Chapter-2

2. LPG Cylinder Life Cycle

An effort has been made in this chapter to document LPG cylinder life cycle from raw material to scrapping. The chapter starts with LPG cylinder terminology and sails through various phases of LPG Cylinder life cycle and ends with a discussion on various factors that can affect LPG cylinder life cycle. All critical phases of LPG cylinder life cycle are discussed in this section. Cylinder handling is the most important things that decide life span of LPG cylinders. This section ends with a brief discussion on cylinder handling with feasible solutions / remedial actions to avoid wrong handling of cylinders.

2.1 LPG Cylinder – Nomenclature

LPG Cylinder bodies are manufactured either with two pieces or three pieces construction. Terminology and parts of both two and three piece cylinders are shown in Figure 4 and is self-explanatory. Although valve is an important component attached to cylinder, it is not an integral part of LPG cylinder’s body. This is required for pressure testing of cylinder during manufacturing. Hence cylinder valve is also shown in the figure.
2.2 Shapes of LPG Cylinder

LPG Cylinders are fabricated in three different shapes and are classified based on their domes [25] & [7]. The domes can be tori-spherical, semi-ellipsoidal and hemi-spherical bodies as shown in Figure 5. Two piece cylinders (eg. Indian domestic LPG cylinders) are not fabricated with hemi-spherical domes as the body loses cylindrical shape and turns to a sphere. Design calculations for these shapes are discussed separately in this chapter. Although LPG Cylinder designs are different (based on domes), test methods to check with standards compliance is same for all shapes of cylinders and are as per Indian Standard IS 3196 Part 3 in India [27].
2.3 Cylinders For Current Research

Indian LPG Cylinders marketed by Government oil companies for domestic use are considered for this current research. These cylinders are fabricated in two piece construction either with Tori-spherical or semi ellipsoidal domes. Water capacity of these cylinders are typically around 33.3 Liters and are manufactured as per Indian standard IS 3196 Part-1. These cylinders are tested as per IS 3196 Part 3 for Bureau of Indian Certification (ISI/BSI Mark). Typical dimensions of LPG Cylinder for Domestic [18] use are shown in Figure 6.

2.4 Domestic LPG Cylinder Life Cycle

LPG Cylinder life cycle is described with a flow chart in Figure 7. In India, government oil companies estimate their new cylinder requirements and procure through tendering process [18]. The manufacturers supplies cylinders as per tender specifications. LPG Cylinders supplied by government oil companies are the property of respective marketing oil company (for example IOCL, HPCL and BPCL). The consumer is only owner for the gas present in it. Oil companies take ownership for the cylinder and they do all repairs and periodic statutory requalification of cylinder during its life cycle. This cost will not be passed on to consumer. Once the cylinder reaches a stage, where it is not fit for use, the cylinder is discarded from market and scraped. Below text describes various stages in LPG cylinder life cycle from cylinder manufacturing to cylinder scrapping.
Figure 6: Domestic LPG Cylinder Specifications
2.4.1 Raw Material

Raw material is the most critical parameter for LPG cylinder construction. Special grade steel complies with Indian standard IS 6240, *Hot rolled steel plate (up to 6 mm) sheet and strip for the manufacture of low pressure liquefiable gas cylinders* or equivalent is used for cylinder body. Standard IS 3196 specifies critical parameters of parent material viz. Yield strength, tensile strength, percentage elongation and material composition (see Table.1). The bung or valve pad should confirms to class 1A or Class2 of IS 1875, *carbon steel billets, blooms, slabs and bars for forging* or IS 2062, *Steel for general structural purposes*. Valve protection ring, Foot ring should confirm to Grade 0 of IS 1079, *Hot rolled carbon steel sheets and strip* or IS 2062 or IS 6240. If the cylinder is manufactured with a butt weld, the backing strip for the butt weld should confirm to IS2062. Majority of cylinder manufacturers are fabricating cylinders with joggling joint, where backing strip is not required for welding.
In case the manufacturer uses an equivalent raw material for cylinder construction, the finished cylinder should guarantee 240 MPa yield stress, 350 MPa to 450 MPa tensile strength and the percentage of permanent elongation of parent metal should not be less than 25% when it is subjected to parent metal tensile test as per Indian Standards IS 3196 part3 (See Table 2).

