UN/SCETDG/52/INF.44

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 **27 November 2017**

Fifty-second session
Geneva, 27 November-6 December 2017
Item 6 (c) of the provisional agenda
Miscellaneous proposals for amendments to the Model Regulations on the Transport of Dangerous Goods: portable tanks

Presentation to IMO as mentioned in the ST/SG/AC.10/C.3/2017/40 - (Russian Federation): Fibre-reinforced plastics portable tanks

Transmitted by the expert from the Russian Federation

Design, Manufacture and Testing of Tank Containers with Shells Made of Fiber Reinforced Plastic (FRP) Materials for Multimodal Transportation of Dangerous Goods

Presented by: Professor, Doctor of Engineering Science Andrey E. Ushakov

«Applied Advanced Technologies – ApATeCh»

(Russian Federation)

MSC98, IMO, London, 09 June 2017

Container **Transportation**

1. According to ITCO information for 2016 year the world number of tank containers is more than 458000 pcs.; 90% are tank containers for chemical and petrochemical products;
2. 100% of tank containers for multimodal transportation by all modes of transport (including maritime) is made of metal (steel, scarcely ever aluminum);
3. Rapid growth of dangerous goods transportation by 5-15% per year (including hydrochloric acid (UN No. 1789); phosphoric acid solution (UN No. 1805); sodium hydroxide solution (UN No. 1824)).

Current Operation Features

1. Aggressive substances transportation requires specific expensive protection of the inner surface of the metal shell body (rubber or special polymer coating);
2. Cleaning is a complex, time-consuming and labor-intensive process of tank steaming causing accelerated wear of the protective coatings;
3. Tank container service life is limited to that of the inner surface protection.
4. Low economic efficiency of operation and maintenance

FRP vs Steel

1. **Global practice demonstrates higher efficiency of FRP products in areas which were considered to be conventional for application of metal structural materials (space engineering, aircraft industry, shipbuilding, bridge engineering, etc.);**
2. **Products manufactured from FRP materials require no additional surface protection from any aggressive substances.**

What is FRP Material?

1. Materials for FRP production are resins, fiber glass, carbon fiber, aramid fiber;
2. FRP product manufacturing process includes hand layup, vacuum infusion, filament winding, etc.

Advantages of FRP Materials

1. Physical and mechanical properties of FRP structures exceed similar properties of structures made of conventional structural metal materials:
2. Reduced energy consumption of FRP material product manufacture (no casting, forging or welding required);
3. Improved serviceability aspects;
4. Reduced final product (container) weight, allowing increased cargo weight;
5. Increased impact resistance (dampening);
6. No special processes are required for cleaning from remaining deleterious substances shipped

Advantages of FRP shell

1. **Reduced weight of structure;**
2. **Reduced transport expenses;**
3. **Reduced manufacture expenses;**
4. **High repairability;**
5. **Reduced maintenance costs connected with the structure repair**

Scope

The innovative materials, including wide range of FRPs are on the way in replacement of traditional materials.

These challenges urge the rulemaking industry to make appropriate steps.

For the moment IMO provides no requirements for materials, design, manufacture and testing of tank containers with FRP shell suitable for maritime transportation.

Our Achievements

1. Design
2. Simulation and calculations;
3. Materials;
4. Joints and connections;
5. Design;
6. Testing of structural specimens and structural elements;
7. Technology and Production;
8. Tests;
9. Pilot operations.

Materials:

- **Selection;**
- **Testing;**
- **Determination of design parameters**

Tests:

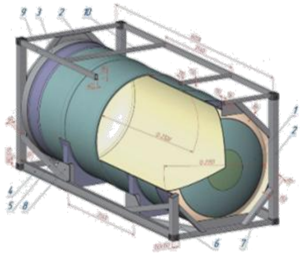
- **Static tests;**
- **Dynamic tests;**
- **Hydraulic tests;**
- **Ball drop test;**
- **Fire resistance tests**

Our Achievements

1. Design

1. Design

Tank container. Option 1
Solid tank barrel with connecting "skirts" in the frame with ring supports on the end frames and bottom supports



