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Importance of Hydro Testing in CNG Cylinders

Prof. Urmila S. Nagargoje [1], Yogesh Subhash Wabale[2],
Dipak Valmik Chavan[3], Waghmode Sakshi Biraji[4], Ukande Sarthak Appasaheb[5]

[1] Assistant Professor, Mechanical Engineering Department, Adsul's Technical Campus, Chas, Ahilyanagar
[2] student of Mechanical Engineering Department, Adsul's Technical Campus, Chas, Ahilyanagar
[3] student of Mechanical Engineering Department, Adsul's Technical Campus, Chas, Ahilyanagar
[4] student of Mechanical Engineering Department, Adsul's Technical Campus, Chas, Ahilyanagar
[5] student of Mechanical Engineering Department, Adsul's Technical Campus, Chas, Ahilyanagar

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Abstract – Compressed Natural Gas (CNG) is widely used as an alternative fuel in automobiles due to its economic benefits, lower emissions and environmental advantages. However, CNG is stored in cylinders under very high pressure, making cylinder safety and structural reliability essential. Hydro testing is an important non-destructive pressure testing method used to evaluate the strength, integrity and safety of CNG cylinders. It involves filling the cylinder with water and applying a specified test pressure to examine its ability to withstand pressure without leakage, excessive expansion or permanent deformation. The present research paper focuses on the importance of hydro testing in CNG cylinders for ensuring operational safety, preventing potential accidents and increasing cylinder reliability. It discusses the hydrostatic test procedure, working principles, testing parameters, permanent volumetric expansion, leakage detection and rejection criteria. The study also highlights the role of periodic inspection and hydrotesting in identifying defects such as corrosion, cracks, material deterioration and structural weaknesses that may develop during long-term service.

Furthermore, the research emphasizes the importance of following relevant safety standards and regulatory guidelines during cylinder testing. Proper hydro testing helps reduce the risk of cylinder failure, protects human life and property, and ensures the reliable performance of CNG storage systems. The study concludes that regular inspection and hydro testing are essential practices for maintaining the safety, durability and reliability of CNG cylinders in automotive and industrial applications.

Keywords: *CNG Cylinder, Hydro testing, Hydrostatic Pressure Test, Cylinder Safety, Volumetric Expansion, Leakage Detection, Pressure Vessel, Non-Destructive Testing*.

1. INTRODUCTION

Compressed Natural Gas (CNG) has become one of the most widely used alternative fuels in the automobile industry due to its lower emissions, cost-effectiveness and environmental benefits compared with conventional fuels such as petrol and diesel. CNG is mainly composed of methane and is stored in specially designed high-pressure cylinders, generally at pressures of approximately 200–250 bar, depending on the vehicle and applicable standards. These cylinders are installed in vehicles and are designed to withstand high internal pressure during normal operating conditions. Therefore, maintaining the structural integrity and safety of CNG cylinders is extremely important CNG cylinders are subjected to continuous pressure variations, temperature changes, vibration and environmental conditions during their service life. These operating conditions may lead to material fatigue, corrosion, cracks, deformation and other structural defects. If such defects are not identified at the appropriate time, they may increase the possibility of gas leakage or cylinder failure, resulting in serious accidents, injuries and property damage. Therefore, regular inspection and testing of CNG cylinders are essential to ensure safe operation.

Hydro testing, also known as hydrostatic testing, is an important method used to evaluate the strength and pressure-retaining capability of CNG cylinders. In this process, the cylinder is filled with water and subjected to a specified test pressure higher than its normal working pressure, according to the applicable testing standard. The test helps identify leakage, excessive expansion and permanent deformation. It also provides information about the structural condition of the cylinder and its ability to withstand the required pressure. One of the important parameters evaluated during hydro testing is permanent volumetric expansion. During the test, the cylinder undergoes temporary expansion due to applied pressure. After releasing the pressure, the cylinder should return close to its original dimensions. Excessive permanent expansion indicates possible deterioration of the cylinder material or structural weakness. Such cylinders must be evaluated according to the applicable rejection criteria. Hydro testing plays a significant role in maintaining the reliability and safety of CNG storage systems. It helps identify potentially unsafe cylinders before they are returned to service. Periodic inspection and hydro testing, in accordance with relevant standards and regulatory requirements, contribute to reducing the risk of accidents and extending the safe serviceability of cylinders.

