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**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**

**Sixty-fourth session**
Geneva, 24 June-3 July 2024
Item 6 (c) of the provisional agenda
**Miscellaneous proposals for amendments to the Model Regulations on the Transport of Dangerous Goods: Portable tanks**

# Proposal for 6.9.4 "Requirements for the design, construction, inspection and testing of portable tanks with shells made of fibre reinforced plastics (FRP) materials intended for the transport of non-refrigerated liquefied gases"

**Submitted by the Government of the Russian Federation***

## I. General

1. The Committee of Experts on the Transport of Dangerous Goods and on the Globally Harmonized System of Classification and Labelling of Chemicals on its tenth session has been reported amendments to the twenty-first revised edition of the Recommendations on the Transport of Dangerous Goods, *Model Regulations* (ST/SG/AC.10/48/Add.1). The amendments include a new chapter 6.9 "Requirements for the design, construction, inspection and testing of portable tanks with shells made of fibre reinforced plastics (FRP) materials" and the appropriate update of chapter 4.2 related to the chapter 6.9.

2. In recent decades, FRP has been widely used for the production of storage tanks for unrefrigerated liquefied gases corresponding to Class 2, including hydrogen. The technologies of production of Type II-V storage tanks are filament winding or robotic winding. The reinforcing materials are carbon, glass or basalt fibres. Both thermosetting and thermoplastic polymers are used for production. Such structures are designed to withstand internal pressure up to 350 bar. The international experience of production and operation of tanks for storage and transportation of unrefrigerated liquefied gases demonstrates the effectiveness and the absence of technological limitations of the use of FRP for manufacturing of UN portable tanks intended for transportation of Class 2 substances.

3. The Russian Federation believes that using FRP materials in the construction of the portable tanks for unrefrigerated liquefied gases corresponding to Class 2, including hydrogen will lead to increase their service life and a reduction of repair costs.

* A/78/6 (Sect. 20), table 20.5.

4. The Russian Federation has acquired certain experience in using FRP materials for the fabrication of the tanks and would like to initiate discussions on the further development of the new sub-chapter 6.9.4 “Provisions for the design, construction, inspection and testing of portable tanks with shells made of fibre-reinforced plastics (FRP) materials intended for the transportation of substances of Class 2 (unrefrigerated liquefied gases)”.

## II. Background

5. At its fifty-fourth session (27 November to 6 December 2017, report ST/SG/AC.10/C.3/108), the Sub-Committee considered, inter alia, requests by the Australasian Explosives Industry Safety Group (document ST/SG/AC.10/C.3/2018/99) and the Russian Federation (document ST/SG/AC.10/C.3/2018/91) to extend the scope of the work to cover transport of explosives and non-refrigerated liquefied gases in FRP tanks.

6. The Sub-Committee noted that the informal working group acknowledged the ability of FRP portable tanks to carry dangerous goods of Class 2, but recognizing the additional complexities involved in the transport of these goods it decided to prioritize and finalize the work on the development of provisions for transport of goods of other classes in FRP portable tanks before addressing transport of gases.

7. The Russian Federation truly believes it is now the right time to develop requirements for design, construction, inspection and testing of fibre reinforced plastic (FRP) portable tanks to carry dangerous goods of Class 2.

8. Keeping in mind the discussion at the sixty-third session (27 November-6 December 2023, report ST/SG/AC.10/C.3/126), some delegations favored going forward with the development of new provisions on FRP portable tanks for the carriage of substances of Class 2 and invited the Russian Federation to collect possible data on this subject from delegations and to submit a proposal to the next session, taking into account the comments received.

9. In view of the above, the Russian Federation would like to present for consideration a draft of the new sub-chapter 6.9.4 “Requirements for the design, construction, inspection and testing of portable tanks with shells made of fibre reinforced plastics (FRP) materials intended for the transport of non-refrigerated liquefied gases”.

## III. Actions requested

10. Considering the above, the Russian Federation would like to discuss further development of chapter 6.9 “Provisions for the design, construction, inspection and testing of portable tanks with shells made of fibre-reinforced plastics (FRP) materials intended for the transportation of substances of classes 3, 5.1, 6.1, 6.2, 8 and 9” to extend its scope to Class 2 transportation.