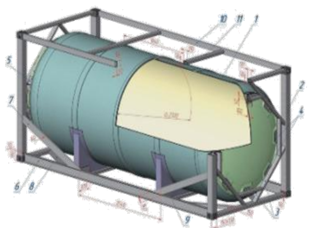
Structural scheme of the tank container No. 1

Technology:
-Winding
-Vacuum infusion

Connection with the frame:
-Through the connecting ring element (skirt)

Tank volume: 24,0 m^3
Tank weight: 1780 kg
Frame weight: 1725 kg
Weight of the valves: 70 kg
Total weight: 3575 kg

Tank container. Option 2
Solid tank barrel with connecting "flange skirts" in the frame with supporting elements on the end frames and bottom supports



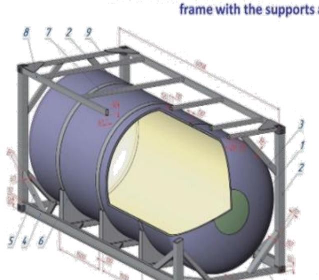
Structural scheme of the tank container No. 2

Technology:
-Winding
-Vacuum infusion

Connection with the frame:
-Flange

Tank volume: 24,0 m^3
Tank weight: 1740 kg
Frame weight: 1650 kg
Weight of the valves: 70 kg
Total weight: 3460 kg

Tank container. Option 3
Sandwich structure of the tank barrel with the ring stiffeners in the frame with the supports and fixing clamps



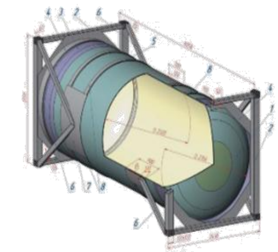
Structural scheme of the tank container No. 3

Technology:
-Winding

Connection with the frame:
-Transverse supports and clamps

Tank volume: 24,0 m^3
Tank weight: 1215 kg
Frame weight: 1860 kg
Weight of the valves: 70 kg
Total weight: 3145 kg

Tank container. Option 4
Bearing solid tank barrel with connecting "skirts" in the space frame with ring supports on the end frames, diagonal support beams and two supporting ring panels



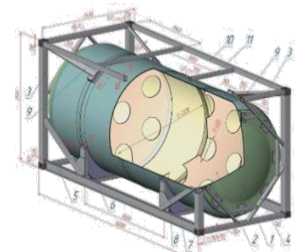
Structural scheme of the tank container No. 4

Technology:
-Winding

Connection with the frame:
-Bearing tank barrel with ring supports on the end frames

Tank volume: 24,0 m^3
Tank weight: 1920 kg
Frame weight: 1450 kg
Weight of the valves: 70 kg
Total weight: 3440 kg

Tank container. Option 5
Solid tank barrel with internal ring stiffeners in the frame with support frames of the end caps and bottom supports



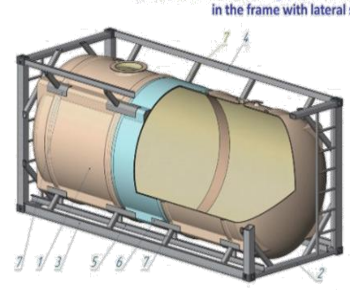
Structural scheme of the tank container No. 5

Technology:
-Winding
-Vacuum infusion

Connection with the frame:
-Flange

Tank volume: 24,0 m^3
Tank weight: 1715 kg
Frame weight: 1650 kg
Weight of the valves: 70 kg
Total weight: 3435 kg

Tank container. Option 6
Solid tank barrel consisting of two halves with the joint in the center in the frame with lateral support beams



Structural scheme of the tank container No. 6

Technology:
-Vacuum infusion

Connection with the frame:
-Through lateral support beams

Tank volume: 24,5 m^3
Tank weight: 1810 kg
Frame weight: 1390 kg
Weight of the valves: 70 kg
Total weight: 3270 kg

