

Taking new approaches in standards-development for products for new markets

The development of ISO 11439 for compressed natural gas vehicle cylinders

By Craig Webster, convenor of ISO/TC 58, Gas cylinders, SC 3, Cylinder design, WG 17, Compressed natural gas cylinders for road vehicles

New approaches are often required for standards covering products for new markets. The growing compressed natural gas (CNG) vehicle market has presented the high pressure gas cylinder industry with a unique challenge – how to make vehicle fuel cylinders that are lighter, less costly, and safer than industrial cylinder designs (See also ISO Bulletin January 2001, p.23 on ISO/TC 22/SC 25). A standard was required that would allow the CNG cylinder industry to safely develop worldwide.

The greatest challenge in developing a new standard was found in the oft-heard statement: “But we have always done it that way!” However, this statement often ignores the fact that advances in materials quality, production quality systems, computerized production methods, and non-destructive inspection

technologies were continually occurring in industry. Instead of prescribing how a product should be made, standards should allow for innovation within a specific framework.



III. 1 – CNG cylinder – aluminium liner hoop-wrapped with glass fibre composite.

Lower costs and less pollution – CNG cylinder development

The large-scale use of CNG as a vehicle fuel was initiated in Italy and Russia during the 1950's and 1960's. Internal combustion petrol engines could readily be converted to use natural gas, although there was a certain loss of power. The lower cost of natural gas compared to liquid fuels was the primary motivation for utilizing CNG.

By using engines designed specifically for the use of compressed natural gas the problem of power loss can be eliminated. It has also been found that dedicated CNG engines could produce significantly reduced amounts of exhaust pollutants. Combined with the fact that many countries have an abundance of natural gas reserves, the use of CNG as a vehicle fuel is

rapidly increasing worldwide for both economic and air pollution reduction reasons.

The high hydrogen to carbon ratio of methane results in an 18% to 25 % decrease in greenhouse gas emissions from vehicles powered by natural gas compared to petroleum fuels. Recent emissions testing in California has resulted in certain dedicated CGN vehicles receiving certification as “super ultra-low emission vehicles”.

Compressed natural gas is stored on-board vehicles in cylinders at a typical pressure of 20 MPa (200 bar). The first vehicle cylinders were steel designs made to various national industrial specifications. In Italy, thick-walled steel cylinders equivalent to the US DOT 3AA specification were used until the early 1970's [1]. However, the natural gas vehicle industry continually demands the use of lighter-weight cylinders, to reduce the effect on vehicle performance while still maintaining the current level of safety. Experience with CNG service conditions led to the development in the late 1970's of new Italian regulations for lighter-weight (“*Leggere*”) steel cylinders. Cylinders made to these Italian specifications have since been used in CNG service in many parts of the world.

In North America, the large-scale conversion of vehicles to natural gas fuel commenced in the 1980's. Light-weight cylinders made of metal liners reinforced with a glass fibre composite wrap developed for aerospace applications began to enter the industrial air breathing markets in 1977. In 1982, cylinders made with aluminium liners reinforced with a hoop-wrapping of glass fibre composite began to be used in CNG service (see III. 1). Steel cylinder

[1] Abraham, R.N. et al., “Report of Overseas Visit to Investigate Compressed Natural Gas in Italy”, New Zealand Liquid Fuel Trust Board, February, 1980.

manufacturers followed this trend to lighter-weight designs for CNG service by producing steel liners hoop-wrapped with glass fibre commencing in 1985. Hoop-wrapped cylinders are considered to have a redundant design by virtue of the fact that the metal liner by itself could contain the working pressure of 20 MPa, in the event that the composite wrap reinforcement was damaged or destroyed.

To further decrease cylinder weight for air breathing and CNG applications, several manufacturers developed fully-wrapped composite designs that used metal or plastic liners for gas containment. In fully-wrapped designs (see Ill. 2), the structural strength of the cylinder is primarily dependent upon the integrity of the composite wrap. In the late 1980's, experimental applications of composite reinforced plastic liners in CNG service occurred in Sweden, Russia and France. Following the development of natural gas vehicle cylinder standards in North America, fully-wrapped designs with relatively thin aluminium liners or plastic liners reinforced with a full wrapping of glass fibre and/or carbon fibre reinforcement were introduced into CNG service commencing in 1992.



Ill. 2 – Fully-wrapped CNG cylinder mounted on a vehicle.

