.2\ X\ 1.5\ X1.5$$
$$K = 10.69$$

b) Load limited allowable unit loading

$$UL = \frac{\text{Ultimate tensile unit strength}}{\text{Design factor K}}$$

$$UL = \frac{200}{10.69}$$

UL = 18.36 N/mm per kg/m2glass

c) Determine allowable strain ε on laminate layer
Assuming resin extension to failure is 3%
This value is greater than maximum strain permitted 0.2% therefore take ε= 0.1 * 3= 0.3%
d) Strain limited allowable unit loading US
US = Unit modulus for CSM * allowable strain…
US = 14000 * 0.2
US = 28.02 N/mm per kg/m2glass
e) Design unit loading
Since UL is less than US the value of UL value is taken for design purpose

Design strain on each layer is εL $= \frac{18.36 \text{ X } 100}{14000}$ = 0.13%

To avoid overloading with CSM layer in the laminate the design strain has to be limited to 0.13% so that design unit loading equivalent to that strain level will be:

For CSM UZ =UL = 18.36 N/mm per kg/m2glass
For winding UZ = XZ Xεd= 16000 X 0.13 X10-2
Uz = 20.8
f) Laminate constant can be determine by equation
u1m1n1 + u2m2n2 + ...+ u3m3n3 ≥Qϕ
if no. of winding layer required = n

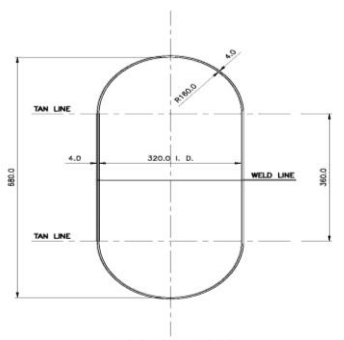

Fig.2 CAD Drawing of the LPG Cylinder

$$20.8 * 0.8n + 18.36 * 0.45\,(n-1) + 18.36 * 1.5 = 112$$

n =3.72 = 4

In one layer of winding thickness = 0.5 mm
4 * 0.5 = 2 mm
2 Layer of CSM = 2 X 0.8 = 1.66
Total thickness = 3.66 mm

Flat end of pressure vessel is difficult to manufacture in filament winding process so dome end is preferred in case of filament winding pressure vessel

Unit load $Q = 0.66 * p * D1 * Ks$

$$Q = 0.66 * 0.7 * 320 * 0.8$$

$$Q = 118.2\ N/mm$$

u1m1n1 + u2m2n2 + ...+ u3m3n3 ≥Qϕ
20.8 X0.8n + 18.36 X 0.45 (n-1) + 18.36 X 1.5 = 118.2
n=3.97 = 4
In one layer of winding thickness = 0.5 mm
4 X 0.5 = 2 mm
2 Layer of CSM = 2 X 0.8 = 1.66
Total thickness = 3.66 mm = 4 mm

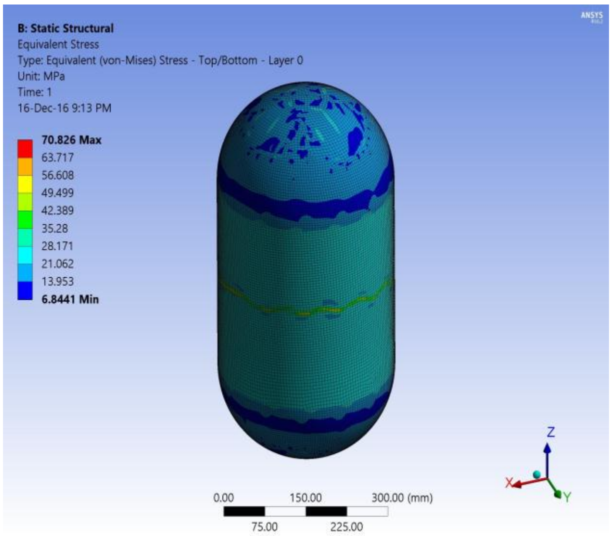

Fig.3. Analysis of the Vertical LPG Cylinder

thickness of cylindrical shell used is 3.66 mm and thickness of hemispherical ends is used 4 mm. Therefore the overall Thickness is to be considered as 4mm.
Weight of the steel cylinder = 13.31 kg (without end frames)

Weight of the GFRP cylinder = 3.02 kg (without end frames)
Weight saving = 10.29 kg

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