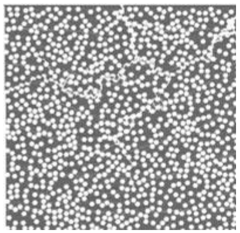
Our Achievements

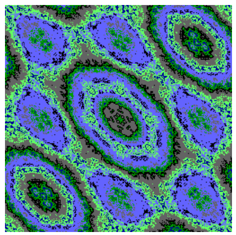
2. Simulation and calculations

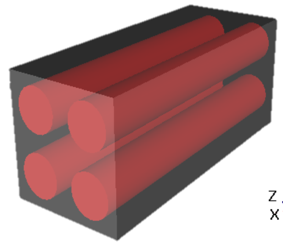
2. Simulation and calculations

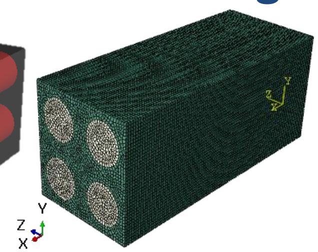
Multiscale Modeling of the "Material State" in the composite tank structure

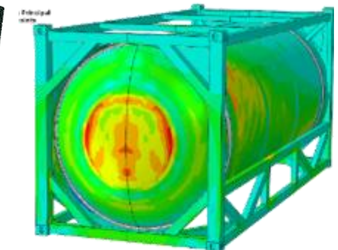
Micro- level modeling | **Meso-level modeling** | **Structural level modeling**











Modeling of material structure

Identification of the model

Dynamic analysis and verification

Effective material component properties:
resin, fibers, fiber/resin interfaces

Macro-mechanical model for viscous-elastic nonlinear material behavior taking into account dissipative properties and "Material State"

Analysis of the "Material State"

2. Simulation and calculations

Regulatory strength criteria applied to the composite tank

For design loads:

1. Safety factor: $K = S \times K_0 \times K_1 \times K_2 \times K_3 \geq 5.775$

$S=1.5$, $K_0=2$, $K_1=1$, $K_2=1.75$ (static), $K_2=1.1$ (dynamic) $K_3=1.1$.

2. Max tensile strain in any direction ≤0. 2%.

3. Buckling load factor ≥ 4.9 (prEN 13121)

4. Additional criteria will be applied to guarantee strength of the structure during its service life (see next page)

For testing loads:

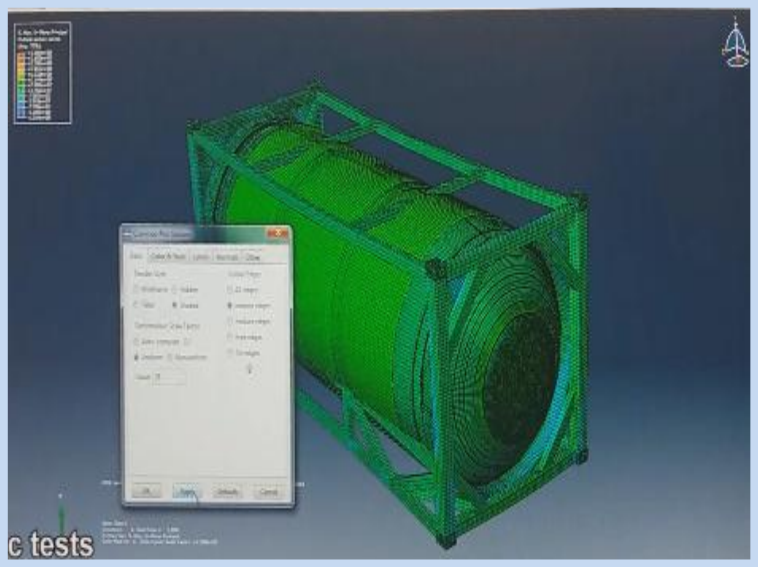
For inner pressure 0.6 MPa and minimum 4g horizontal inertia the tank must not have any damage and leakages.

