

ADVANCEMENTS AND CHALLENGES IN THE INTEGRATION OF COMPRESSED NATURAL GAS (CNG) AS AN ALTERNATIVE FUEL

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ABSTRACT

Natural gas, which is mostly made up of methane, is an environmentally beneficial energy source that has gained popularity as a potential solution to the present environmental pollution issue. However, its low density and transportation problems have prevented its widespread use. This analysis looks at the qualities and advantages of compressed natural gas (CNG) and liquefied natural gas (LNG) in compared to conventional fuels. It also delves into the design and construction of pressure vessels used to store CNG, including the use of composite materials to increase safety and performance. Furthermore, the research examines contemporary literature on improving the performance of CNG cylinders using sophisticated production processes and regulatory standards. The findings illustrate CNG's potential as an acceptable substitute for fuel, provided that issues with material selection, manufacturing methods, and long-term reliability are addressed.

Keywords: Compressed Natural Gas (CNG), Composite Material, Durability Compressed Natural Gas Etc.

1. INTRODUCTION

Natural gas is an ecologically beneficial energy source since it is widely available and operates safely. This is an effective answer to the present environmental pollution problem. However, its low density and transportation issues have hampered its wider adoption. The worst thing is that natural gas has less calorific value than gasoline or fuel. For this reason, compressed natural gas (CNG) was utilized at a pressure of roughly 20 MPa at room temperature, whereas liquefied natural gas (LNG) was used at an exceptionally low temperature of around -162°C at normal pressure. Chemically, natural gas is normally composed of more than 90% methane gas, a blend of ethane, propane, butane, and CO₂. A high methane percentage results in a higher-octane rating, cleaner burning characteristics, and improved engine performance.

Natural gas is an environmentally favourable energy source since it is readily available and safe to use. This is a feasible answer to the present environmental pollution problem. However, its low density and transportation issues have prevented widespread usage. The worst thing is that natural gas is less calorific than gasoline or fuel. For this reason, compressed natural gas (CNG) was utilized at a pressure of around 20 MPa at room temperature, whereas liquefied natural gas (LNG) was used at a temperature of roughly -162°C at normal pressure. Natural gas is normally composed of more than 90% methane, a mixture of ethane, propane, butane, and carbon dioxide. A high methane concentration yields a high-octane rating, clean burning characteristics, and improved engine efficiency.

The pressure vessel's construction is mostly constructed of metal-lined composite materials, which are completely wrapped and ring-wrapped. In a fully wrapped composite cylinder, the cylinder is made of composite material, which is entirely wrapped around the dome. When putting together a tire, just wrap the material in a layer of tire. Figures 1 and 2 depict a completely wrapped and wrapped cylinder, respectively.

This figure also displays the distinction between spiral ply and tire ply. Because vessel design is responsible for safe operation, government organizations have established building requirements for mass manufacture of pressure vessels. Different construction businesses across the world use different design standards based on the commission's safety rules.

The government regulates the technical and safety criteria for mass-produced composite cylinders. The regularity committee for CNG cylinders is listed below:

- DoT (United States Department of Transportation)
- NGV2 (Natural Gas Vehicle Standard, USA)
- TUV (Germany) and • HSE (UK)
- ISO has recently published a standard for CNG cylinders (ISO 11439, first edition: 2000).

The many types of gas cylinders are described below.

Figures 1(a) and (b) illustrate a fully enclosed CNG pressure vessel and an enclosed gas cylinder.