Development of CNG cylinder standards

Since the late 1970's, the CNG industry worldwide has mainly relied on steel cylinders designed to Italian specifications, or to variations of the US Department of Transportation specification 3AA. Following the detection of imported CNG steel cylinder designs with poor fatigue (pressure cycle) life, New Zealand published their NZS 5454 standard in 1989 [2]. This was the first cylinder standard dedicated specifically for CNG service, focusing primarily on steel

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cylinders, but allowing for the approval of composite-wrapped designs. In addition to requiring the hardness testing of every cylinder to ensure proper heat treatment, the NZS 5454 standard included some performance test requirements (pressure cycle testing) based on natural gas vehicle (NGV) service conditions.

During the 1980's in North America, cylinder designs that did not comply with existing industrial standards were provided with Special Permits or Exemptions by federal authorities. However, this approval process was limited to only metal and hoop-wrapped designs. The demand for lighter-weight fully-wrapped designs, in particular for the transit bus market, prompted the cylinder and natural gas suppliers to develop their own industry standards specific to CNG applications.

Canada followed the New Zealand lead by introducing the CSA B51-1991 Appendix G standard [3]. The CSA B51 standard expanded on NZS 5454 requirements by including requirements for metal-lined composite-wrapped designs based on industrial standards for transportable cylinders. It also included some tests to ensure cylinder materials compatibility with the CNG service environment. At about this time in 1989, work was also commenced by ISO/TC 58/SC 3/WG 17 on the development of the international CNG cylinder standard ISO 11439 [4].

In 1992, the US developed their ANSI/AGA NGV2-1992 standard [5] for CNG cylinders. This standard was largely based on the industrial standards, including the US DOT 3AA regulation for steel, the 3AL regulation for aluminium, the draft FRP-1 standard for fully-wrapped designs and the draft FRP-2 standard for hoop-wrapped designs. In addition to defining some CNG service

conditions and accompanying performance tests, the NGV2 standard was notable for allowing the use of plastic-lined cylinders and specifying the allowable stresses that could be applied to different fibre types, including carbon fibre. The NGV2 standard first defined the four basic types of cylinder designs currently in general usage:

- *Type 1* – metal (aluminium or steel) cylinders
- *Type 2* – metal-lined hoop-wrapped cylinders
- *Type 3* – metal-lined fully-wrapped cylinders
- *Type 4* – plastic-lined fully-wrapped cylinders

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Several failures of composite-wrapped cylinders in CNG service in the US in 1994 identified problems with using cylinder designs based on industrial standards in automotive environments. As a result, the NGV2-1992 standard was refined in Canada and issued as the CSA B51-95 standard [6]. This standard provided a complete sum-

[2] New Zealand Standard NZS 5454-1989, “Requirements for Lightweight Steel Automotive Compressed Natural Gas Cylinders for Use in New Zealand”.

[3] CSA B51-1991 Appendix G, “Requirements for CNG Refuelling Station Pressure Piping Systems and Containers for CNG”, Canadian Standards Association.

[4] ISO 11439, *High Pressure Cylinders for the On-Board Storage of Natural Gas as a Fuel for Automotive Vehicles*, ISO/TC 58/SC 3/WG 17.

[5] ANSI/AGA NGV2-1992, “American National Standard for Basic Requirements for Compressed Natural Gas Vehicle (NGV) Fuel Containers”.

[6] CSA B51-1995, “High Pressure Cylinders for the On-Board Storage of Natural Gas as a Fuel for Automotive Vehicles”, Canadian Standards Association.

mary of CNG service conditions and performance tests for all cylinder types, including plastic-lined designs. It also specified external protective coating requirements and an external environmental exposure test.

Since 1992 the ISO/CD 11439 document, the US NGV2 standard, and the Canadian CSA B51 standard have been developed concurrently. In-service experience with composite hoop-wrapped designs (since 1982) and composite fully-wrapped designs (since 1992) have been heavily considered in the development of all three standards.

Providing CNG cylinders with a specified design life— the development of ISO 11439

A primary concern of CNG users is the weight of the vehicle fuel storage system. Cylinders used in industrial applications are designed to provide an essentially infinite lifespan. Industrial cylinders remain in service until they eventually fail a periodic retest or visual inspection. An objective of the ISO 11439 standard was to provide CNG cylinders with a specified design life, after which they are scrapped. This design life was intended to correspond with the usual service life of a vehicle. Using the concept of a limited lifespan, cylinders could be designed to provide the necessary resistance to CNG service conditions for only a given period of time.

The second concept adopted by the ISO 11439 standard was to develop performance-based requirements. Industrial cylinder standards typically specify the materials of construction, and the allowable wall stresses in designs. Since CNG cylinders would only be used under automotive environments, performance tests could be specified for each service condition to demonstrate the adequacy of designs for the defined lifespan (see Ills. 3 and 4). In addition, by defining performance tests for materials, higher strength metals could be utilized, thus further decreasing the weight of cylinder designs. Except for limits on the amount of stress that can be applied to different types of composite fibres (to prevent the phenomenon of stress rupture), there are no specified cylinder wall stresses for CNG cylinder designs.