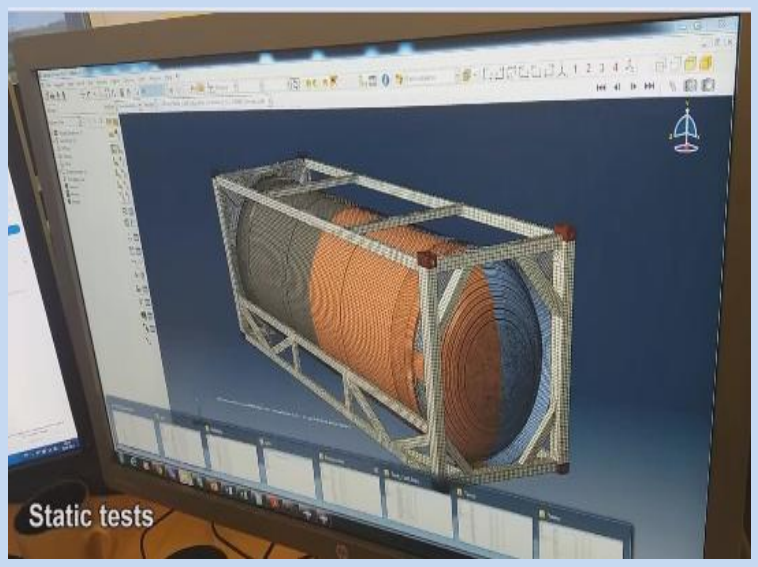
2. Simulation and calculations

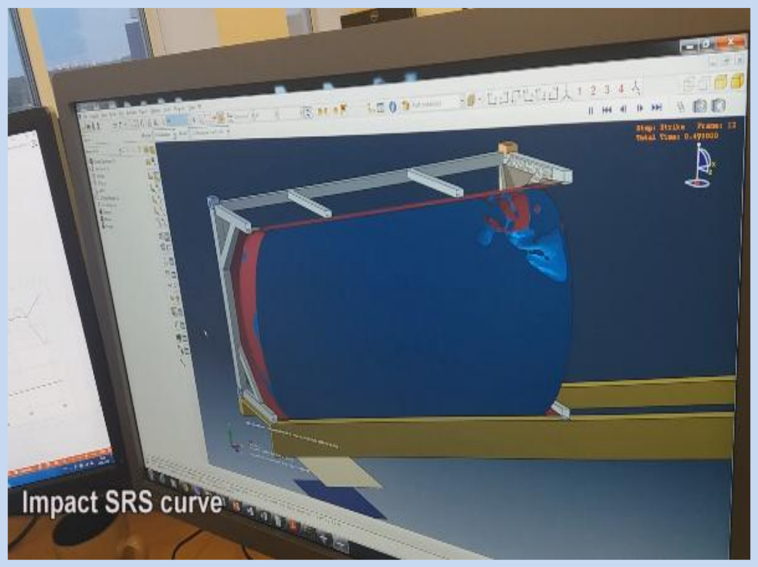
Additional strength criteria applied to the composite tank

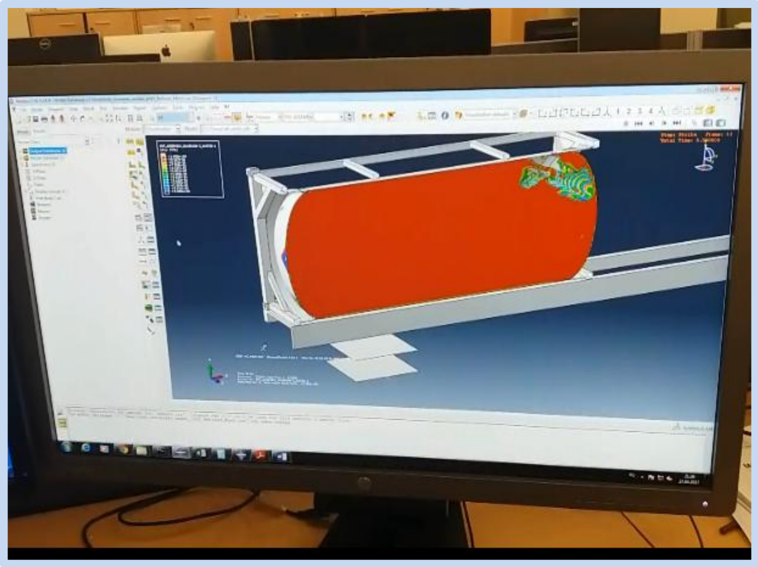
Safety factor	Description
$K_\sigma^t = R^t/\sigma^t$	R^t - tensile strength, σ^t – applied tensile stress
$K_\sigma^c = R^c/\sigma^c$	R^c - compression strength, σ^c – applied compression stress
$K_\sigma^s = R^s/\sigma^s$	R^s - shear strength, σ^s – applied shear stress
$K_\varepsilon^t = \varepsilon_{allow}^t/\varepsilon_t$	ε_{allow}^t - allowable tensile strain =0.2%, ε_t – applied tensile strain
$K_\varepsilon^c = \varepsilon_{allow}^c/\varepsilon_c$	ε_{allow}^c - allowable compression strain =0.2%, ε_c – applied compression strain
$K_\varepsilon^s = \varepsilon_{allow}^s/\varepsilon_s$	ε_{allow}^s - allowable shear strain =0.2%, ε_s – applied shear strain
K_{buckl}	*buckling safety factor*
$K_{delam}=1/\sqrt{G_{eqiuv}}$	$G_{eqiuv} = \left(\frac{G_I}{G_{I,C}^{Init}}\right)^\alpha + \left(\frac{G_{II}}{G_{II,C}^{Init}}\right)^\beta + \left(\frac{G_{III}}{G_{III,C}^{Init}}\right)^\gamma$
$K_\sigma^b = R^b/\sigma^b$	R^b - bearing strength, σ^b - applied bearing stress

