LPG Tank Burst Pressure Determination using FEM

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Abstract - In this study, the burst pressure of liquefied-petroleum gas (LPG) tanks of cylindrical shape made up of carbon steel is determined using Finite element methods. LPG Cylinder of 12.5 Kg capacity with 2.8mm thickness has been investigated by using Finite Element Method (FEM) method by increasing internal pressure values linearly. The results of simulation are compared with experimental results of similar model obtained from already published research paper. Bursting pressure is extremely important parameter for LPG cylinders and helpful in determining its failure. The FEM results burst pressure values are found closer to values of burst pressure obtained from the experiments.

Keywords: **LPG Cylinder, Non Linear Static Analysis, Optistruct, Burst Pressure**

1. Introduction

The LPG tanks are evaluated as pressure vessels. LPG gas is widely used at domestic and commercial level for cooking. To transport the LPG gas from plant to homes pipelines or cylindrical storage containers are used. LPG Cylinder as shown in Fig 1 is robust in design. LPG Cylinder allows the user to cook food by using the LPG gas in compressed form. Storage device can be of any type but mostly cylindrical shape is used. They come in various capacities such as 5-50 kg. In homes mostly 14.2kg capacity cylinders are used The LPG consists of following parts: Cylindrical Dome, Cylindrical Shell, Foot Ring, Valve Protection Ring, Bung, Vertical Stay Plates. Generally they are made up of carbon steel. Hydraulic burst is the case in which linearly increasing pressure is applied from inside the cylinder until it burst or crack. This study includes the cylinder of 300mm OD with 26 Litre water capacity. The tanks have been produced from 2.8 thick sheets.

Objective of this study is to determine the burst pressure of LPG cylinder using FE and compare the results with experimental results available from already published research paper.

2. Experimental study

The LPG tanks burst pressure determination is done using experiments in which linearly increasing pressure is applied from inside the cylinder and structure is visually inspected for crack. Crack is noted at ultimate tensile strength of material and pressure corresponding to UTS is considered as burst pressure. Pressure corresponding to yield stress of material is also noted down and known as yield pressure.

2.1 Properties of LPG Gas

Liquefied petroleum gas is normally colorless and odorless. For easily distinguishing a possible gas leak by the user it has been specially aromatized. The boiling points of liquefied petroleum gases (the temperatures that they transform from liquid state to gaseous state) are very low. Propane can become gaseous at −42 ◦C, butane at −0.5 ◦C. By this property it can be used at very cold regions. The liquid butane and propane is approximately 50-50 lighter than water. Therefore, in a tube with a water capacity of 26L approximately 12.5 kg of LPG can be filled. When the LPG is in gaseous state, it is approximately two times heavier than air. LPG has a low boiling point and lower than ambient temperature. Hence, LPG evaporates when leak happens. It accumulates in the cavities around the floor level. Thermal values of liquefied petroleum gases are higher than other gases. LPG gas properties are as follows:

Property	Propane (40%)	Butane (60%)
Density (liquid condition) (kg/m3)	510	575
Density (gas condition) (kg/m3)	1.86	2.46
Boiling point (°C)	-42	-0.5
Min. ignition limit (in air)	2.37%	1.86%
Max. ignition limit (in air)	9.50%	8.41%
Required air quantity for burning (m3/m3)	23.82	30.97
Required air quantity for burning (m3/kg)	12.15	12.02
Evaporation heat (at 15.6°C) (cal/kg)	85	88.6
Thermal value (kcal/kg)	11070	10920