The present research focuses on studying the importance of hydro testing in CNG cylinders, understanding the hydrostatic testing procedure, identifying possible cylinder defects and evaluating the role of testing in ensuring safety, reliability and performance. It also highlights the importance of proper inspection procedures, testing equipment, safety precautions and compliance with applicable standards in the CNG industry.

1.1 Importance of the Study

1. To understand the safety requirements of high-pressure CNG cylinders.
2. To study the hydro testing procedure and its significance.
3. To identify defects such as corrosion, cracks, leakage and permanent deformation.

4. To understand the importance of permanent volumetric expansion measurement.
5. To promote periodic inspection and safe utilization of CNG cylinders.

1.2 Scope of the Study

This research is focused on hydrostatic testing of CNG cylinders used in automotive applications. It covers the testing principle, procedure, inspection parameters, safety precautions, cylinder acceptance and rejection criteria, and the importance of following applicable national and international standards.

2. PROBLEM STATEMENT

The increasing use of Compressed Natural Gas (CNG) as an alternative fuel in the automobile industry has increased the demand for high-pressure CNG storage cylinders. These cylinders operate under high internal pressure and are continuously exposed to temperature variations, vibration, environmental conditions and repeated pressure cycles. Over time, these operating conditions may cause corrosion, material fatigue, cracks, leakage and permanent deformation, which can affect cylinder strength and safety.

One of the major challenges associated with CNG cylinder safety is identifying internal and external defects before they lead to serious failures. Improper inspection, lack of periodic testing and inadequate maintenance may increase the risk of gas leakage, cylinder rupture and accidents. Therefore, an effective testing method is required to evaluate the structural integrity and pressure-retaining capacity of CNG cylinders.Hydro testing is an important method for assessing the strength and safety of CNG cylinders. However, improper testing procedures, inaccurate measurement of volumetric expansion, inadequate inspection facilities and a lack of awareness regarding testing standards can affect the reliability of test results.

Therefore, the main problem addressed in this research is to study how hydro testing can be effectively used to identify defects, evaluate the structural condition and ensure the safe operation of CNG cylinders. The research also focuses on understanding the importance of periodic hydro testing, permanent volumetric expansion measurement and compliance with applicable safety standards to minimize the possibility of cylinder failure and improve operational reliability.

2.1 Key Problems Identified

1. Risk of cylinder failure due to high internal pressure.
2. Development of corrosion, cracks and material fatigue during service.
3. Difficulty in identifying hidden defects through visual inspection alone.
4. Possibility of inaccurate results due to improper hydro testing procedures.
5. Lack of awareness regarding periodic inspection and testing requirements.
6. Need for reliable acceptance and rejection criteria for unsafe cylinders.

2.2 Research Question

How does hydro testing help identify structural defects and evaluate the safety, strength and reliability of CNG cylinders during their service life?

3. OBJECTIVES

The main objective of this research is to study the importance of hydro testing in CNG cylinders and evaluate its role in ensuring safety, structural strength and operational reliability.

3.1 Main Objectives

1. To study the basic construction, working principle and applications of CNG cylinders.
2. To understand the principle and procedure of hydrostatic testing of CNG cylinders.
3. To evaluate the importance of hydro testing in maintaining cylinder safety and reliability.
4. To identify possible defects such as corrosion, cracks, leakage and permanent deformation.
5. To study the measurement of total and permanent volumetric expansion during hydro testing.
6. To understand the acceptance and rejection criteria of CNG cylinders as per applicable standards.
7. To investigate the effect of high pressure and repeated pressure cycles on cylinder strength.
8. To study the importance of periodic inspection and hydro testing in preventing cylinder failure.
9. To examine the role of proper testing equipment and safety precautions in obtaining reliable test results.
10. To suggest suitable inspection and maintenance practices for improving the service life and safety of CNG cylinders.