11. The Russian Federation invites the Sub-Committee to:

(a) Consider the development of the new sub-chapter 6.9.4 “Requirements for the design, construction, inspection and testing of portable tanks with shells made of fibre reinforced plastics (FRP) materials intended for the transport of non-refrigerated liquefied gases” as presented in Annex I to this document; and

(b) Invite all experts to contribute to the development of new sub-chapter 6.9.4 and also invite the existing working group currently dealing with FRP service equipment to proceed with the development of a new chapter sub-chapter 6.9.4 if so decided.

# Annex

## 6.9.4 Requirements for the design, construction, inspection and testing of portable tanks with shells made of fibre reinforced plastics (FRP) materials intended for the transport of non-refrigerated liquefied gases

**6.9.4.1** ***Application and general requirements***

6.9.4.1.1 The requirements of section 6.9.4 apply to portable tanks with an FRP shell intended for the transport of non-refrigerated liquefied gases of Class 2, by all modes of transport in accordance with 6.7.1.

6.9.4.1.2 The requirements of chapter 6.7, and section 6.7.3 apply to FRP portable tank shells except for those concerning the use of metal materials for the construction of a portable tank shell and additional requirements stated in this chapter.

6.9.4.1.3 In recognition of scientific and technological advances, the technical requirements of this chapter may be varied by alternative arrangements. These alternative arrangements shall offer a level of safety not less than that given by the requirements of this chapter with respect to compatibility with substances transported and the ability of the FRP portable tank to withstand impact, loading and fire conditions. For international transport, alternative arrangement FRP portable tanks shall be approved by the applicable competent authorities.

**6.9.4.2** ***Definitions***

For the purposes of this section should be apply definitions in 6.7.3.1 and 6.9.2.1.

*Gas-tight liner* means a layer of the inner surface of an FRP shell designed as the primary barrier to provide the long-term impermeability of non-refrigerated liquefied gases through the FRP shell, to prevent any dangerous reaction or the formation of dangerous compounds and any substantial weakening of the structural layers of the shell. The liner may be an metallic liner or a FRP liner.

**6.9.4.3** ***General design and construction requirements***

6.9.4.3.1. The requirements of 6.7.3.2 are applied to FRP shell excluding 6.7.3.2.1, 6.7.3.2.10 and 6.7.3.2.11. FRP shell shall be designed and constructed in accordance with the requirements of a pressure vessel code recognized by the competent authority. For the purposes of this section the requirements of 6.9.2.2 shall be applied excluding 6.9.2.2.3.3, 6.9.2.2.3.5, 6.9.2.2.3.6, 6.9.2.2.3.8, 6.9.2.2.3.13, 6.9.2.2.3.14

6.9.4.3.2. The structural layer shall be designed to withstand the design loads according to 6.7.3.2.9 and 6.9.4.4.2.

6.9.4.3.3. The long-term impermeability of the FRP shell with the gas-tight liner shall be verified in accordance with standard ISO 15105-1:2007.

**6.9.4.4** ***Design criteria***

6.9.4.4.1 FRP shells shall be of a design capable of being stress-analysed mathematically or experimentally by resistance strain gauges, or by other methods approved by the competent authority.

6.9.4.4.2 FRP shells shall be designed and constructed to withstand a test pressure not less than 1.3 times the design pressure. The shell design shall take into account the minimum MAWP values provided in portable tank instruction T50 in 4.2.5.2.6 for each non-refrigerated liquefied gas intended for transport.

6.9.4.4.3 At the specified test pressure the maximum tensile relative deformation measured in mm/mm in the shell shall not result in the formation of microcracks, and therefore not be greater than the first measured point of elongation based fracture or damage of the resin, measured during tensile tests prescribed under 6.9.2.7.1.2 (c).

6.9.4.4.4 For the design loads according to 6.7.3.2.9 and the test pressure specified at 6.9.4.4.2, failure criteria (*FC*) in the longitudinal direction, circumferential direction, and any other in-plane direction of the composite layup shall not exceed the following value:

$$FC \leq \frac{1}{K}$$

where:

$$K = K_0 \times K_1 \times K_2 \times K_3 \times K_4$$

where:

***K*** shall have a minimum value of 4.

$\boldsymbol{K_0}$ is a strength factor. For the general design the value for $\boldsymbol{K_0}$ shall be equal to or more than 1.5. The value of $\boldsymbol{K_0}$ shall be multiplied by a factor of two, unless the shell is provided with protection against damage consisting of a complete metal skeleton including longitudinal and transverse structural members;

$\boldsymbol{K_1}$ is a factor related to the deterioration in the material properties due to creep and ageing. It shall be determined by the formula:

$$K_1 = \frac{1}{\alpha\beta}$$

where "α" is the creep factor and "β" is the ageing factor determined in accordance with 6.9.2.7.1.2 (e) and (f), respectively. When used in calculation, factors α and β shall be between 0 and 1.