Table 1: Physical properties of Propane & Butane

2.2 Structure of LPG Cylinder

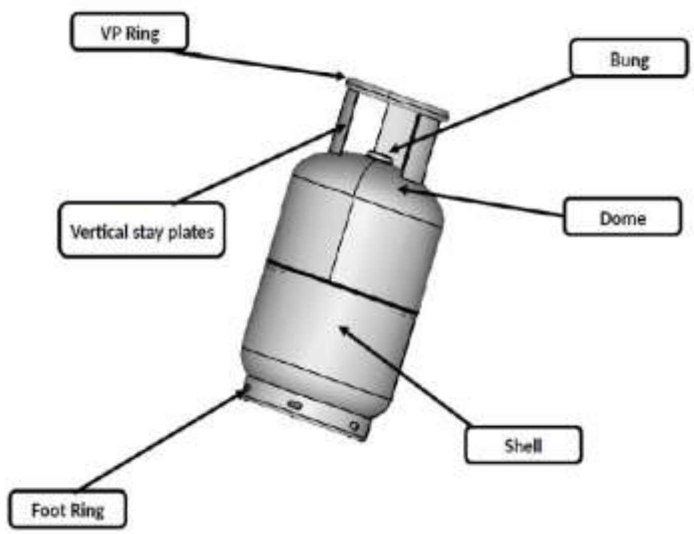


Fig 1: LPG Cylinder parts details

2.3 Material and Properties

Material	Yield Strength	% Elongation	UTS(MPa)
P265GH	265	24	480
Young Modulus(GPa)	**Poisson Ratio**	**Density(Kg/m3)**	**Thickness(mm)**
190	0.3	7890	2.8

Table 2: Material Properties

C Max	Si Max	Mn min	Pmax	Smax	Al min	Nmax	Nb max	Ti max
19%	25%	40%	2.5%	1.5%	2%	0.9%	5%	3%

Table 3: Chemical Properties of LPG Cylinder material

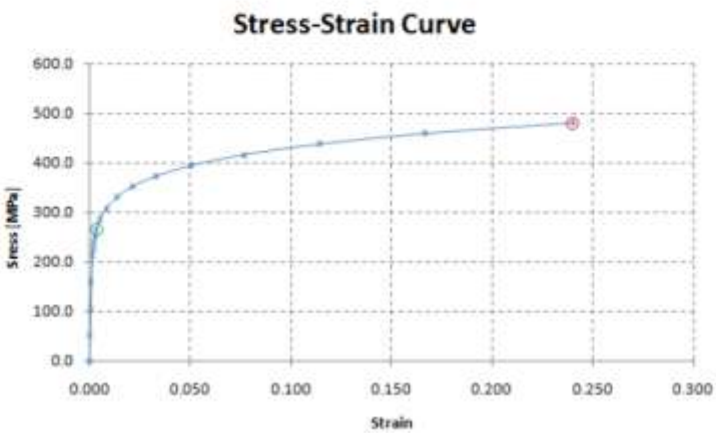


Fig 2: Steel Engineering Stress Strain curve

2.4 Burst Test Conditions

1. All welding shall be completed on cylinder subjected to this test
2. The hydraulic burst test shall be carried out using a test rig which allows pressure to be increased at a controlled rate until the cylinder bursts and the curve of pressure variation versus volumetric expansion to be produced. The test shall be carried out at room temperature. (The temperature of the cylinder shall be less than 40 °C.)
3. During the first stage (elastic deformation), the rate of increase in pressure shall be approximately constant up to the level at which plastic deformation starts. The duration of the test shall not be less than 2 min.

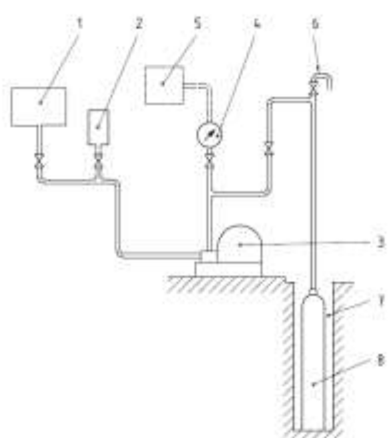


Fig 3: Burst Test setup

2.5 Burst Test Interpretations

$$p_b \geqslant 2{,}0 \times p_h$$

The observed yield pressure (p_y) shall be

$$p_y \geqslant 1/F \times p_h$$

The specific change in volume of the cylinder is given by $\frac{100(V - V_o)}{V_o}$

where

V is the capacity of the cylinder subsequent to bursting,

V_o is the capacity of the cylinder before expansion.