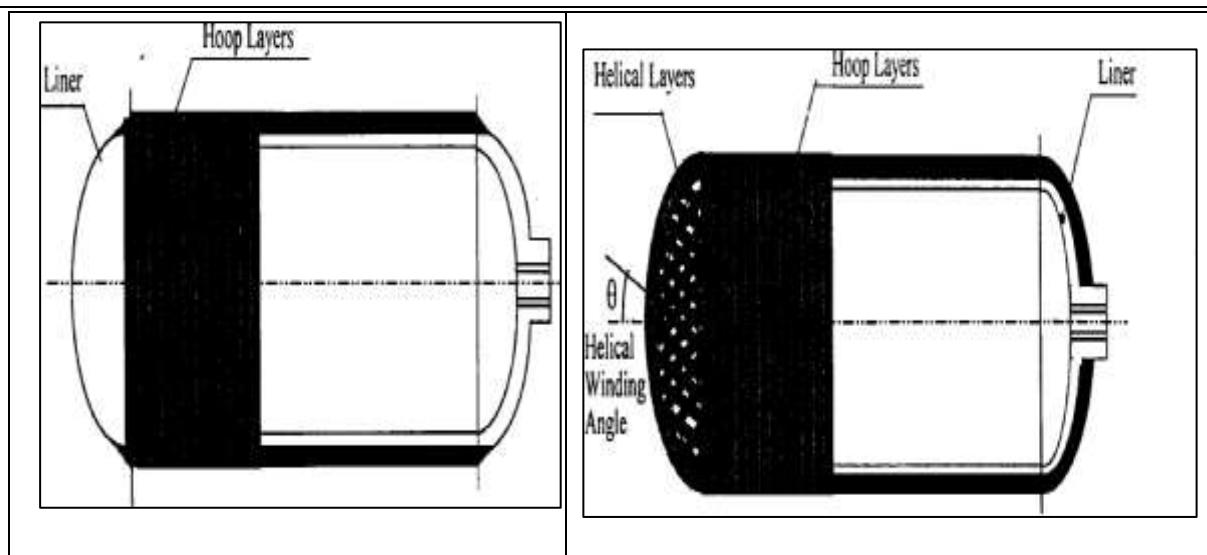


Figure 1a: Fully Wrapped Cylinder

Figure 2b: Hoop Wrapped Cylinder

Material of Construction:

CNG cylinders are made from glass, aluminide (Kevlar), and carbon fibre, with glass fibres being the most cost-effective option due to their strength and fatigue properties. Other materials like aluminium alloys, steel alloys, and titanium alloys are used for their strength and toughness. Pressure vessels are constructed using welding and NDT testing techniques, with the main requirement being safety and reliability at a low cost. Pressure vessels are designed to operate under high pressure and in various environments, and predicting and optimizing burst pressure is crucial for improving their functionality. Finite element methods and continuum damage mechanics studies are used to investigate burst pressure under various operating conditions.

2. LITERATURE REVIEW

- 1) **Kashyzadeh K, Kolor s, Bidgoli M et al. (2021)** This research focuses on designing a high-fatigue performance hoop wrapped compressed natural gas (CNG) composite cylinder using an optimization algorithm combining finite element simulation (FES) and response surface analysis (RSA). The geometrical model was prepared, and transient dynamic analysis was performed to investigate the interaction effects of polymer composite shell manufacturing process parameters on the fatigue life of the polymer composite CNG pressure tank. The proposed new design improved the fatigue life by 2.4 times compared to the initial design.
- 2) **Xiong S, Huang S, Li B et al (2020)** The Leak-before-break (LBB) test is an important test for ensuring safety performance verification of CNG-II bottles. A CNG-II gas cylinder ruptured during the LBB test, causing crack growth and failure due to oxide slag inclusions, which are used as fatigue sources during the fatigue test.
- 3) **Tschirschitz R, Krentel D, Kluge M et al. (2019)** Compressed natural gas (CNG) is a widely used automotive fuel, but its failure can pose severe hazards to the environment. A comprehensive analysis of 21 CNG automotive cylinders with no safety device revealed that Type IV CNG cylinders showed less critical failure behavior than Type III cylinders under fire impingement. The study included burst tests on Type III and Type IV cylinders, as well as fire tests with 8 Type III and 3 Type IV cylinders. The results highlight the importance of proper safety measures in ensuring the safety of CNG automotive fuel.
- 4) **Rafiee R, Torabi M et al. (2018)** This research aims to predict burst pressure in composite pressure vessels subjected to internal pressure, considering manufacturing uncertainties. First-ply-failure (FPF) is studied to compare performance of different failure criteria. Burst pressure is deterministically predicted using progressive damage modelling, validated using experimental data. Stochastic modelling is conducted to estimate burst pressure, considering fibre volume fraction, winding angle, and mechanical properties as random parameters.
- 5) **Tschirschitz R, Krentel D, Kluge M et al. (2018)** Tank failure in LPG vehicle tanks can pose severe hazards in case of a vehicle fire. A study conducted 16 tests on toroidal shaped LPG vehicle tanks, with three tanks equipped with safety devices and ten without. All ten tanks failed within a time of $t < 5$ minutes in a BLEVE explosion, with seven resulting in catastrophic failure and three in partial failure followed by catastrophic failure. Fragment throwing distances of $1 > 250$ m occurred.
- 6) **Jeevan Kumar B, Madhavi M et al. (2017)** Pressure vessels, used in a large variety of fields, are subjected to unusual conditions in industrial processing equipment. These vessels, typically made from isotropic materials like steel and aluminium, are now being designed using composites. A 70-liter capacity CNG gas cylinder, designed for

