Experimentally Determination of Burst Pressure and Failure Location of Liquefied Petroleum Gas Cylinder

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Abstract

Liquefied Petroleum Gas (LPG) cylinder is a thin pressure vessel used to meet energy requirements in household applications. Bursting of a pressure vessel is disastrous and many fatal accidents are happened due to pressure vessel bursting. The main goal of the current paper is focused to determine experimentally the burst pressures (BP) and failure locations of LPG cylinders. To ensure that the cylinders are in conformance with International Standards. The experiments were carried

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out on two samples of LPG cylinders used in Libya (C_1 and C_2). The experimental burst test investigations done by hydrostatic test in which the cylinders were internally pressurized with water. The permanent volume expansions of the LPG cylinders due to internal pressure were also examined. All tests in this study were subject to standard specifications (ISO 4706), which is needed to be conducted on LPG cylinders before introducing them to the Libyan market. Among these tests, the hydro-tests are major tests to be conducted on LPG Cylinders to get approval and acceptance. Hydro-tests on LPG cylinders reveal permanent volumetric expansion of the cylinder, nominal hoop stresses at the time of destruction and the internal pressure at which a cylinder burst. These values are important to ensure that the design and construction of cylinders are safe and compiled to standards.

Keywords*: Hydrostatic Testing of LPG Cylinder, Volumetric Expansion (VE), Burst Pressure (BP), Nominal Hoop Stresses (NHS), and failure locations.*

1. Introduction

Energy holds a vital importance in our lives. Thus, the ever reduced energy resources must be conserved to ensure sustainable development. One of these forms of energy is employed in cooking (Liquefied petroleum gas LPG). LPG fuel is widely used in domestic, industrial and commercial purposes. In addition to its household uses, Liquefied petroleum gas (LPG) is commonly used as an alternative fuel for internal combustions engines of vehicles in Europe. Liquefied Petroleum Gas (LPG) is a colourless liquid that readily evaporates into a gas. And normally have an odour added to help detect leaks. When mixed with air, the gas can burn when it meets a source of ignition. It is heavier than air, so it tends to sink towards the ground [1]. LPG is composed predominantly of a mixture of hydrocarbons such as propane, propylene, butane or butylene. The gas can be liquefied at moderate pressure, and can be stored in cylinders as a liquid under pressure and is drawn out and used as gas. This means that it can be transported and stored as a liquid and burnt as gas. The expansion ratio of gas-liquid is 270:1 at atmospheric pressure [1]. The expansion factor makes LPG more economical to transport and store with large quantities of gaseous fuel in small containers. Containers are normally filled 80-85% liquid, leaving 15-20% vapour space for expansion due to temperature increase. Nowadays, composite materials have been widely using which have been proven to be more effective. These composite materials are wound over metal liner thus acting as over wrapped composite pressure vessels. LPG cylinder is one kind of pressure vessel that stores pressurized gases. LPG cylinder material should have high tensile and compressive strength for withstanding the high pressure of the gases [2]. The Cylinders play a crucial role in containing and transporting hazardous LPG from filling plant to end consumer [3]. LPG cylinders are to be manufactured from definitely prescribed raw material to ensure the safety of cylinders through material quality specifications [4]. Although there are clear standards and statutory norms for the design, manufacturing and usage of cylinders, there are certain gaps in these standards in terms of ensuring material safety compliance. LPG cylinder production is collected of several sheet metal forming, surface treatment and testing processes. The process starts with blanking, deep drawing and piercing, trimming and joggling. Next are the welding operations for the valve boss, valve guard ring, foot ring and the two halves. The complete cylinder is then heat-treated, tested, shot blasted, painted and then the valve is attached and tested finally [5]. Two cylinders from each manufactured lot are exposed to a destructive test for confirmation of cylinder material properties, as a part of the certification process. For every manufactured lot of 203 and below one cylinder is tested for acceptance test [6]. Parent metal physical properties like yield strength, tensile strength, percentage elongation of the parent metal, weld joint strength etc. are revealed in the acceptance test [7]. Similarly, every manufactured lot of 403 cylinders and below one cylinder is subjected to various hydro-tests. The hydro-test on the cylinder reveals cylinder water capacity, leaks, volumetric expansion, burst pressure and nominal hoop stress at which a cylinder bursts [6]. Requirements of various hydro-tests for LPG cylinders are mentioned in ISO 4706. There, are a few factors that can influence these results during the manufacturing process and are cylinder raw material selection, cylinder manufacturing process, heat treatment process parameters [8-10]. The burst pressures BP is the maximum pressure cylinders can withstand without bursting. Noting that, the (BP) and burst failure locations of liquefied petroleum gas (LPG) cylinders can be determined also by using finite element analysis (FEA approaches) as mentioned by Kisioglu et al. [11]. The hydro-test is one of the most important tests carried out on household petroleum gas cylinders and knowledge appears to be available in the literature for the burst pressures BP and the failure locations for household petroleum gas cylinders seems to be lacking or limited. For those reasons, the primary aim of this study is to determine experimentally the burst pressures (BP) and the failure locations. Moreover, the purpose was also to ensure that the cylinders are in conformance with international standards to ensure safety. The experiments were carried out on two similar types of household petroleum gas cylinders (C1 & C2).