The volumetric expansion (V_{exp}) shall be

$$V_{exp} \geqslant 8\ \%$$

Where F is material Factor
In this study experimental results are obtained from already published paper for carbon steel cylinder of 12.5Kg Capacity.

Experimental Results

Burst experiment results for material of 2.8 mm thickness

Test number	Before test, volumetric capacity of cylinder V_{first} (l)	During bursting, volumetric capacity of cylinder V_{final} (l)	After test, volumetric variation $V_{first} - V_{final}$ (l)	Volumetric expansion (%)	During bursting, measured pressure P_b (bar)	Crack location
1	26.40	36.87	10.47	39.65	121.38	Main welding
2	26.25	36.49	10.24	39.01	121.41	Body
3	26.35	35.99	9.64	36.59	120.86	Body
4	26.30	37.52	11.22	42.65	121.38	Main welding
5	26.25	35.94	9.69	36.91	118.92	Body
6	26.25	35.90	9.65	36.74	121.36	Body
7	26.35	37.47	11.12	42.20	121.46	Body
8	26.35	36.72	10.37	39.34	120.45	Body
9	26.35	36.09	9.74	36.98	118.33	Body
10	26.30	36.75	10.45	39.71	122.92	Body
11	26.35	35.68	9.33	35.41	116.79	Body
12	26.30	35.79	9.49	36.09	118.01	Body
13	26.25	36.83	10.58	40.32	120.73	Body
14	26.25	36.64	10.39	39.56	118.94	Main welding
15	26.30	35.89	9.59	36.45	118.15	Main welding
16	26.25	36.38	10.13	38.60	118.65	Body
17	26.30	35.58	9.28	35.29	117.29	Body
18	26.25	35.69	9.44	35.97	119.54	Body
19	26.25	35.22	8.97	34.17	115.44	Body
20	26.30	35.90	9.60	36.49	115.84	Body
21	26.35	36.13	9.78	37.11	116.73	Body
22	26.25	34.34	8.09	30.83	114.27	Main welding
23	26.25	37.22	10.97	41.79	117.79	Body
24	26.25	34.81	8.56	32.62	116.98	Body
25	26.30	36.66	10.36	39.40	120.80	Body
26	26.30	36.39	10.09	38.36	120.05	Body
27	26.35	35.39	9.04	34.31	117.62	Main welding
28	26.30	34.11	7.81	29.68	116.41	Body
29	26.25	36.39	10.14	38.62	118.67	Body
30	26.25	36.47	10.22	38.91	120.14	Body
31	26.25	35.16	8.91	33.95	120.01	Main welding
32	26.30	36.05	9.75	37.05	120.43	Body
33	26.30	36.33	10.03	38.15	119.35	Body
34	26.30	35.17	8.87	33.71	118.34	Body
35	26.35	35.40	9.05	34.33	119.28	Body
36	26.30	34.70	8.40	31.95	116.53	Body
37	26.30	33.66	7.36	27.97	117.23	Body
38	26.20	35.89	9.69	36.98	123.15	Body

Fig 4: Experimental Test Results

3. Finite Element Model

Making any changes in production system generally can cause high costs. For any small modification prototype has to be made and then experimental test needs to be performed which results in high cost. FEM has been frequently used in the recovery of the production process in recent years. In this way, the result of the modification to be done can be simulated in computer by using Finite element Method which results in low cost. The LPG tanks subjected to the burst test have also been analyzed by the use of the finite element method. The purpose of FEM analysis in this study to estimate the burst pressure and volumetric expansion. As a method "Explicit non-linear analysis" method has been used. The reason of preferring this method is to capture the breaking that occurs during the event. In the FEM analysis performed, as the tank is modeled in two halves which are welded together by elements. CAD model is modeled in Solid Edge student edition. Proper connectivity is maintained between different mating parts as shown. Shell elements are used to model most of the parts and weld elements are modeled with solid elements.