burst pressure of 730 bar, is tested under given loading and boundary conditions, proving safe under these conditions.

- 7) **Stefana E, Marciano F, Alberti M et al. (2016)** FTA, FMEA, and bow-tie analysis were utilized to evaluate the risk of a Dual Fuel system in heavy-duty diesel trucks. The analysis identified causes, critical events, and potential accident scenarios. The bow-tie analysis also identified safety measures throughout the system's life cycle. The Dual Fuel system's risk level was similar to traditional diesel systems.
- 8) **Stojanovic B, Ivanovic L et al. (2015)** Composite materials, such as aluminum alloys, are increasingly used in mechanical constructions due to reduced weights and increased exploitation periods. These lightweight metal matrices are used in engine cylinders, pistons, disc brakes, Cardan shafts, and other automotive and aviation elements, offering improved mechanical properties and reduced prices.

3. OBJECTIVES

CNG cylinders are critical for worker safety, and their performance may be greatly enhanced by using cutting-edge materials. These materials can improve durability, fatigue life, and impact resistance while also allowing for better layer arrangement. Production techniques can also have an influence on the mechanical properties and operation of CNG cylinders. To guarantee resilience and safety, detailed models should be developed, and failure analysis should be performed to detect weaknesses. Strict safety rules should be implemented to ensure the dependability of CNG cylinders. Furthermore, long-term performance study and the investigation of alternative fuels like as hydrogen can assist reduce environmental and safety concerns.

4. PROBLEM FORMULATION

Despite its environmental benefits, CNG cylinders have limitations such as low density, transportation constraints, and a lower calorific value than conventional fuels. These issues demand improved pressure vessel technology for storage and transportation. The fatigue life and safety of CNG cylinders are vital, and material and design optimization is required for durability and safety. Compliance with international safety standards is critical for large manufacturing and reliable operation. Understanding failure modes and mitigating possible dangers is critical to ensure the dependability and safety of CNG tanks.

5. CONCLUSION

Natural gas is a possible alternative to traditional fuels because of its environmental benefits and availability. Despite its low calorific value and transportation challenges, advances in compressed (CNG) and liquefied natural gas (LNG) have cleared the path for wider use. Pressure vessels constructed using composite materials have greatly improved safety and performance while conforming to demanding regulatory norms. This study emphasizes the necessity of ongoing research and development in improving material selection, manufacturing methods, and failure analysis to maintain the robustness and dependability of CNG tanks. Furthermore, the investigation of alternate fuels, such as hydrogen, has the potential to reduce environmental effect while also improving energy safety. Continuous advancement in CNG technology and regulatory backing is critical for wider use and contribute to a cleaner environment.

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