3.2 Expected Outcomes

1. Improved understanding of CNG cylinder safety requirements.
2. Identification of defective and unsafe cylinders.
3. Better understanding of hydrostatic pressure testing procedures.
4. Reduction in the possibility of accidents caused by cylinder failure.
5. Improved reliability and safe operation of CNG storage systems.

4. METHODOLOGY

The research methodology adopted for the study entitled "Importance of Hydro testing in CNG Cylinders: A Study on Safety, Reliability and Performance Evaluation" focuses on understanding the hydrostatic testing process, evaluating cylinder strength and identifying possible defects that may affect the safety and reliability of CNG cylinders.

The study is based on the collection of technical information, analysis of hydro testing procedures, examination of testing parameters and review of applicable safety standards. The methodology is divided into the following stages.

4.1 Research Methodology Steps

1. Literature Review

Information is collected from research papers, technical journals, textbooks, manufacturer manuals and relevant national and international standards related to CNG cylinders and hydrostatic testing.

2. Study of CNG Cylinder Construction

The construction and working principles of CNG cylinders are studied, including:

- Cylinder body and material.
- Cylinder neck and valve arrangement.
- Internal pressure capacity.
- Cylinder types and applications.
- Operating conditions and safety requirements.

3. Study of Hydro Testing Equipment

The equipment used for hydrostatic testing is studied, including:

- Hydrostatic testing pump.
- Water storage tank.
- Pressure gauge.
- Expansion measurement system.
- Connecting pipes and fittings.
- Safety arrangements.

4. Hydrostatic Testing Procedure

The general hydro testing procedure is studied in the following sequence:

1. Inspect the cylinder externally for visible damage and corrosion.
2. Verify the cylinder identification and testing history.
3. Remove the cylinder valve according to the approved procedure.
4. Fill the cylinder completely with water to eliminate trapped air.
5. Connect the cylinder to the hydrostatic testing equipment.
6. Increase the pressure gradually to the specified test pressure.
7. Measure the total volumetric expansion during pressurization.
8. Release the pressure and measure the permanent volumetric expansion.
9. Inspect the cylinder for leakage, abnormal deformation and other defects.
10. Compare the test results with applicable acceptance and rejection criteria.

5. Measurement of Volumetric Expansion

During hydro testing, the following parameters are considered:

- Initial cylinder volume.
- Total volumetric expansion.
- Permanent volumetric expansion.
- Test pressure.
- Permanent expansion percentage.

6. Analysis of Test Results

The recorded testing parameters are analyzed to understand the structural condition of the cylinder. The results are compared with the applicable testing standards to determine whether the cylinder satisfies the specified acceptance criteria.

7. Identification of Defects

The study considers possible defects such as:

- External and internal corrosion.
- Cracks and surface damage.
- Leakage.
- Excessive permanent expansion.
- Material deterioration.
- Abnormal deformation.

8. Conclusion and Recommendations

Based on the technical study and analysis, suitable recommendations are developed to improve CNG cylinder inspection, hydro testing practices, maintenance and operational safety.

4.2 Research Approach

The research follows a descriptive and analytical approach. It explains the hydro testing process and evaluates its importance using technical parameters, standard testing procedures and published information.

4.3 Safety Considerations

Hydro testing must be performed only by trained and authorized personnel using approved equipment and procedures. The specified test pressure, testing interval and rejection limits must follow the applicable cylinder standard and regulatory requirements. This research does not recommend testing damaged or pressurized cylinders without appropriate safety controls.

