Committee of Experts on the Transport of Dangerous Goods and on the Globally Harmonized System of Classification and Labelling of Chemicals

Sub-Committee of Experts on the Transport of Dangerous Goods **16 September 2024**

Sixty-fifth session
Geneva, 25 November-3 December 2024
Item 6 (c) of the provisional agenda
Miscellaneous proposals for amendments to the Model Regulations on the Transport of Dangerous Goods: Portable tanks

Gas-FRP solutions and related matters

Submitted by the expert from the Russian Federation[1]

This informal document contains scientific-technical data related to the proposal in document ST/SG/AC.10/C.3/2024/104.

I. FRP products for gas storage and transport

A. FRP balloons

Image 1

FRP high-pressure gas balloons have been used for the last 40 years over the world.

https://hpcr.cz/

https://hexagonragasco.com/our-composite-lpg-cylinders-3/our-composite-lpg-cylinders

[1] ***Note by the secretariat:*** *The author of the document gave the authorization to use the materials contained in the section for the purpose of the discussion at the sixty-fifth session of the Sub-Committee of Experts on the Transport of Dangerous Goods. For reproduction permission and all other issues, please contact: i.sergeichev@skoltech.ru.*

B. FRP gas distribution modules

Image 2

TITAN 450 enables the safe transport of almost half a million standard cubic feet of CNG/RNG in a 40-foot module, allowing customers to deliver more gas with fewer trips, resulting in reduced operating costs.

1. The product employs the latest technology in Type 4 composite cylinders and high-strength frame design, while building on the proven simplicity and reliability of TITAN. As with the current generation of TITAN products, the modules are approved for a variety of gases including CNG, RNG, Helium, and Hydrogen.

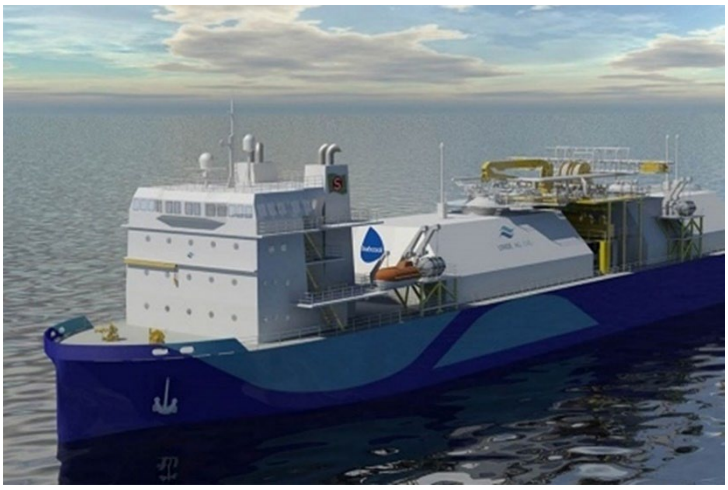
2. The new design delivers best in class Static Rollover Threshold (SRT) in the industry. SRT is a measure of a trailer’s resistance to rollovers.

https://hexagonagility.com/solutions/gas-distribution

https://hexagongroup.com/news/hexagon-agility-launches-next-generation-mobile-pipeline-modules-with-deliveries-to-certarus

C. FRP gas fuel tanks on marine ships

Image 3



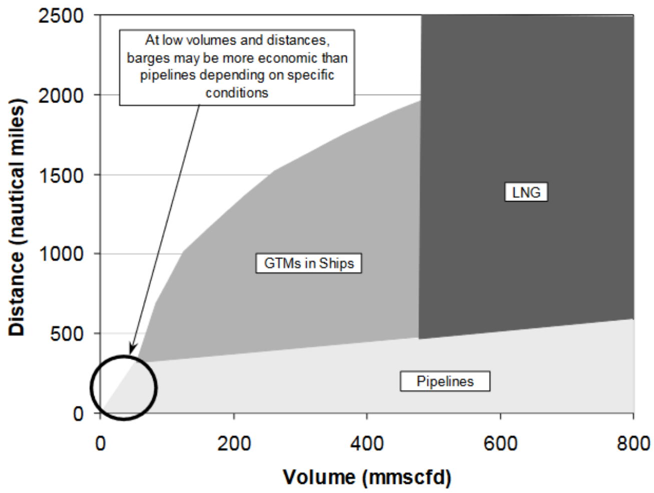
Babcock Schulte Energy (USA) has installed FRP fuel tanks on its LNG supply vessel.