**Table 1: LPG Cylinder Raw Material chemical Composition**

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Unit</th>
<th>Permissible Variation Over max and under min. specified limit in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon (C)</td>
<td>0.16 max</td>
<td>0.02%</td>
</tr>
<tr>
<td>Silicon (Si)</td>
<td>0.25 max</td>
<td>0.03%</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>0.30 min</td>
<td>0.03%</td>
</tr>
<tr>
<td>Phosphorous (P)</td>
<td>0.025 max</td>
<td>0.005%</td>
</tr>
<tr>
<td>Sulphur (S)</td>
<td>0.025 max</td>
<td>0.005%</td>
</tr>
<tr>
<td>Aluminum (Al)</td>
<td>0.020 min</td>
<td>--</td>
</tr>
<tr>
<td>Nitrogen (N)</td>
<td>0.009 max</td>
<td>--</td>
</tr>
</tbody>
</table>

**Table 2: LPG Cylinder Parent Material Specifications**

<table>
<thead>
<tr>
<th>Mechanical Properties</th>
<th>Tensile strength MPa</th>
<th>Yield Stress MPa</th>
<th>Percentage Elongation in %</th>
<th>Internal diameter of bend</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Between</td>
<td>Minimum</td>
<td>Minimum</td>
<td>Maximum</td>
</tr>
<tr>
<td>350-450</td>
<td>240</td>
<td>25</td>
<td>t</td>
<td></td>
</tr>
</tbody>
</table>

Note: where ‘t’ is the thickness of test piece

### 2.4.2 Design

Wall thickness is primary factor to be arrived while designing LPG cylinder. Thickness depends on several factors such as cylinder test pressure, outer diameter of cylinder, shape of cylinder dome, yield strength of material, weld joint factor, ratio of domed end diameter to height, dishing radius, knuckle radius and length of straight flange [25]. In order to design the thickness, a test pressure of 23.53 bar and minimum yield strength is 240 MPa is considered as per Indian standard IS3196 Part 1. Further, weld joint factor to be considered as 1.0, 0.9
and 0.7 depends on type of radiographic examination adopted to check the welds during and after manufacturing process [25].

Design calculations of any cylinder are based on cylinder dome shape (see Figure 5). Thickness is calculated separately for domes and cylindrical portions of a cylinder body. The thickness whichever is higher among these two values is considered as a final thickness [25].

The thickness of cylindrical portion is calculated using below two formulas and the larger thickness value is considered as the cylindrical portion thickness of a cylinder [25][27]&[70].

\[
t = \frac{PhDo}{200 \times 0.8 \times Re + Ph}
\]

Or

\[
t = \frac{PhDi}{200 \times 0.8 \times Re - Ph}
\]

And

\[
t = 0.136 \times \sqrt{Do}
\]

Where

- \( t \) = calculated minimum wall thickness, in mm
- \( t_e \) = calculated wall thickness of doom, in mm
- \( P_h \) = Test pressure, in Kgf/cm²
- \( D_i \) = inner diameter, in mm
- \( D_o \) = outer diameter in mm
- \( h_o \) = external height of domes end in mm
- \( h_i \) = internal height of domed ends in mm
- \( R_e \) = yield strength in MPa
\[ J = \text{weld joint factor} \]
\[ = 1.0 \text{ fully radio graphed welds} \]
\[ = 0.9 \text{ for two piece cylinder} \]
\[ = 0.9 \text{ where every 50 cylinders in batch are spot radio graphed as per standard} \]
\[ = 0.7 \text{ all other cases} \]
\[ K = \text{ratio} \frac{D_o}{h_o} \geq 0.192 \]
\[ R_i = \text{dishing radius} \leq D_o, \text{ in mm} \]
\[ r_i = \text{knuckle radius} \geq D_o \]
\[ S_f = \text{length of straight flange in mm} \]
\[ \geq 0.3 \sqrt{D_o} \]
\[ z = \frac{20r_i}{R_i} + 3 \]
\[ = \frac{20r_i}{20R_i} + 1 \]

Further, the thickness of a tori-spherical cylinder dome is calculated from the following formula

\[ t_e = \frac{Ph Do}{200 \times 0.8 J \text{Re} + Ph} \times \frac{KZ}{5} \]

Thickness of a semi ellipsoidal cylinder dome is calculated using below formula

\[ t_e = \frac{Ph Do}{200 \times 0.8 J \text{Re} + Ph} \times \frac{K(0.65 + 0.1K)}{4} \]

In addition to the above, the Indian Standard IS 3196 part 3 stipulates minimum cylinder thickness should be 2.0 mm for LPG cylinders up to and including 13 liter water capacity and 2.4 mm for cylinders above 13 liter water capacities [27]. Thus for a 33.3 liter domestic LPG cylinder thickness should be minimum 2.4 mm and maximum thickness should be as per above design calculations. Once LPG cylinder design is finalized, a prototype cylinder to be produced and to be subjected to various tests to ensure deemed fit [25]. Bureau of Indian
Standards authorities verifies and accept the design and allows the manufacturer to start production.