5. PRINCIPLE OF HYDROSTATIC TESTING

The basic principle is to fill the cylinder and the connected test circuit with water, remove trapped air, and increase hydraulic pressure in a controlled manner to the specified test pressure. The cylinder expands elastically while

pressure is applied. When pressure is released, a sound cylinder should recover substantially towards its original dimensions. A residual increase in volume is called permanent expansion.

For a volumetric expansion test, the total expansion is the volume change measured at test pressure. Permanent expansion is the residual volume change after the pressure has been released. The permanent expansion ratio is commonly expressed as:

Permanent expansion ratio (%)

= (Permanent expansion / Total expansion) × 100

The permitted ratio is defined by the applicable cylinder specification and test code. Under the Indian Gas Cylinders Rules, 2016, Schedule IV provisions for cylinders subject to hydrostatic stretch testing state that the permanent stretch must not exceed 10% of the total stretch; the prescribed test pressure is retained for at least 30 seconds. A pressure reduction during the hold period, leakage, visible bulging or deformation is treated as failure. The precise applicability of these provisions must be checked against the cylinder type and current approved code.

6.METHODS OF HYDROSTATIC / VOLUMETRIC EXPANSION TESTING

6.1 Water-jacket method

In the water-jacket method, the water-filled cylinder is placed inside a sealed jacket that is also filled with water. The jacket is connected to a measuring arrangement such as a calibrated burette or an approved electronic/gravimetric measuring system. When the cylinder is pressurised internally, it expands and displaces water from the jacket into the measuring device. The reading at test pressure represents total expansion. After pressure is released, the remaining displaced-water reading represents permanent expansion.

The water-jacket method is widely used because it directly measures the external volumetric change of the cylinder. Air trapped in the jacket, temperature differences, leakage, poor calibration or incorrect reading technique can affect the result. The test arrangement must be designed to contain or safely manage the energy if a cylinder fails.

6.2 Non-water-jacket method

In the non-water-jacket method, the amount of water entering the cylinder during pressurisation and the amount returned after pressure release are measured. The calculation must account for water compressibility and the relevant volume effects. The method requires careful control of trapped air, leakage, temperature and equipment calibration. It should only be used where permitted by the applicable standard and with equipment capable of achieving the required accuracy.

6.3 Selection of method

The test method is not selected merely for convenience. It must be consistent with the cylinder material, construction, applicable standard, approved testing procedure and equipment capability. The water-jacket method is identified as the preferred method in several volumetric expansion test descriptions, but the governing standard for the particular cylinder remains decisive.

7. GENERAL TESTING PROCEDURE

1. Verify cylinder identity: manufacturer, serial or rotation number, specification, service gas, water capacity, working pressure, test pressure and previous test history.
2. Confirm that the cylinder is safely emptied, isolated and made gas-free in accordance with the approved procedure. Only trained and authorized personnel should handle or prepare cylinders.
3. Remove the valve and clean the cylinder using methods permitted by the applicable code. Avoid any cleaning or heating method that could damage the cylinder.
4. Carry out external and, where practicable, internal visual examination for corrosion, cracks, dents, gouges, bulges, fire damage, thread damage and other defects.
5. Set up the approved hydrostatic equipment. Check the pressure gauge, measuring device, connections, safety enclosure and calibration status.
6. Fill the cylinder and test circuit with suitable water and remove trapped air. Air pockets can distort readings and increase stored energy.
7. Raise pressure gradually to the specified test pressure. Do not exceed the pressure authorized for that cylinder.
8. Maintain the required pressure for the period specified by the applicable procedure. Observe the pressure and the cylinder/test system for leakage or abnormal behavior.
9. For a volumetric expansion test, record total expansion at test pressure and permanent expansion after pressure release; calculate the ratio using the prescribed method.
10. Depressurise in a controlled manner, drain the water and dry the cylinder internally using an approved process to prevent internal corrosion.
11. Evaluate the results against all applicable acceptance/rejection criteria. Mark, certify and update the cylinder history record as required.

12. A cylinder that fails must be quarantined and dealt with under the applicable condemnation or disposal procedure. It must not be returned to service.