“The ISO 11439 standard is based on the experience of the last 20 years involving the worldwide use of compressed natural gas (CNG) cylinders on vehicles.”

It was not practical to devise a performance standard that would allow the use of almost any kind of materials or methods of construction. The performance test requirements would be necessarily enormous to cover every situation. The ISO 11439 standard was therefore limited to the use of materials and fabrication methods considered to be economical to the CNG industry, since the cost of cylinders is a major factor in the conversion of vehicles to operate on natural gas fuel. As a result, in ISO 11439 cylinder manufacturing is limited to seamless (non-



III. 3 – Bonfire test of steel cylinder to evaluate the performance of pressure relief devices.



III. 4 – Stress corrosion cracking – testing of glass fibre wrap on pressurized tanks.

welded) designs, and metals selection is limited to aluminium alloys and low alloy steels.

“In ISO 11439, by specifying a cylinder lifespan, and defining the compressed natural gas (CNG) service conditions that a cylinder may experience, it was possible to define performance tests that could be used to demonstrate whether a particular cylinder design has fitness-for-purpose.”

“But we have always done it that way!”

A consideration in the design of CNG cylinders is the number of pressure cycles a cylinder may experience from filling operations. CNG cylinders will experience a significantly greater number of pressure cycles than cylinders used in industrial service. Repeated pressurization cycles will eventually result in the growth of fatigue cracks in metal cylinders and liners. A “worst-case” pressure cycle life was defined as 1 000 pressure cycles per year of life, i.e. 15 000 pressure cycles for a 15-year design life. In the development of ISO 11439 some traditionalists wanted an excessive pressure cycle life requirement applied to the performance testing of designs (“But we have always done it that way!”); for example, requiring a 15-year design to provide a minimum 30 000 pressure cycles in performance tests. This effort at overdesigning was avoided by instead requiring the 100% non-destructive inspection by ultrasonic scanning (or equivalent) of each and every metal

cylinder and metal liner produced to detect any defects that could cause a premature fatigue failure. Allowable defect sizes were to be calculated using fracture mechanics, or by conducting pressure cycle tests on cylinders containing defects of known size. In the event that cylinders did remain in service beyond their specified design life, and a fatigue failure did occur, a test requirement was included to ensure that designs demonstrate “leak-before-burst” performance; i.e. cylinders would leak and not rupture.

Despite efforts to eliminate from ISO 11439 any requirements that were not necessary to ensure the safety of cylinder designs, it was found expedient to include some aspects to prevent a stalemate from developing. One such requirement desired primarily by several national regulatory authorities was the specification of minimum burst pressures for different cylinder designs (“But we have always done it that way!”). The ultimate burst strength of a cylinder has traditionally been used as an indicator of relative safety – the higher the burst pressure, the greater the safety. However, for CNG service it has been found that the burst pressure could not be used to predict the cylinder fatigue life, its resistance to environmental effects, its resistance to impact damage, or the resistance of the composite fibres to stress rupture overload.

Advances in batch testing philosophy were also introduced in ISO 11439. Traditionally in cylinder production, one or two units would be tested to destruction out of every 200 cylinders produced. This statistical approach of randomly checking for compliance with design specifications was no longer necessary considering that manufacturers were required to implement a recognized quality system, to non-destructively test (ultrasonic and hardness) all metal cylinders and metal liners, and to hydrostatically proof test all cylinders. These quality system and inspection requirements are intended to eliminate randomness from cylinder production. Batch testing is no longer required as a random check, rather it has become a periodic confirmation that all production systems are functioning properly.

Defining performance tests to demonstrate fitness-for-purpose

CNG cylinders were originally adapted from industrial designs made to prescribed standards that specified allowable design stresses, materials of construction, and manufacturing processes. In-service experience demonstrated that industrial cylinder designs were often inadequate for vehicle service conditions, providing insufficient resistance to environmental attack or the necessary fatigue life. In ISO 11439, by specifying a cylinder lifespan, and defining the CNG service conditions that a cylinder may experience, it was possible to define performance tests that could be used to demonstrate whether a particular cylinder design has fitness-for-purpose. The intention was to develop a performance standard that would promote

About the author

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In addition to being convener of the ISO/TC 58/SC 3/WG 17 for ISO 11439, Craig Webster is also convener of the joint working group of ISO/TC 197/WG 6 and ISO/TC 58/SC 3 for the development of a hydrogen vehicle fuel tank standard (ISO 15869).