2. Materials and Design of LPG Cylinders

The household petroleum gas steel cylinders are manufactured either in two pieces or three pieces construction. In this study, two household petroleum gas cylinders (C1 & C2) were fabricated by welding two domed ends directly together. The domed ends can be torispherical, semi-ellipsoidal or hemispherical in shape. The tested cylinders have been taken randomly from two different places in the Libyan market for the purpose to investigate volumetric expansion (VE), burst pressure (BP), nominal hoop tresses (NHS), and failure locations. Moreover, to be sure these household gas cylinders fit the ISO 4706 requirements in the field of this study. The chemical analysis (Table 1) reveals both cylinders being studied are made of low alloy carbon steel. The low alloy carbon steel, because of its low content of carbon (0.0937, 0.0963) it is expected to have low yielding strength, which makes it suitable for industries that require high formability and weldability similar to gas cylinders industries. While by increasing the amount of carbon as in medium carbon steel which exhibits the yield strength in the range of 700- 1000 MPa [19-25]], that results in the difficulty of welding and shaping processes. Details of the specifications of these gas cylinders are given in table 2.

Table 1: Chemical Composition of LPG Cylinders

Empty Weight by Kg	Overall Height by mm	Inner Diameter by mm
18.5	675	318
Min. Wall Thickness by mm	Test Pressure by bar	Water Capacity by liter
≥ 3.00	30	36

Table 2. Specifications of the gas cylinders being studied

Gas Cylinder Number	Chemical Composition by W.t %				
	C	Mn	Si	S	P
C_1	0.0937	0.4694	0.0122	0.0074	0.0122
C_2	0.0963	0.4260	0.0215	0.0038	0.0101
ISO 4706 requirements	0.250 Max.	1.60 Max.	0.450 Max.	0.040 Max.	0.040 Max.

Regarding the guidelines and the design of these cylinders can be found in many international codes such as BS-5500 (British Standard) and the ASME codes (Section VIII, Division 1) [11,26]. These rules are restricted mostly to the load-carrying capacity under internal pressure. However, these LPG cylinders are designed and manufactured according to the restrictions of the refillable welded steel gas cylinders ISO/DIN 4706.2 codes, considering the SP and TP of the LPG cylinders. The pressure specifications of the most commonly manufactured cylinders of 318mm inner diameter used in industrial applications are given as an example in table 2. These cylinders are equipped with a valve system and a label welded to the shell body, as shown in Fig. 1.

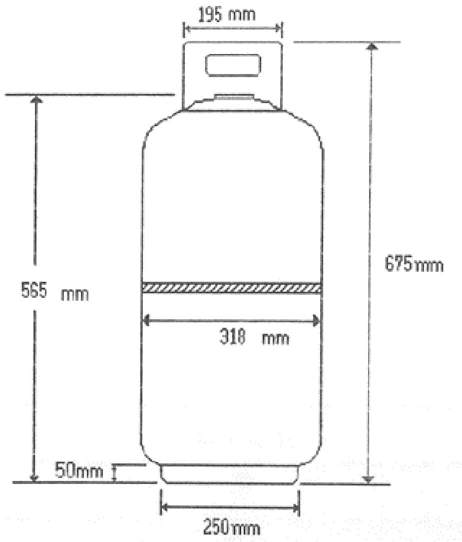

Fig.1 The LPG cylinder and its design parameters.