8. IMPORTANCE AND BENEFITS OF HYDROTESTING

8.1 Detection of permanent deformation

Volumetric expansion measurement helps identify cylinders that do not recover adequately after the proof pressure is removed. Excessive permanent expansion can indicate that the cylinder has undergone unacceptable plastic deformation or has lost the required structural performance.

8.2 Identification of leakage and pressure loss

A pressure decrease during the prescribed hold period, leakage, visible bulging or deformation are important failure indications. Detecting these conditions before refilling helps prevent an unsafe cylinder from returning to service.

8.3 Support for fatigue and lifecycle management

CNG cylinders undergo repeated pressure cycles. Periodic examination and testing provide a controlled checkpoint in the cylinder lifecycle. Test history can help owners and operators track service age, previous results and recurring damage.

8.4 Reduction of risk to people and property

A cylinder that is inspected and tested in accordance with the applicable requirements is less likely to remain in service with an identified unacceptable defect. Hydrotesting therefore contributes to the protection of drivers, passengers, service technicians, filling-station personnel and the public.

8.5 Regulatory compliance and traceability

Indian rules require cylinders whose prescribed periodic retest is due to be retested before they are charged and transported. Proper records—including cylinder identity, specification, test pressure, working pressure, water capacity, tare weight, condition and test details—support traceability and accountability.

8.6 Confidence in CNG vehicle operation

A documented testing programme, combined with correct installation and routine inspection, improves confidence in the safe use of CNG as an automotive fuel. It also supports responsible fleet maintenance and reduces the likelihood of avoidable service interruptions

9.COMMON CAUSES OF CYLINDER DETERIORATION

- External corrosion caused by moisture, road salts, chemical exposure or damaged protective coatings.
- Internal corrosion or contamination associated with moisture or unsuitable handling.
- Repeated pressure cycling and fatigue damage over the service life.
- Mechanical impact, dents, gouges, abrasion or damage caused during installation and maintenance.
- Exposure to fire or excessive heat, which may alter material properties.
- Improper mounting, contact with vehicle components, vibration or inadequate protection.
- Unauthorised repair, modification, heating, machining or use outside the cylinder's approved service conditions.

10. LIMITATIONS AND PRECAUTIONS

Hydrostatic testing is not a complete guarantee against every possible failure. A cylinder may contain a defect that is not detected by the particular test, and a test result is valid only when the method, equipment, calibration and acceptance criteria are appropriate. Hydrotesting must be combined with the required visual examination and any additional tests specified for the cylinder type.

Testing must never be attempted using improvised equipment or by untrained persons. The cylinder must not be subjected to an arbitrary pressure. The pressure value, hold time, retest interval, preparation, drying and rejection criteria must be taken from the applicable standard and approval. Special care is required for composite cylinders because damage assessment and periodic testing requirements may differ from those for all-metal cylinders.

The test station should prevent over-pressurisation, use pressure-rated components, maintain calibrated instruments, remove trapped air, control access to the test area and provide suitable guarding or a safety enclosure. Records should be legible, complete and retained for the period required by law.

11. CONCLUSION

Hydrotesting is an essential component of the periodic examination of applicable CNG cylinders because it provides a controlled way to assess pressure-retaining behaviour and, where required, measure total and permanent expansion. It can reveal unacceptable permanent deformation, leakage, pressure loss and visible abnormality before a cylinder is returned to service. Its contribution to safety depends on correct cylinder identification, visual examination, approved equipment, calibrated instruments, careful removal of trapped air, use of the prescribed test pressure and hold time, accurate evaluation and complete documentation.

Hydrotesting should not be treated as an isolated activity or as a replacement for other inspection requirements. The safest approach is a lifecycle-based programme in which cylinders are used, inspected, retested, marked and withdrawn strictly in accordance with their design approval, applicable Indian Standards and current PESO requirements. Only approved testing facilities and trained personnel should perform the work.

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