Alternatively, a conservative value of $\boldsymbol{K_1}$ = 2 may be applied for the purpose of undertaking the numerical validation exercise in 6.9.2.3.4 (this does not remove the need to perform testing to determine α and β);

$\boldsymbol{K_2}$ is a factor related to the service temperature and the thermal properties of the resin, determined by the following equation, with a minimum value of 1: $\boldsymbol{K_2}$ = 1.25 - 0.0125 (HDT - 70) where HDT is the heat distortion temperature of the resin, in °C;

$\boldsymbol{K_3}$ is a factor related to the fatigue of the material; the value of $\boldsymbol{K_3}$ = 1.75 shall be used unless otherwise agreed with the competent authority. For the dynamic design as outlined in 6.7.2.2.12 the value of $\boldsymbol{K_3}$ = 1.1 shall be used;

$\boldsymbol{K_4}$ is a factor related to resin curing and has the following values:

1.0 where curing is carried out in accordance with an approved and documented process, and the quality system described under 6.9.2.2.2 includes verification of degree of cure for each FRP portable tank using a direct measurement approach, such as differential scanning calorimetry (DSC) determined via ISO 11357-2:2016, as per 6.9.2.7.1.2 (h);

1.1 where thermoplastic resin forming or thermoset resin curing is carried out in accordance with an approved and documented process, and the quality system described under 6.9.2.2.2 includes verification of whichever is applicable formed thermoplastic resin characteristics or degree of cure of thermoset resin, for each FRP portable tank using an indirect measurement approach as per 6.9.2.7.1.2 (h), such as Barcol testing in standard ASTM D2583:2013-03 or EN 59:2016, HDT in ISO 75-1:2013, thermo-mechanical analysis (TMA) in ISO 11359-1:2014, or dynamic thermo-mechanical analysis (DMA) in ISO 6721-11:2019;

1.5 in other cases.

A design validation exercise using numerical analysis and a suitable composite failure criterion is to be undertaken to verify that the stresses in the plies in the shell are below the allowables. Suitable composite failure criteria include, but are not limited to, Tsai-Wu, Tsai-Hill, Hashin, Yamada-Sun, Strain Invariant Failure Theory, Maximum Strain, or Maximum Stress. Other relations for the strength criteria are allowed upon agreement with the competent authority. The method and results of this design validation exercise are to be submitted to the competent authority.

The allowables are to be determined using experiments to derive parameters required by the chosen failure criteria combined with factor of safety $K$, the strength values measured as per 6.9.2.7.1.2 (c), and the maximum elongation strain criteria prescribed in 6.9.2.3.5. The analysis of joints is to be undertaken in accordance with the allowables determined in 6.9.2.3.7 and the strength values measured as per 6.9.2.7.1.2 (g). Buckling is to be considered in accordance with 6.9.2.3.6. Design of openings and metallic inclusions is to be considered in accordance with 6.9.2.3.8.

6.9.4.4.5 At any of the stresses as defined in 6.7.3.2.9 and 6.9.4.4.2, the resulting elongation in any direction shall not exceed the value indicated in the following table or one tenth of the elongation at fracture of the resin determined by ISO 527-2:2012, whichever is lower.

Examples of known limits are presented in the table below:

| Type of resin | Maximum strain in tension (%) |
|---|---|
| Unsaturated polyester or phenolic | 0.2 |
| Vinylester | 0.25 |
| Epoxy | 0.3 |
| Thermoplastic | See 6.9.4.4.3 |

6.9.4.4.6 For the external design pressure the minimum safety factor for linear buckling analysis of the shell shall be as defined in the applicable pressure vessel code but not less than three.

