EXECUTIVE SUMMARY

LPG Cylinder material plays very crucial role in containing and transporting hazardous Liquefied Petroleum Gas (LPG). In the existing LPG Cylinder manufacturing process, cylinder testing practices are destructive in nature and only two cylinders (one in 203 cylinders for acceptance test and one in 403 cylinders for Hydro-test) are tested for their parent material safety or compliance requirements. There are more than 150 LPG cylinder manufacturers in India and are producing approximately 18 million of cylinders to meet the Indian government oil companies’ requirement alone. It is a difficult process to monitor all these cylinder manufacturing plants on continuous basis for any enforcing authority. Non-compliant cylinders can enter into market, if the sampling is biased before testing a batch at any manufacturing plant. These non-complied cylinders cannot be retrieved from market till the cylinder life cycle ends. Although, oil companies are aware of this fact, there is no process in place to identify or trace non-compliant cylinders in market for segregation. Cylinder consumers are not aware of this fact and may be using a non-compliant cylinder in their homes. Non-compliant cylinders can pose potential safety hazard, if they are subjected to adverse conditions or wrong handling. It is necessary to stop entry of such non-compliant cylinders into market at point of origin i.e manufacturing location itself.

If there is a method or process in which the cylinder material properties can be checked easily and quickly in a convenient manner, without destroying or damaging the cylinder; entry of such non-complied cylinders into market can be easily identified and thereby exists a chance to eliminate at the point of identification. However, for efficient implementation, such novel method or process should not demand skilled persons for testing or demand expensive test setups to conduct inspection on cylinders. In this research an attempt has been made to
develop a fail-safe inspection plan to cylinder manufacturer to test all cylinders (100%) in their manufacturing location easily and quickly without destroying or damaging cylinder. Further, LPG cylinder material properties can be verified effortlessly at any point time in its life cycle; especially at all critical stages of its life cycle for material compliance requirement.

Acceptance and hydro tests are the two important tests to be conducted on new LPG cylinders for ensuring cylinder parent metal material properties. These two tests are most important to accept a batch of newly produced cylinders in any LPG cylinder manufacturing location. In the existing sampling system as per Indian standard IS 3196, one cylinder in every 203 cylinders undergoes acceptance test and one cylinder in 403 cylinders batch is tested for hydro-test.

As per Indian standard, IS 3196, a batch of cylinders produced in a manufacturing location should be with same raw material and same production methods including same heat treatment process parameters. There are two possible scenarios in a manufacturing location for any batch produced in a plant. They are; cylinders produced by following all necessary guidelines and cylinders produced without or partially followed guidelines or standards. The second one could be intentional to reduce production cost or inadvertent action due to power failures, machine breakdowns, unavailability of skilled manpower for prolonged batch production etc. In both scenarios, if the cylinder batch passes the test, they are sent to market for usage at customer home. However, if the sample cylinder from the batch fails, Indian standard allows to test another random sample cylinder testing for verification by discarding the first sample results. If this second sample passes the test the batch can be sent for market. If not, entire batch needs to be heat-treated and conduct the testes once again on the batch. Current standard allows this repetition till the batch passes the acceptance test results. If the
cylinder sampling is biased for acceptance testing non complied cylinders can enter into market, which cannot be traced afterwards in market due to vast area for circulation.

Although oil companies are having some system to act on new cylinder failures in market, there is no clear procedure or a system for old cylinders which are already in circulation. In case of new cylinders, the procedure is limited to impose suspension on cylinder manufacturer (which can be revoked later) and in case of old cylinders, the cylinder is just scrapped, if they are not under warranty (as per tender clauses / one year). However, there is no procedure for retrieving non complied cylinders of same manufacturer and same batch from market in both these cases. (Certification sample testing is only 1 in 203 cylinders)

Suppose, a cylinder fails during its first filling or initial entry in market, state owned oil company tender specifications allows to propose suspension of cylinder manufacturer from producing cylinder further. Upon suspension the manufacturer needs to produce a fresh trail batch of cylinders after correcting their manufacturing process parameters. This trial batch should meet all standard requirements. Once the trail batch is approved, the suspension is revoked on a particular manufacturer and the manufacturer can resume production. In addition to this suspension clause, government oil companies clearly outlined various kinds of restricted practices in cylinder manufacturing business and their disciplinary actions on such restricted practices in their tender documents. It means oil companies are aware of some restricted practices in the business but unable to act, as there is no comprehensive solution for addressing these issues. Further, it is evident from the past cases in competition commission of India that the cylinder manufacturing business is not so clean and there are certain grey areas in the business to survive peer competition in cylinder manufacturing business.
Although majority of the cylinder manufacturers are assumed to follow all the statutory guidelines and national standards, some manufacturers may tend to deviate these requirements and manages to pass their non-standard cylinders into market.