2. Simulation and calculations









Our Achievements

3. Materials selection

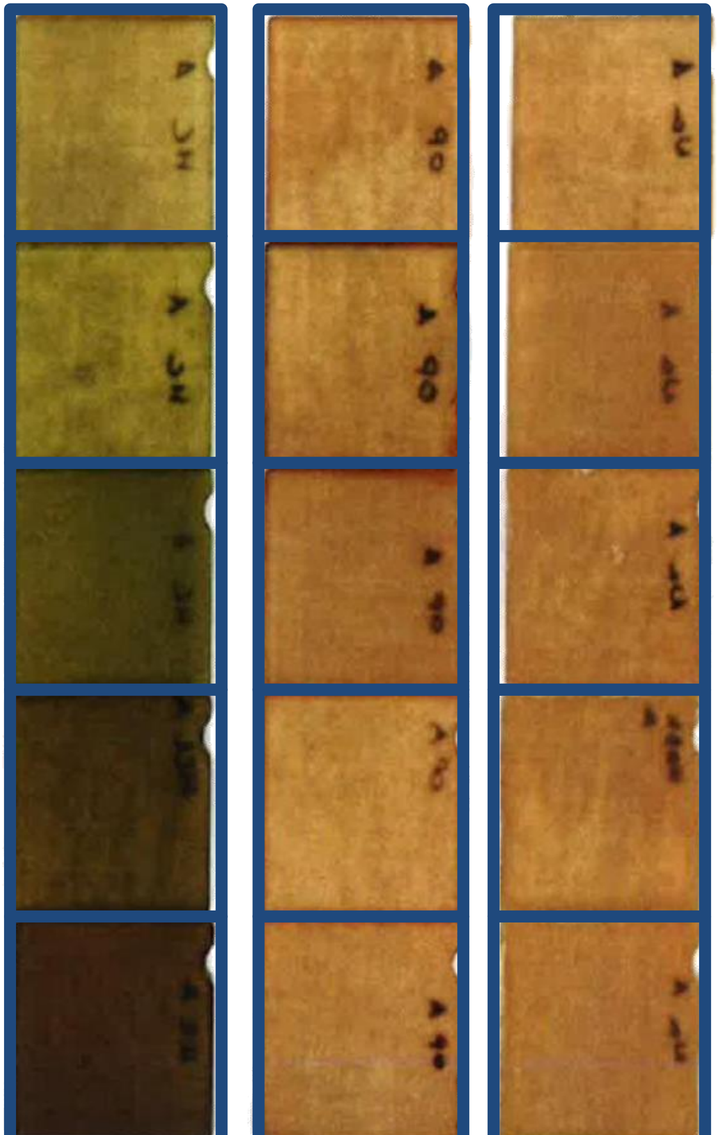
List of goods allowed for transportation

No.	Name	Hazard class	UN No.
1	**Phosphoric acid solution**	8	1805
2	**Hydrochloric acid (up to 37%)**	8	1789
3	**Sodium hydroxide solution**	8	1824

3. Materials selection

3. Materials selection

hydrochloric acid | phosphoric acid | sodium hydroxide



1 day (24 h.)

