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 When gas is withdrawn, the pressure drops and the liquid reverts to gas.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 -42°C inside a container would register zero pressure. At 0°C, propane vapour pressure will increase to 380 kpa. At 38°C, the vapour pressure of propane would be 1200 kpa.

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. 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 up to 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].

MATERIAL PROPERTIES FOR COMPARISION AND FURTURE CALCULATIONS:

<table>
<thead>
<tr>
<th>MATERIAL PROPERTIES</th>
<th>ELASTIC MODULUS N/m²</th>
<th>POISSONS RATIO</th>
<th>MASS DENSITY Kg/m³</th>
<th>YIELD STRENGTH N/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>METAL</td>
<td>2 X 10¹¹</td>
<td>0.3</td>
<td>7800</td>
<td>2.4 X 10⁸</td>
</tr>
<tr>
<td>GFRP</td>
<td>1.9 X 10¹⁰</td>
<td>0.29</td>
<td>3400</td>
<td>1.315 X 10⁸</td>
</tr>
<tr>
<td>FRP</td>
<td>8.47 X 10⁸</td>
<td>0.28</td>
<td>1800</td>
<td>1.5 X 10⁸</td>
</tr>
</tbody>
</table>

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

\[ Qϕ = \frac{pD1}{2} \]

Here \( p \) = Internal pressure \( D1 \) = Internal diameter

This gives

\[ Qϕ = \frac{0.7 \times 320}{2} \]

\[ Qϕ = 112 \text{ N/mm} \]

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 \( K \)

\( K = 3X1.5X1.2X1.2X1.5X1.5 \)

\( K = 10.69 \)

b) Load limited allowable unit loading
c) Determine allowable strain $\varepsilon$ on laminate layer
   Assuming resin extension to failure is 3%
   This value is greater than maximum strain permitted
   0.2% therefore take $\varepsilon = 0.1 \times 3 = 0.3\%$

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 $\varepsilon_L = \frac{18.36 \times 100}{14000} = 0.13\%$
   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 Xc = 16000 X 0.13 X10-2
   UZ = 20.8

f) Laminate constant can be determine by equation
   $u_1m_1n_1 + u_2m_2n_2 + \ldots \ldots + u_3m_3n_3 \geq Q\phi$
   if no. of winding layer required = n
Weight of the GFRP cylinder = 3.02 kg (without end frames)
Weight saving = 10.29 kg

REFERENCES