2.4.3 Manufacturing

Cylinder manufacturing process flow diagram is shown in Figure 8 [36]. Cylinder body manufacturing process is common across the world. However, the stay plates (also known as valve protection rings) and base ring (also known as foot ring) designs are different as per the requirements of customers (oil companies; to distinguish or to identify a cylinder). Normally cylinders are produced in batches of 203 and above. This process starts from raw material. The diagram shows both three piece and two piece cylinder manufacturing process. Steel plates are cut to the required dimensions to produce cylindrical body by rolling operation. This is only for a three piece cylinders manufacturing. Indian domestic LPG cylinders are in two piece construction and cylindrical portion does not exist for these cylinders. Valve protection rings (or collars) are fabricated by blanking; rolling and forming operations as shown in the Figure 8. There are no specific guidelines for the shape of valve protection rings as it is not an integral part of cylinder body. Hence, the shape can be differed from different marketing oil companies. Valve protection ring for Indian domestic LPG cylinder (marketed by government oil companies) is fabricated with a circular steel pipe with three stay plates attached to it (see Figure 6). The domes are manufactured by blanking and deep drawing process. The top dome undergoes trimming and piercing operations for attaching a bung to it. The bottom dome undergoes only trimming operation as shown in Figure 8. The base plates (also known as foot rings) are manufactured by blanking, rolling, welding and forming operations. Similar to valve protection ring, the base ring or foot ring shape is not specified in standard. It can be manufactured as per the requirements of marketing oil company.
specification. The foot rings design for Indian domestic oil company cylinders are slightly differ from these base rings shown in Figure 8 (see Figure 6).

Figure 8: LPG Cylinder Manufacturing Process Flow Diagram
All these components undergo degreasing operation and then welded together to form either a two piece or three piece cylinders. The complete cylinder then subjected to heat treatment to relieve internal stresses developed due to welding operation. Welding and heat treatment are critical operation in cylinder manufacturing. The requirements of weld methods and welder qualifications are prescribed in IS 3196 Part1. Similarly the heat treatment process parameters are particularly important to get required mechanical properties in finished cylinder. Cylinder should be heat treated correctly as per the recommendations of raw material suppliers. Otherwise, the finished cylinder may exhibit tensile strength values above or below stated specifications in Indian Standard and leads to failure in cylinder mechanical properties testing (acceptance testing).

After the heat treatment process, every cylinder is subjected to hydro test. This test reveals leaks, if any in finished cylinders. At this stage LPG cylinder are subjected to test pressure for a specified period to check leaks from body and weld joint. All cylinders produced in a manufacturing location should undergo this test. Hydro test passed cylinders are sent for painting. At this stage cylinder surface is prepared either by shot blasting or grit blasting. Once the surface is prepared, cylinders are powder coated and baked to achieve smooth paint thickness all over cylinder body as per the oil company specifications. The cylinders are then weighed and stamped tare weight on their collars or valve protection rings. Also other details of cylinder like serial number, manufacturing date are punched on cylinder body. The cylinders are then fitted with a valve and tested for leaks, if any once again. LPG cylinder is ready for dispatch, if it crosses all these stages successfully.

In addition to the above, manufacturer should test few sample cylinders from each lot for ISI certification purpose. The tests to be conducted on LPG cylinders for certification are
Acceptance tests, Burst test, volumetric expansion test, hydrostatic stretch test, hydrostatic test, pneumatic leak test, radiographic examination, and fatigue/cycle test.

The acceptance test reveals the parent metal mechanical properties and weld mechanical properties. Tensile samples are cut from cylinder body and tested for measuring yield strength, tensile strength, percentage elongation and weld tensile strength. One cylinder should undergo this test for every batch/lot of 203 or above cylinders.