1 week (168 h.)

2 weeks (336 h.)

4 weeks (672 h.)

6 weeks (1000 h.)

Results of specimen exposure to:

- hydrochloric acid (UN No. 1789);
- phosphoric acid solution (UN No. 1805);
- sodium hydroxide solution (UN No. 1824)

During 1000 hours at 50°C

Our Achievements

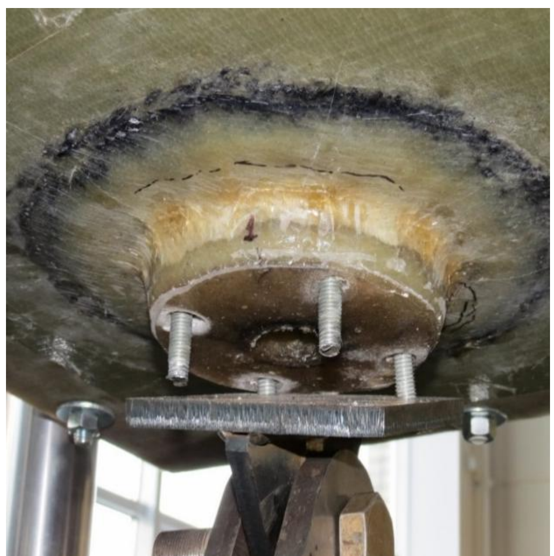
3. Materials
Determination of design parameters

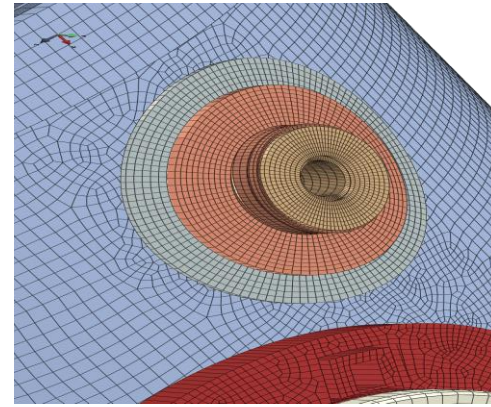
3. Materials
Determination of design parameters