The LPG cylinders are usually manufactured within different groups, which are classified by their water capacities (2, 5, 18 and 35 liters). Each group of cylinders has a different wall thickness ranging from 2 to 3 mm. In the present study, the BP and failure locations of the most commonly used group (35 l) of LPG having 3mm wall thickness are investigated. These cylinders consist of three main parts: one cylindrical shell and two torispherical end closures. The cylindrical shell is folded up and welded horizontally at the middle. Some design parameters are also shown in Fig. 1. such as inner diameter (ID), minimum wall thickness (t) and length of the cylindrical shell (L). As represented in Table 1, LPG cylinders are constructed from low alloy carbon steel using the welding process for the cylindrical body, which is manufactured by the deep drawing process. The low alloy carbon steel is a hot rolled steel with 0.094% carbon content and is a ductile material suitable for the cold forming process used to construct the LPG cylinders. The deep drawing process changes the material properties and thickness variations. After completing all manufacturing and welding processes, these cylinders have been subjected to a heat treatment process before service.

3. Results and Discussion

3.1 Water Capacity Test

In this test, gas cylinder capacity is measured by filling it with water and checking whether they are within acceptable limits or not. The mean capacity values obtained are about 36 liters and its acceptable limit is within 35 ± 5 liters as per standard.

3.2 Burst Tests

Burst test results of two domestic LPG cylinders of 35 liter capacity are selected for this study. These cylinders are the most common type of cylinders used in Libya houses. The burst test was carried out at room temperature under a hydraulic pressure test machine. The pressure is to be increased gradually until the cylinder bursts. The specifications of the gas cylinders being studied are shown in Table 2. On the other hand, the requirements according to ISO 4706 of hydro-test of these cylinders are present in Table 3. The experimental setup starts by filling the gas cylinders completely with water and the pressure is controlled using a single-acting hydraulic pump. The LPG cylinder was placed vertically during the experiments and air was vented during filling as seen in Fig. 2 and the burst cylinders are shown in Fig. 3. The wall thickness was variable due to the thickness tolerances for the blank sheet as can be seen in figure 2. The BP results obtained ranged from a minimum of 102 bar to a maximum of 104 bar. The mean BP values obtained are about 103 bar.

Table.3 Household gas cylinders' test results and requirements.

Type of Test	Requirements as per ISO 4706
Burst Pressure (BP)	Min. 50 bar (5 MPa)
Nominal Hoop Stress	Min. 323.5 MPa
Volumetric Expansion	≥ 15% (for TS > 410 MPa)
Ratio of hydrostatic extend	Max. 9%
Failure Locations	Not initiate in a welding region
Household Gas Cylinders Test Results	
Burst Pressure (BP)	104 and 102 bar (10.4 and 10.2 MPa)
Nominal Hoop Stress	533 and 523 MPa
Volumetric Expansion	25 % for both
Ratio of hydrostatic extend	3.9 and 4.0 %
Failure Locations	Initiate out of a welding region

3.3 Thickness Homogeneity Test

The LPG cylinders' thickness variation was investigated point-by-point by the ultrasound device test. The measured thickness was very close to the nominal thickness of ISO / DIN 4706.2. except in the weld zone. However, four slightly different thicknesses were measured between points (see Fig.2). As can be seen in Fig.2., the wall thickness is altered mostly in weld regions. It was also observed that the maximum thickness change of about 17% occurred in the weld region, and the minimum thickness change of about 6% occurred in both bottom and top regions.

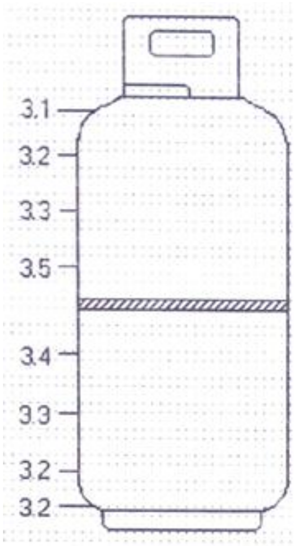

Fig. 2. Results Homogeneity Thickness of the cylinders by mm.