Tanks in the form of rotating shells are designed to store compressed evaporated gas from LNG tanks and evaporated gas from cargo operations and supply it as fuel to the ship's dual-fuel engines.

https://www.manifoldtimes.com/news/bses-lng-bunker-tanker-to-utilise-composite-fuel-tanks/

D. LNG gas carrier (marine vessels)

Image 4



The concept of the Gas Transport Module (GTM) was derived from original work conducted over 20 years ago by NCF Industries on small scale pressure vessels made of FRP used in light weight breathing packs and fuel tanks for natural gas vehicles.

3. These vessels were manufactured in accordance with U.S. and Canadian regulations using the U.S. Department of Transportation's (DOT) FRP-2 code. These applications have had a long history of safe performance with close to 300,000 vessels being produced and utilized in North America alone.

4. These technologies have been protected under a number of issued patents (U.S. Patent No. 4,589,562, U.S. Patent No. 4,676,276). Multiple GTMs can be installed on a wide range of ship types with the choice dependent on the volumetric capacity required.

5. The main advantage of GTM vessels for offshore transport is reduced weight. When compared to conventional, "all steel" pressure vessels with the same rated storage capacity, the GTM design is up to 40% less weight.

6. This makes CNG transport using GTMs economic over a wide range of distances and volumes with a lower economic threshold than LNG.

7. Currently proposed GTM vessels have a nominal diameter of 1.07 m (42 in.), lengths up to 24.5 m (80 ft.) and an overall wall thickness of 38 mm (1.5 in.) which gives a approximate storage capacity of 172,000 scf of natural gas per vessel at an operating pressure of 20.7 MPa (3,000 psi).

8. Based on these values, the estimated design capacities for GTM based carriers are 250 mm scf up to 1,000 mm scf for large ships, and 30 mm scf up to 250 mm scf for smaller carriers, such as barges.

9. Economic Range of Volumes and Distances for Transport of Stranded Gas Reserves Using GTM, LNG and Pipeline Technologies is shown at the figure above.

Wolodko, John, et al. "Design and Testing of Large Diameter Composite Reinforced Pressure Vessels for Offshore Gas Applications." International Conference on Offshore Mechanics and Arctic Engineering. Vol. 37432. 2004.

II. Technologies and materials

10. For the manufacture of FRP shells for gas tanks, the technology of winding a reinforcing fibre impregnated with resin is usually used. A technology with the laying out of prepregs based on roving and binder can also be used.

11. The technology of manufacturing cylinders for the transport of gases has already been formed. In this technology, the shell consists of the following: The liner layer, which is in direct contact with the substance, provides protection of the structural layer from the substance, and also provides gas tightness.

12. The structural layer – perceives dynamic external and internal loads. The outer protective layer protects against external climate factors (including ultraviolet radiation), and can also combine a fire protection coating.

III. Related standards and regulations

GOST 33986-2016 Automotive vehicles. High-pressure cylinders for compressed natural gas used as motor fuel. Technical requirements and test methods;

GOST R 55559-2013 Composite cylinders for liquefied petroleum gases at pressure up to 2,0 MPa. General technical requirements. Test methods;

EN 12245:2009/AC: 2010 Transportable gas cylinders - Fully wrapped composite cylinders;

EN 14427:2004+A1:2005 «Transportable refillable composite cylinders for LPG -Design and construction;

ASME Boiler & Pressure Vessel Code Case 2390-1, 2003, American Society of Mechanical Engineers, New York, N.Y., 21 pages;

Gas cylinders. Refillable composite reinforced tubes of water capacity between 450 L and 3000 L — design, construction and testing. Standard ISO FDIS 11515. Geneva, Switzerland: ISO; 2022;

Transportable gas cylinders. Fully wrapped composite cylinders, BS EN 12245. Brussels, Belgium: European Standards; 2022;

BPVC section X-fiber-reinforced plastic pressure vessels, BPVC-X. New York, NY, USA: ASME; 2021;

Gas cylinders. Design, construction and testing of refillable composite gas cylinders and tubes — Part 3: fully wrapped fibre reinforced composite gas cylinders and tubes up to 450 l with non-load-sharing metallic or non-metallic liners or without liners. Standard ISO 11119-3. Geneva, Switzerland: ISO; 2020;

Gas cylinders. Refillable permanently mounted composite tubes for transportation. Standard ISO/TS 17519. Geneva, Switzerland: ISO; 2019;