Our Achievements

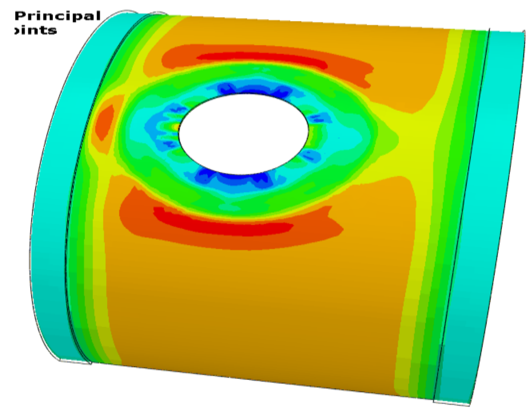
4. Joints and connections

4. Joints and connections





Finite-element model of the valve

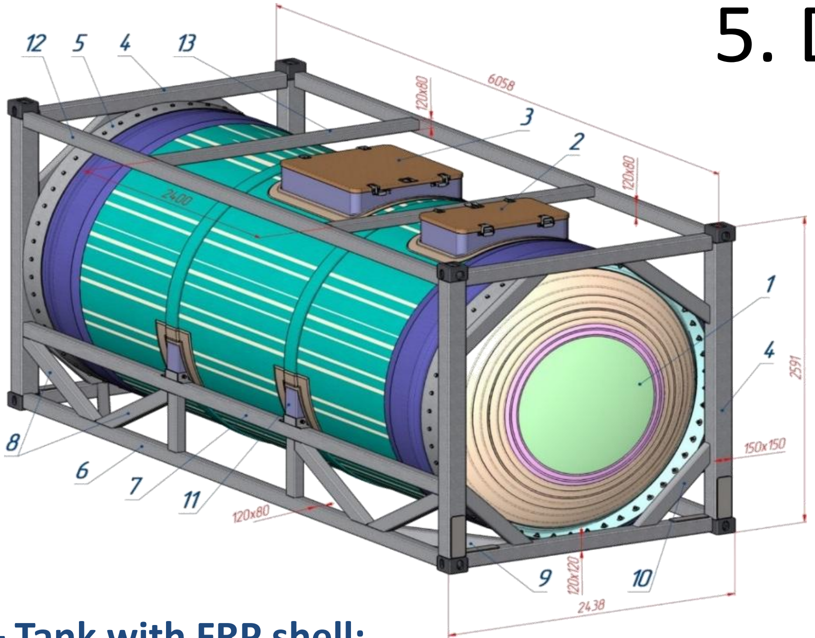


Strain distribution in the wound structural layers of the FRP shell under the design pressure 0.4 MPa

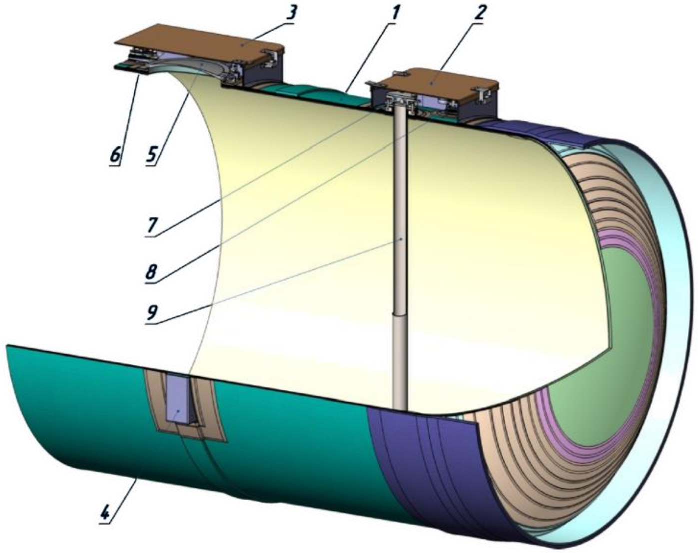
Our Achievements

5. Design

5. Design



1 – Tank with FRP shell;
2 – Small valve compartment;
3 – Large valve compartment;
4 – End frame;
5 – Support ring;
6 – Bottom longitudinal beam;
7 – Middle longitudinal beam;
8 – Longitudinal beam knee braces;
9 – Bottom brace;
10 – Front frame knee brace;
11 – Lower support;
12 – Top longitudinal beam;
13 – Top-end transverse member.



1 – Tank with FRP shell
2 – Small valve compartment
3 – Large valve compartment
4 – Lower support
5 – Manhole
6 – Safety valve
7 – Top loading-unloading unit
8 – Air stop valve
9 – Siphon pipe

Our Achievements

6. Testing of structural specimens and structural elements

(measurement of creep and ageing factors according to the international standard EN978)

6. Testing of structural specimens and structural elements

6. Testing of structural specimens and structural elements

Factor	Structural specimen 1	Structural specimen 2
α	0,895	0,825
β	0,99	1,00

$$K_0 = \frac{1}{\alpha \times \beta} = \frac{1}{0,825 \times 0,99} = 1,224$$

Value of the standard safety factor is

K=S×K0×K1×K2×K3=3.54 < 5.775

Based on the requirements to the FRP tanks designed for multimodal transportation of aggressive chemicals, the minimal safety factor value shall be K=4 despite the fact that the actual experimental value is K = 3.54.