Suppose a batch of non-complied cylinders slips into market, it is absolutely not possible to trace these cylinders in the vast cylinder market in India. It means, although BIS mark is on LPG Cylinder, there is a chance that it need not comply existing Indian standard. Surprisingly it is a fact. The scope of the research is not to point the grey areas in LPG Cylinder business but to provide a solution to this issue which is acceptable to all stakeholders of LPG Cylinder business in a balanced way and to reduce the risk associated with LPG in customer kitchen.

To address this, current research is focussed on study existing standards, systems and procedures to focus on developing empirical relation among various physical parameters of LPG cylinder material and suggest fail-safe inspection plan for manufacturing.

Liquefied Petroleum Gas (LPG) cylinders in India are produced as per Indian standard IS 3196 part1: 2006, *Welded low carbon steel cylinders exceeding 5 liter water capacities for low pressure liquefiable gases – Specification*. These cylinders are produced undergo stringent procedures and critically scrutinized at every stage in their life cycle from manufacturing to withdrawal of cylinders from service. Indian standard IS 3196 part 3 states the guidelines for testing of new cylinders for Bureau of Indian Standards (BIS) certification. Every cylinder is having a permanent BIS logo on it and it certifies that the cylinder underwent stringent norms and tested as per the code of practice. In India, state-owned oil companies market different type of cylinders, intended for variety of business segments like domestic, commercial and industrial. Technically, all these cylinders are identified with
volume of cylinder in water capacity. For example the domestic LPG cylinder marketed by state owned oil companies is 33.3 liters water capacity and are fabricated in two piece constructions. All the government oil companies market same kind of cylinder for domestic segment. Current research is carried out on this domestic cylinder.

Once a batch of cylinders is produced, manufacturer should test few sample cylinders from each lot for certification purpose. Those tests 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. As per the requirement, test tensile samples are cut from cylinder and tested for measuring yield strength, tensile strength, percentage elongation, weld tensile strength. One cylinder should undergo this test for every batch of 202 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. Among these tests, acceptance and hydro-tests are the critical tests for BIS certification process and are conducted on sample cylinders as per Indian standard IS 3196 part 3. Once the batch is accepted by bureau of Indian standards, certified cylinders are released to market for use.

From the national standards and literature survey, the identified physical parameters for study are derived from acceptance and hydro-test viz. Longitudinal Tensile Strength (LTS),
Longitudinal Yield strength (LYS), Longitudinal Percentage Elongation (LPE), Circumferential Tensile Strength (CTS), Circumferential Yield strength (CYS), Circumferential Percentage Elongation (CPE), Burst pressure (BP), Volumetric expansion (VE) and Nominal Hoop stresses (NHS).

Based on the scope, the objectives of the current research are divided into three broad categories and are

1. Establish LPG Cylinder life cycle and to study various phases in LPG Cylinder life cycle
2. Identify critical variables that influence cylinder material requirements and develop relations among these critical variables with primary test data. Establish dependent variables and independent variables among the critical variables. Conduct additional experiments (Hardness tests) on cylinders and develop empirical relations for estimating all critical variables from hardness values.

Extensive literature review carried out under broad categories of LPG Cylinder design, manufacturing, testing, material properties, national, international standards, statutory guidelines, incidents etc. From the literature, it is evident that LPG cylinders are manufactured from low carbon steel. Yield strength and tensile strength are the critical material properties and for a low carbon steel. These two parameters can be estimated from material hardness. Material hardness can be measured or estimated either with conventional hardness test or advanced non-destructive test methods using a portable hardness tester.
Literature also states that material hardness, yield strength and tensile strength of low carbon steel are having a linear relation. Keeping in view of the hardness and the relation of tensile and yield strength with hardness, cylinder test data was analysed with correlation study, trend analysis and regression analysis, based on 11 critical parameters 37 relations were developed and these relations are grouped in to four different categories. Each group can potentially estimate all critical parameters of LPG cylinder material. Estimates are studies with actual and identified best possible group for estimating the result of acceptance and hydro test results. From the analysis, it is identified; test results on circumferential direction are less than longitudinal direction except percentage elongation. Lower values are always critical as the standard specifies only minimum requirements for material specifications. Thus if the empirical formulas are developed in terms of circumferential tensile strength cylinder critical properties can be estimated. Now the circumferential tensile value can be obtained by conducting surface hardness test. Surface hardness is not required to measure in existing practice and hence experiments were conducted on LPG cylinder to get surface and actual material hardness. Relations were developed among these parameters. From literature, it is also evident that if the surface hardness is known tensile and yield strength can be estimated. Thus with the help of surface hardness, circumferential tensile strength can be estimated and from circumferential tensile strength all other critical parameters related to acceptance and hydro test details can be calculated.