6.9.4.4.7 The adhesive bondlines and/or overlay laminates used in the joints, including the end joints, connection between the equipment and shell, the joints of the surge plates and the partitions with the shell shall be capable of withstanding the loads of 6.7.3.2.9 and 6.9.4.4.2. In order to avoid concentrations of stresses in the overlay lamination, the applied taper shall not be steeper than 1:6. The shear strength between the overlay laminate and the tank components to which it is bonded shall not be less than:

$$\tau = \gamma \frac{Q}{l} \leq \frac{\tau_R}{K}$$

where:

$\tau_R$ is the interlaminar shear strength according to ISO 14130:1997 and Cor 1:2003;

Q is the load per unit width of the interconnection;

$K$ is the safety factor determined as per 6.9.4.4.4;

$l$ is the length of the overlay laminate;

γ is the notch factor relating average joint stress to peak joint stress at failure initiation location.

Other calculation methods for the joints are allowed following approval with the competent authority.

6.9.4.4.8 Metallic flanges and their closures are permitted to be used in FRP shells, under design requirements of 6.7.3. Openings in the FRP shell shall be reinforced to provide at least the same safety factors against the static and dynamic loads as specified in 6.7.3.2.9 and 6.9.4.4.2 as that for the shell itself. The number of openings shall be minimized. The axis ratio of oval-shaped openings shall be not more than 2.

If metallic flanges or componentry are integrated into the FRP shell using bonding, then the characterisation method stated in 6.9.4.4.7 shall apply to the joint between the metal and FRP. If the metallic flanges or componentry are fixed in an alternative fashion, e.g.

threaded fastener connections, then the appropriate provisions of the relevant pressure vessel standard shall apply.

6.9.4.4.9 Check calculations of the strength of the shell shall be performed by finite element method simulating the shell layups, joints within FRP shell, joints between the FRP shell and the container frame, and openings. Treatment of singularities shall be undertaken using an appropriate method according to the applicable pressure vessel code.

**6.9.4.5** ***Minimum wall thickness of the shell***

6.9.4.5.1 Minimum thickness of the FRP shell shall be confirmed by check calculations of the strength of the shell considering strength requirements given in 6.9.4.4.4.

**6.9.4.6** ***Service equipment***

Service equipment, pressure relief devices, capacity and setting of pressure-relief devices, gauging devices, portable tank supports, frameworks, lifting and tie-down attachments shall meet the requirements of 6.7.3.5 to 6.7.3.12. If any other metallic features are required to be integrated into the FRP shell, then the requirements of 6.9.4.4.8 shall apply.

**6.9.4.7** ***Design approval***

6.9.4.7.1 Design approval of FRP portable tanks shall be as per 6.7.3.14 requirements.

6.9.4.7.2 The prototype, equipped with strain gauges at all locations of high strain, as identified by the design validation exercise in accordance with 6.9.4.4.4, shall be subjected to the test pressure specified in 6.9.4.4.2. Under this load, the shell shall exhibit no visual damage or leakage. The stress corresponding to the measured strain level shall not exceed the minimum factor of safety calculated in 6.9.4.4.4.

6.9.4.7.3 The prototype test report for the purpose of the design approval shall additionally include the following:

(a) Results of the material tests used for FRP shell fabrication in accordance with 6.9.2.7.1 requirements;

(b) Results of the ball drop test in accordance with the requirements of 6.9.2.7.1.4.

(c) Results the fire resistance test in accordance with provisions of 6.9.2.7.1.5.

6.9.4.7.4 The prototype shall be inspected for compliance with the design type specification. This shall include an internal and external inspection and measurement of the main dimensions.

6.9.4.7.5 A service life inspection programme shall be established, which shall be a part of the operation manual, to monitor the condition of the tank at periodic inspections. The inspection programme shall focus on the critical stress locations identified in the design analysis performed under 6.9.4.4.4. The inspection method shall take into account the potential damage mode at the critical stress location (e.g., tensile stress or interlaminate stress). The inspection shall be a combination of visual and non-destructive testing (e.g., acoustic emissions, ultrasonic evaluation, thermographic). For heating elements, the service life inspection programme shall allow an examination of the shell or its representative locations to take into account the effects of overheating.

**6.9.4.8** ***Additional requirements applicable to FRP portable tanks***

6.9.4.8.1 The additional requirements shall be applied according to 6.9.2.7 excluding 6.9.2.7.1.3.

**6.9.4.9** ***Inspection and testing***

6.9.4.9.1 The requirements of 6.7.3.15, 6.9.2.8.2 and 6.9.2.8.3 shall be applied to FRP portable tanks.

**6.9.4.10** ***Marking***

6.9.4.10.1 Marking shall be provided according to 6.7.3.16.