Gas cylinders. Refillable composite gas cylinders and tubes — design, construction and testing — Part 3: fully wrapped fibre reinforced composite gas cylinders and tubes up to 450L with non-load-sharing metallic or non-metallic liners. Standard ISO 11119-3. Geneva, Switzerland: ISO; 2013;

Pressure vessels, AS 1210. Sydney, Australia: Standards Australia; 2021;

Filament-wound FRP pressure vessels. Materials, design, manufacturing and testing, BS EN 13923. Brussels, Belgium: European Standards; 2005;

Space systems - Pressure vessels and pressurized structures. Design and operation. Standard ISO 14623. Geneva, Switzerland: ISO; 2003;

Gas cylinders of composite construction. Specification and test methods — Part 3: fully wrapped fibre reinforced composite gas cylinders with non-load-sharing metallic or non-metallic liners. Standard ISO 11119-3. Geneva, Switzerland: ISO; 2002;

DNV Offshore Standard, DNV-OS-C501 Composite Components;

DOT FRP-2 Standard, 1987, U.S. Department of Transportation, Washington, D.C.

IV. Related patents

US20220065399A1, Composite gas storage tank

https://patents.google.com/patent/US20220065399A1/en

RU2526870C1, Heat-insulating sealed wall of reservoir made of polymeric composite materials for compressed natural gas

https://patents.google.com/patent/RU2526870C1/en

DE19751411C1, Composite fibre-reinforced pressurised gas tank including liner with end neck sections

https://patents.google.com/patent/DE19751411C1/en

RU2533874C1, Tank from composite materials for storage and transportation of liquefied gases and method of its fabrication

https://g.co/kgs/suSFBG4

V. Related international conferences

International Ocean and Polar Engineering Conference

https://onepetro.org/ISOPEIOPEC/proceedings-abstract/ISOPE03/All-ISOPE03/ISOPE-I-03-372/8625

ASME International Conference on Offshore Mechanics and Arctic Engineering

https://www.cfertech.com/insights/design-and-testing-of-large-diameter-composite-reinforced-pressure-vessels-for-offshore-gas-applications/

VI. Related publications

Campbell, S. "CNG Transportation Utilizing FRP Pressure Vessels." PETSOC Canadian International Petroleum Conference. PETSOC, 2004.

13. Over the past 10 years, the world has witnessed a steady increase in the demand for natural gas. It has now become the fuel of choice. All energy analysts predict global demand to double in 15 to 20 years.

14. In North America and areas of Southeast Asia, the value of natural gas has more than doubled due to a steady decline of supply. With half of the world's reserves considered stranded, an alternative method to economically transport gas by ship will be highly valued.

15. Compressed Natural Gas (CNG) transport is viewed by many industry and industry-related companies as that viable transport option. Within this emerging industry, many consider the Trans Ocean Gas method as the optimal solution for CNG transport.

16. CNG can economically transport stranded gas reserves to existing markets or create new natural gas markets not applicable to LNG. In contrast to LNG, compressed gas requires no processing to offload.

17. So it can economically deliver natural gas fuel for electrical power generation startups. There are hundreds of places in the world where CNG would be ideal for new market creation.

18. Trans Ocean Gas Inc. (TOG) proposes the most unique method of CNG transport using composite pressure vessels.

19. The fibre reinforced plastic (FRP) pressure vessel gas containment system overcomes all the deficiencies of proposed steel-based systems. FRP pressure vessels have been proven safe and reliable through critical applications in the national defence, aerospace, and natural gas vehicle (NGV) industries.

20. They are light-weight, highly reliable, have very safe failure modes, are corrosion resistant, and have excellent low temperature characteristics. The TOG method utilizes FRP technology, modified in size to store a large quantity of gas on a ship.

21. TOG has already obtained an approval in principle for the gas containment system from the American Bureau of Shipping. With its strategic partners, General Dynamics ATP and BMT Fleet Technology, TOG will now perform detailed design of a complete CNG carrier for approval in principle of the entire ship.

22. It will then perform design verification testing on prototype pressure vessels. With a successful testing program, Trans Ocean Gas will be ready to commercialize its technology.

23. Fibre reinforced plastic pressure vessels are safe, very reliable, light-weight, corrosion resistant, and have excellent low-temperature characteristics. They are therefore the optimal solution for CNG transport.