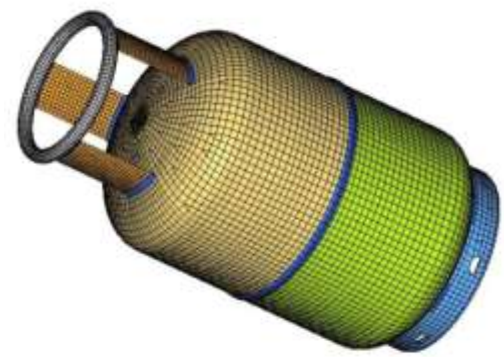


Fig 5: Finite Element Model

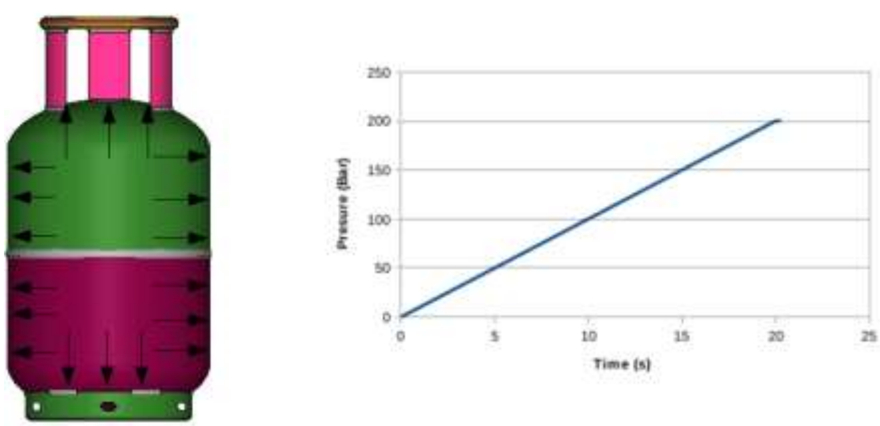


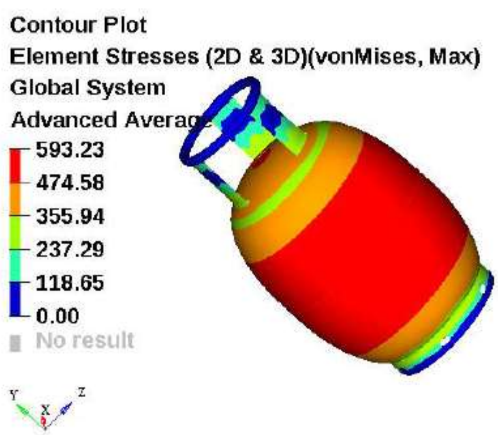
Fig 6: Boundary Conditions

Cylinder is constrained in all 6 DOF at Footring base
Pressure of 0-200bar is applied from inside the cylinder as shown

4. Results

Yield Pressure = 42bar

Fig 7: Yield Pressure Results



Burst Pressure = 115bar
Volumetric Expansion = 27.5bar
Avg Burst Pressure(Experimental) = 115-125bar

Fig 8: Burst Pressure Results

Cylinder wall thickness (mm)	Average experimental burst pressure (bar)	FEM simulation burst pressure (bar)	% Error
2.8mm	120bar	115bar	5

Table 4: FEM and Experimental Results Comparison

5. Comparison of Experimental and FEM results

As it can be seen from Table 4, the physical experiment results and simulation results are very close values to each other. Error ratio is within the acceptable limits and this ratio can be reduced by the use of more detailed material model and comprehensive experiment data. This error can be further reduced by capturing the actual physics of burst experimental setup in simulation. From the above simulation it has been observed that it is a reliable method that can yield correct results of burst pressure which can be used towards decreasing the cost of LPG cylinder prototyping and testing.

6. Conclusion

The experiment results from paper are for 2.8mm thickness cylinder. Experimental method shows that they are very costly and dangerous and should be done precisely to avoid any harm to workers/person. Experimental physical conditions are replicate in simulation to obtain the burst characteristics of cylinder. Matching of the experiment and FEM results has indicated that the FEM studies can be used effectively for testing of cylinders. In this study cylinder of 12.5kg capacity with 2.8mm wall thickness is studied but this method can be applied to any capacity & sheet thickness model. This will bring the cost reduction of testing and making prototypes.

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