Volumetric expansion test indicated permanent volumetric expansion of cylinder under test pressure conditions. One cylinder should undergo this test for every batch of 403 cylinders. The same cylinder can be subjected to burst test to measure burst pressure and nominal hoop stress in cylinder at burst pressure conditions.

Radiographic examination is intended to check the weld quality and the depth of penetration. Fatigue test is a type test to check the cylinder under cyclic internal pressures. Leak tests are intended to check visible leaks in cylinders. All these tests to be conducted on sample cylinders as per Indian standard IS 3196 part3. Once the batch is accepted by Bureau of Indian standards, certified cylinders are released to market for use.

### 2.4.4 Filling and Usage

Typical process flow diagram of an LPG cylinder movement in a bottling plant is shown in Figure 9. Empty cylinders received in plant for filling are initially checked for body damage, repairs or requalification requirements. Once the cylinder passes this stage, cylinders are washed and dried to remove dirt and loose particles on their bodies. The dried cylinders are then sent for filling. The filling process may be either automated system on a carrousel or
through standalone manual scales, depending on bottling plant size, market demand etc. Filled Cylinders undergo weight check to ensure the cylinders are filled with correct quantity.

Figure 9: Cylinder Filling to Scrapping - Flow Diagram

In case of any deviation observed in weight, the quantity is adjusted in correction scale and then sent back for weight check. The filled cylinders are then sent for valve leak check, internal washer leak check and body leak checks. If the cylinder is found to be alright, the cylinder finally goes for sealing. Sealed cylinders are dispatched to dealer or customer from bottling plant. An empty cylinder from customer / dealer comes back to plant and follows the empty cylinder check and subsequent process in a cycle.

2.4.5 Repairs, Requalification and Scrapping

LPG cylinders subjected to wear and tear during usage. Suppose if any cylinder is found to be valve or internal washer or bung leak during filling, such cylinders are segregated and sent for evacuation. The product from LPG cylinder is evacuated in evacuation process (see
Figure 9). The evacuated cylinders are subjected to repairs and finally sent back to system for filling. If the cylinder found to be body leak during filling or any other stages, the cylinder needs to be scrapped, irrespective of the gravity of the leak. Similarly, if a cylinder is identified that it caught fire in its usage, it should be scrapped and no repair is allowed on such cylinders. In case cylinders are found to be severely damaged and needs replacement of foot ring or valve protection ring, such cylinders are considered as hot repair cylinders and they are transported to cylinder manufacturer or authorized hot repairer for necessary repair [96]. Hot repairing is a process in which the damaged foot rings and valve protection rings are replaced with new ones. This is performed by cutting the damaged component from cylinder body and welds a new part to cylinder. Due to involvement of welding operation, such cylinders needs to be heat treated after the hot repair process to relieve stresses generated in cylinders due to the welding operations. These cylinders need to be checked under hydrostatic test conditions for leaks before they dispatched to market. Once the cylinders are repaired and tested, they are inducted back to the system as empty cylinders for filling.

As per the statutory guidelines, all used cylinders needs to be re-qualified (Also known as retesting of LPG cylinders) at periodic intervals to ensure the cylinders are safe to withstand test pressures for its operation. Presently in India, new cylinders are to be first re-qualified after 10 years and there after the subsequent re-qualifications to be done once in 5 years. That means a new cylinder is subjected to hydrostatic test pressure after 10 years of manufacturing. At this stage, LPG cylinder is subjected to various tests including visual inspection, internal inspection, bottom pitting, corrosion and hydrostatic test. The cylinder requalification date needs to be punched permanently on cylinder body for future reference. In case the cylinder is not meeting the test hydrostatic test criteria, the cylinder needs to be
scraped. LPG cylinder scraping is a process, in which the cylinders are crushed after degassing a defective cylinder with the help of a hydraulic press to approximately 300 mm blanks. These blanks cannot be used in any way except steel scrap. Scraping is the end process in LPG cylinder life cycle.

2.5 Concerns in LPG Cylinder Handling

Although, at every stages of LPG Cylinder life cycle from manufacturing to bottling are regulated or controlled with several statutory regulations, guidelines and best practices, they are unfortunately ill-treated in market i.e. from the gap between dispatches of filled cylinder to receipt of empty cylinder in LPG cylinder bottling plant. This abuse is mainly in the form of body rolling, dropping cylinders from heights on hard surface, usage of wrong adaptor for withdrawing gas from cylinders, using hot water baths for generating more vapors from cylinders, illegal transfers of LPG from one cylinder to another cylinder, wet and humid kitchen condition, usage of cylinder close to hotplate etc. This kind of ill-treatment to cylinder affects cylinder life cycle and continuation of such practices reduces the life of a cylinder as described below [6].