3.4 Burst failure locations

These hydro-tests reveal Volumetric Expansion (VE), Burst Pressure (BP) and Nominal Hoop Stresses (NHS). These VE, BP and NHS values are considered critical parameters in hydro-testing of LPG cylinders [12-14]. These values can be correlated with tensile strength and yield strength of material [15]. The burst location of the LPG cylinders is well known from the experimental burst tests (see Fig. 3). The failure initiated in the middle area at the top of horizontal welding regions (Initiate out of a welding zone), cylinder specimens fractured in such a way that the burst crack continues longitudinally as illustrated as shown in Fig.3. This point defined as the burst failure location of the LPG cylinders.

Fig.3. Failure Locations of the cylinders.

3.5 Hydrostatic Test

This test was performed by using equipment that ensured the application of international specifications. In this test, two cylinders (C_1 and C_2) are subjected to a hydrostatic test pressure of 30 bar and retained at this pressure for up to 30 seconds to check any pressure drop. Once the cylinder external surface is dried, they are checked for visual external leaks and pressure drop. If there is any pressure drop or any visible external leaks observed on the cylinder body or welds, the cylinder is considered as a failed cylinder for usage [16-18]. Moreover, the rate of pumping should not exceed five times the water capacity of the cylinder per hour i.e. the pressure in the cylinder must be increased gradually until the test pressure is reached.

3.6 Hydrostatic Stretch Test

In this test, the cylinder initially is filled with a measured quantity of water say, V1. This filled cylinder is gradually pressurized with water till it reaches hydrostatic test pressure of 30 bar through an apparatus that can measure the pumped water quantity in a precise manner. Once the pressure reaches the test pressure, the pressure is retained for not less than 60 sec and measures the water contained in the cylinder as V2. The water capacity of the cylinder is measured once again after releasing the test pressure and recorded as V3. Based on the records, the volumetric expansion is calculated as; the difference between V1 and V2 represents the total volumetric expansion and the difference between V1 and V3 represents the permanent expansion. This value should be ≤ 9 % or 1/5000 of the original volume of the cylinder [6] to pass the test. The test results showed that the ratio of hydrostatic extend is equal to 3.9 and 4.0 % for both household petroleum gas cylinders (C1 & C2) the results obtained were within the allowable limit in international standard ISO 4706.

3.7 Permanent volume expansions

When the cylinders are pressurized hydrostatically, they balloon shape permanently in both the x- and y- directions as seen in Fig. 3. Based on the ISO 4706 requirements, the permanent volume expansions of these cylinders before burst must be ≥ 15% of the initial volume. After the explosion of the cylinder due to burst pressure, an expansion has happened to the cylinder. This expansion was measured manually. Based on these measurements, the volumetric expansion values were exceeded about 25% of the initial volume of the cylinder. This expansion was within the allowable range of the International Standards ISO 4706.

3.8 Burst test and nominal hoop stresses

Initially, the cylinder used previously in the volumetric stretch test can be used for this purpose. In this test, the cylinder is subjected to an increasingly and continuous hydrostatic internal pressure until it bursts.

The internal pressure of the cylinder at which its burst is noted and recorded as burst pressure. Based on that, burst pressure nominal hoop stresses can be calculated using the below formula:

$$fb = (Pb \times Di)/2t \qquad (1)$$

Where *fb* is the nominal hoop stress; *Pb* is the internal hydrostatic pressure at which cylinder bursts in MPa; *Di* id the nominal original internal diameter of the cylinder in mm and *t* is the minimum agreed finishing thickness of the cylinder in mm [16]. The result values obtained of nominal hoop stress using that equation were as follows 533 and 523 MPa for C_1 and C_2 cylinders, respectively. These values are within ISO 4706 requirements.

Conclusions

The aim of this work was to determine experimentally the Burst Pressure (BP), Nominal Hoop Stress (NHS) and Burst Failure location of two household petroleum gas cylinders under internal pressure. The tested cylinders contained 0.0937%C, 0.4694%Mn and 0.0122%Si. By the interpretation of results obtained in this study and as mentioned in Table 3. There is good compatibility between the results obtained and cylinders requirements as per ISO 4706.

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