In order to estimate these properties quickly and easily Microsoft Excel based software was developed. The software is developed in such a way that the values can be estimated with all four methods instantaneously using the surface hardness values obtained from portable hardness tester in BHN. The dashboard provides all critical parameters instantaneously and with a single click after the surface hardness value is fed to the software.
The research concludes with proposed Fail proof inspection plan for manufacturing using the combination of spot hardness test and set of empirical formulas. This plan not only intended for manufacturers but can also be extended beyond manufacturing premises. The methodology was discussed with 4 different plans to estimate critical parameters of cylinder material i.e using any one of the critical parameters circumferential tensile strength, circumferential Yield strength, longitudinal tensile strength and longitudinal yield strength as independent variable to determine other critical parameters..

The literary contributions from current research are:

1. The state of art LPG Cylinder life cycle was documented. Various factors affecting cylinder life cycle were described in details with appropriate justifications.

2. Acceptance testing and hydro testing processes of LPG Cylinder at manufacturing premises were described in detail and highlighted possible areas, where the national standard can be interpreted wrongly against the interests of consumer.

3. Various factors that can affect LPG Cylinder testing process are outlined with necessary reasoning and appropriate clauses of Indian Standard.

4. Carried out an in-depth study on LPG Cylinder parent metal tensile test and proposed a method for preparing tensile specimen from LPG Cylinder.

5. The process dealing with non-compliant cylinder in market was pronounced with all supporting documents, which is the basis for this work.

6. Detailed study was carried out on LPG Cylinder longitudinal and circumferential tensile samples and proved that the circumferential samples exhibits lower yield and tensile values than longitudinal samples all the time. Hence, there exists a chance to discard longitudinal sample testing in existing acceptance testing practices.
7. Carried out a study on LPG Cylinder material hardness by measuring the hardness with two different methods. It was proved that the surface hardness of cylinder is higher than the actual material hardness. The reasons for this phenomenon was outlines in the current research.

8. Correlation analysis was carried out for 55 combinations of 11 parameters of LPG Cylinders material properties. Trends between 55 combinations were established the reasons for correlation values that are deviating from the expected values were outlined with justifications.

9. 37 Empirical formulas were developed with 4 different plans to estimate all 9 critical parameters. Compared the actual and estimated values and suggested the best formulas for estimating critical parameters.

10. Reasons for compression in interquartile range boxes in box plots of actual and estimated values are described with appropriate justifications. As a result of this the empirical values can be used for indicative purpose only and not for replacing the existing test practices.

11. Microsoft excel based software was developed to estimate critical parameters quickly with four different plans to estimate critical values quickly. This can be used as a basis for modifying existing portable testers to get the critical parameters directly at the time of testing hardness.

12. Suggested a fail-safe inspection plan for cylinder manufacturers for estimating cylinder critical parameters quickly and effectively. With this methods cylinder manufacturers can ensure all cylinders produced in their plant are complying the requirements of Indian Standard.
Further it is recommended to discard longitudinal sample testing in existing acceptance testing of LPG Cylinder parent metal tensile test to save 50% of testing cycle time. Also, it is recommended to implement fail-safe inspection plan in manufacturing locations to inspect all cylinders using the combination of hardness test and empirical formulas, besides existing destructive test methods. This will avoid entry of non-complied cylinders into market.

While studying LPG Cylinder Life cycle, an opportunity is available to study the factors affecting the cylinder life cycle and a separate study was carried out on this area. 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 ill-treated in market place i.e. from dispatch of filled cylinder to receipt of empty cylinder in bottling plant. This ill-treatment is mainly in the form of body rolling, dropping cylinders from heights on hard surface, usage of wrong adaptor for extracting gas from cylinders, using hot water baths for generating more vapours from cylinders, illegal transfers of liquid from one cylinder to another cylinder, wet and humid kitchen condition, usage of cylinder close to hotplate etc. This kind of abuse to cylinder affects cylinder life cycle and adoption of such practices on continues basis reduces the life of cylinders.

Similarly, while establishing the critical and influencing parameters for acceptance test, the results of longitudinal and circumferential tensile test specimens were analysed. This led the study towards various sample preparation methods in the existing practice and studies the sample preparation process in detailed. Several factors in sample preparation can affect the test results. An optimal method was suggested in this study for sample preparation for accurate results.
Following advantages are expected from implementation of research recommendations.

- Implementation of fail-safe inspection plan can ensure elimination of non-complied cylinders in to market (to consumer)
- If acceptance test sample failed twice in cylinder manufacturer location, they can segregate the cylinders and only non-complied cylinders can be sent for heat treatment process instead of the entire lot. This saves fuel cost to the cylinder manufacturer and also the implementation of fail-safe method can protect manufacturers from unwarranted suspensions from enforcement bodies and oil companies. The cylinder manufacturers can prove their point with valid and scientific data.
- Statutory authorities need no depend on cylinder manufacturers for compliance testing. A simple hardness tester is sufficient to check the cylinder parameters at any point of time in its life cycle.
- Oil companies being the owners of cylinders, they can assure safe cylinders to their customers and can verify the properties at any point of time
- Investigation agencies can verify the accident and incident analysis without destroying the sample.

Thus the research concludes with a solution to address the gaps in existing national standards with an aim to improve the regulatory compliance and to enhance public safety.

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