Body rolling of cylinder in horizontal position on roads or on any hard surfaces like cemented or concrete floors, causes erosion of cylinder’s circumferential weld. This erosion leads LPG leaks from weld joint and may cause safety hazard while using a cylinder. Also this erosion causes leaks during hydro testing of cylinders when they are subjected to internal hydrostatic test pressures. As described earlier, kid of leak from hydro-testing should be scraped. Cylinders are recommended to handle only in upright positing by rolling on their foot rings. In such case, even foot ring is eroded; it can be replaced during its life cycle [6].
Dropping of cylinders from heights is a common concern in Indian market. Due to heavy weight of cylinder or insufficient infrastructure to carry cylinder, both filled and empty cylinders are dropped from trucks and from different heights at customer premises and cylinder distribution warehouses. This kind of ill-treatment badly damages foot rings, valve protection rings and cylinder body. Frequent replacement of foot ring and subsequent heat treatment process causes changes in metallurgical properties of parent metal. Such cylinders cannot withstand hydro test and needs to be scrapped much advance in their life cycle [6].

Usages of illegal or non-standard adaptors on cylinders are common in India, especially when the cylinders are connected to commercial burners while cooking large volumes of food. This practice can lead cylinder valve damage and requires valve replacement in plant. Further, Illegal product transfer from domestic cylinders to commercial cylinders or auto gas cylinders (due to duel pricing in India) is having an impact on cylinder life cycle. These transfers are performed in crude and unsafe manner. Cylinder valves are damaged severely in such crude operations and require replacement of valves in plant. Cylinder bung is having gas thread, which is a taper thread. The valve bungs are cleaned with appropriate National Gas thread (NGT) tap at the time of valve replacement. Frequent replacement of valve causes excessive wear of bung threat due to the tapping operation. This wear causes bung leaks and also regulators or adaptors cannot fit on cylinders due to insufficient gap between regulator base and the cylinder bung. Although, the cylinder body is in good shape, such bung worn out cylinders cannot be used and should be scraped [6].

Cylinder is having a limitation in LPG vapor generation in ambient conditions depending on the liquid level in cylinder. If the vapor consumption is excessive than vapor generation, sweating observed on the body of cylinder. Sweating is a phenomenon, in which the moisture
from atmosphere accumulates on cylinder body due to low surface temperatures of cylinder body. This is possible if the ambient conditions are extremely humid when the cylinder is in use or the cylinder is connected to multiple appliances and the vapor consumption is more than generation. In such cases, often hot water bath is given to cylinders in Indian commercial establishments like hotels and restaurants by placing a LPG cylinder in hot water tub for producing more vapors. This practice is not advisable at all. Sweating and hot water bath leads body corrosion to cylinder. Excessive body corrosion leads erosion of cylinder body and weakens parent metal as the thickness reduces due to rusting. Such cylinders cannot pass hydro test during requalification and needs to be scrapped. Appropriate cylinder manifold design, avoiding usage of domestic cylinder for commercial purposes, avoiding usage of commercial non-standard adaptors and a system that comprises combination of cylinder with liquid withdrawal valve and a LPG vaporizer can be used for safe and reliable operation [6].

Most of Indian kitchens conditions are wet and humid. Cylinder foot rings can be damaged as a result of corrosion caused due to prolonged exposure to moisture in kitchens. This leads damage to foot ring or bottom pitting and reduction of parent metal thickness in bottom dome. Such cylinders are not fit for use. Also, in some kitchens the hotplates in kitchens are kept very close to the cylinders due to limitation in space. The pressures inside the cylinder can increase drastically if cylinder is exposed to heat. In such condition and a cylinder can fail due to internal fatigue loads and bulges its shape. This condition also ultimately leads withdrawal of cylinder from market i.e. from its life cycle [6].

Although, LPG cylinder confirms to applicable standards and statutory requirements, majority of its life is beyond cylinder manufacturer or bottling plant premises, where there is
no control on wrong handling of cylinder. Any kind of wrong handling definitely affects LPG cylinder life cycle.[6]

2.6 Scholar’s Publications based on this Chapter


---End of Chapter 2---