24. FRP pressure vessels are manufactured using the plastic liner as a mandrel on a computer controlled winding machine. As the mandrel is spun, a continuous filament of carbon, aramid, or glass fibre is drawn through an epoxy bath then wound onto the liner in a helical formation.

25. It is the filament windings that provide the strength in an FRP pressure vessel when cured, the filament windings are held in place by the epoxy matrix.

26. The main criteria in the NGV industry are ultra-light weight and safety. Therefore, carbon fibre is the filament fibre primarily used to manufacture pressure vessels for that industry. Carbon fibre has a very high strength to weight ratio. It is about 12.7 times stronger than high-strength steel.

Gaiotti, M., et al. "Material selection for the gas containment system of a compressed natural gas carrier fleet." Applied Ocean Research 55 (2016): 37-47.

27. In this work, the possible exploitation of fibre-reinforced composites in the context of maritime transport of compressed natural gas (CNG) is investigated. In addition to a more conventional steel configuration, two different fibre materials, carbon and glass, are considered as construction materials for pressure vessels (PVs) to be stored on board ships, with thickness optimized by FEM analysis.

28. The considered scenario is represented by the transport of CNG from an offshore well to a terminal on shore. Fleets of ships carrying CNG in pressure vessels manufactured with the investigated materials are generated by means of a ship synthesis model (SSM) software and compared on the basis of technical and economical indicators.

29. The choice of the construction material influences considerably the weight of the PVs, which represent a major item of total ship weight and reflects directly on the general transport performances in terms of resistance, seakeeping and reliability in the service. On the other hand, capital as well as operating expenditures are considerably affected by the choice.

30. When exploring the design space, the ship synthesis model is able, at a preliminary stage of the design, to account for the various technical and economical aspects, their implications and relationships. Results are presented of computations carried out in a specific case, identified by the annual gas production and other characteristics of the well terminal and a cruising route for the ships.

31. The comparison is carried out on the basis of the cost per transported unit of gas and of the percentage of success in the transport process. The computations show that the choice

of the PV material has a key influence on the results in terms of optimal number, dimensions and speed of the ships.

Shivamurthy, B., Siddaramaiah, and M. S. Prabhuswamy. "Design, fabrication, and testing of epoxy/glass-reinforced pressure vessel for high-pressure gas storage." Journal of reinforced plastics and composites 29.15 (2010): 2379-2386.

32. The design, fabrication, and testing of an epoxy-glass reinforced polymer composite pressure vessel suitable for high-pressure gas storage have been reported. In this study composite pressure vessels are made up of aluminum alloy 6063 seamless liner and glass/epoxy composite reinforcement.

33. The aluminum liner, which is developed by extruded aluminum tube of internal diameter 141 mm and wall thickness 4 mm, is subjected to super plastic deformation. Continuous glass fibres impregnated in epoxy resin are wound on the seamless liner by filament winding process. In this work, 10 pressure vessels were manufactured for 3.5MPa service pressure with marginal safety of 3. Four pressure vessels were subjected to cyclic and burst test; the burst pressures were 10.9, 11.0, 11.0, and 13.0 MPa.

Wolodko, John, et al. "Design and Testing of Large Diameter Composite Reinforced Pressure Vessels for Offshore Gas Applications." International Conference on Offshore Mechanics and Arctic Engineering. Vol. 37432. 2004.

34. Bulk transport of compressed natural gas is becoming a viable and flexible option for moving stranded gas reserves to existing or remote markets. One such technology that is currently being developed for this application is the Gas Transport Module (GTM™).

35. Gas Transport Modules are large diameter, high pressure, fibre reinforced composite/steel pressure vessels intended for the mobile transport of natural gas on a variety of carriers including ships, barges, trucks and trains. The purpose of this paper is to discuss recent work concerning the design and testing of these large diameter, composite pressure vessels.

36. The advantages of the proposed hybrid composite/steel design for offshore use are discussed. An overview of current standards development, specialized analysis methods and testing requirements is also provided.

Sklemina, Olga Yu, and Alexander N. Polilov. "Method of structure reinforcement optimizing for composite gas tank." AIP Conference Proceedings. Vol. 2697. No. 1. AIP Publishing, 2023.

37. The article proposes a method for calculating a composite tank for compressed gas with a symmetrical reinforcement structure using pairs of layers. The ply-by-ply method of calculation for pairs of layers turns out to be much simpler than for monolayers, since it relies on elastic and strength characteristics that are reliably determined by experiments.

38. The strength criteria has been substantiated, which enable simple engineering estimates of critical stresses and optimal reinforcement schemes.

Yu, Young Ho, and Bu Gi Kim. "Cryogenic reliability of composite insulation panels for liquefied natural gas (LNG) ships." Composite structures 94.2 (2012): 462-468.

39. The major carrier of liquefied natural gas (LNG) is LNG ships, whose containment system is composed of dual barriers and composite insulation panels. The LNG containment system should have cryogenic reliability and high thermal insulation performance for safe and efficient transport of LNG.

40. The secondary barrier composed of adhesive bonded aluminum strips should keep tightness for 15 days, when the welded stainless primary barrier fails. However, cracks are

generated in the composite insulation panels due to the local stress concentration and the brittleness of insulation materials at the cryogenic temperature of −163°C.

41. If cracks generated in the insulation panel propagate into the secondary barrier, LNG leakage problem might occur, which is a remaining concern in ship building industries. In this study, crack retardation capability in the composite insulation panel was investigated with glass fabric reinforcement.

42. Finite element analysis was conducted to estimate the thermal stress at the cryogenic temperature and a new experimental method was developed to investigate the failure of secondary barrier of composite insulation panel. From the experimental results, it was found that the glass fabric reinforcement was effective to retard the crack propagation into the aluminum secondary barrier from the polyurethane insulation foam at the cryogenic temperature.

S.R. de Ceuster. The Composite Gas Carrier. Exploring the technical and financial aspects associated with the production and design of a composite gas carrier

https://repository.tudelft.nl/record/uuid:5ba37b27-1b0f-4014-b8e2-00527a1d799d

43. This report considers a research about the usage of composites (FRP) as structural material of a 7500 m^3 gas carrier. The focus of this research is on two different subjects, namely the feasibility of producing such a structure and secondly to determine how the lightweight characteristics of this material can be utilised in the design of the ship and thereby generate financial benefits to the shipowner.

Lavrov, N. A., and M. S. Igumenov. "A technique for production of high-pressure vessels from polymer-composite materials." Polymer Science, Series D 11 (2018): 113-116.

44. A new technique for production of high-pressure vessels from polymer-composite materials is suggested. The vessel has the form of a double-layer balloon, the internal layer of which is made from linear low density polyethylene by rotational moulding and the external layer of which is formed by winding of a reinforcing fibre impregnated with an oligomer on a polymer liner. The suggested technique for production of high pressure vessels is compared to the other known techniques.

Wang, Dongliang, et al. "Experimental analysis on residual performance of used 70 MPa type IV composite pressure vessels." Journal of Failure Analysis and Prevention 19 (2019): 204-211.

45. This paper was aimed to study residual performance of five 70 MPa type IV hydrogen composite pressure vessels that were employed in vehicles with same driving distance through a series of experiments. Firstly, external and internal visual inspections were performed to evaluate the damage status of hydrogen composite pressure vessels.

46. Then the nonmetallic liner performance tests of one vessel were carried out including crystallinity test, hardness test, and tensile test. Besides, hydraulic fatigue test and hydraulic burst test for the remaining four vessels were conducted to evaluate residual strength. Experimental results show that the nonmetallic liner performance differs in different regions and temperature has an important influence on liner mechanical performance.

47. The comparison between the results of direct burst tests and post-fatigue burst tests shows that long-term fatigue cycles lead to a reduction in burst pressure, but the effect is not significant by using hydraulic fatigue cycles in the current tests.

Al-Habahbeh, Osama M., and Naser S. Al-Huniti. "Composite Pressure Vessels in Petroleum Industry: Status and Outlook." Proceedings of the 5th International Conference on Composite Science & Technology, Sharjah, UAE. 2005.

48. The use of composite pressure vessels in petroleum industry is one of the major areas of application of such vessels, particularly for storage and transport of fuels. Existing studies related to this field have considered various types, designs and applications of composite pressure vessels.

49. The current state of the art composite pressure vessels are light, safe, but unfortunately rather expensive compared to steel vessels. This is one of the main reasons why a broad introduction of composite vessels for liquefied petroleum gas (LPG) storage and transport has not taken place yet.

50. In this work the current status of composite pressure vessels in the petroleum industry is highlighted. Various existing models and studies of composite pressure vessels are discussed. Potential for application in the area of composite LPG cylinders is discussed.