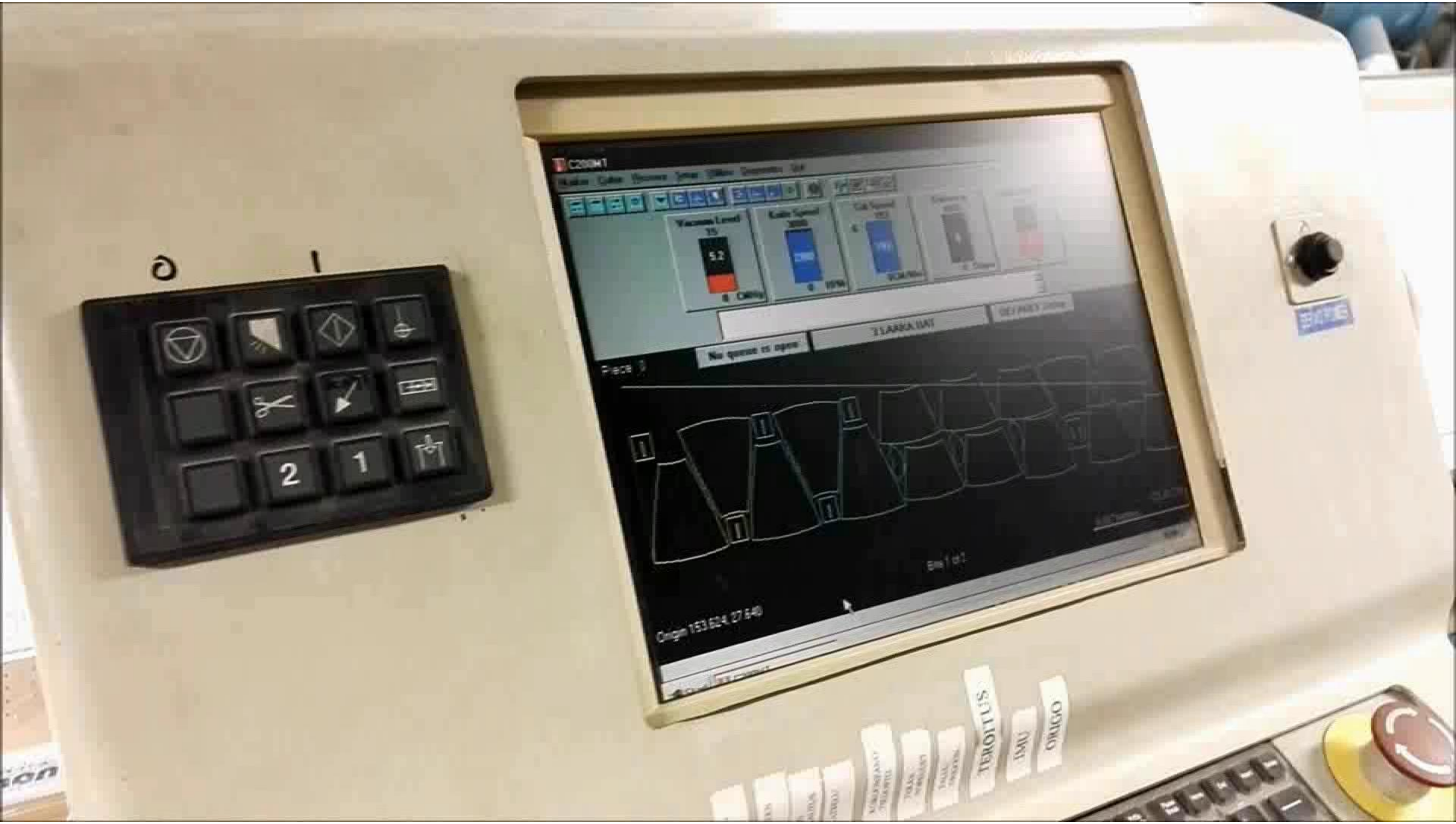
Nevertheless, even application of the safety factor K=4 will help to increase the level of allowable stresses by 5.775/4×100% = 144.3%.

This, in turn, will help to reduce weight of the structural shell of the FRP tank by more than 30%

Our Achievements

7. Technology and Production

7. Technology and Production



7. Technology and Production

Workshop tests with internal pressure

0,6 MPa

Our Achievements

8. Tests

- Static tests;
- Dynamic tests;
- Hydraulic tests;
- Ball drop test
- Fire resistance tests;

All tests complying with the current approaches used in the transport machine building for testing tank containers have been carried out under technical supervision of the Competent authority in the accredited laboratories.

Our Achievements

8. Tests

- Static tests

8. Tests

Static tests

№	Test type	Load	
		Symbol	Value
1	Lifting by top corner fittings	2R	72 000 kg
2	Lifting by bottom corner fittings	2R	72 000 kg
3	Stacking	P	848 kN per corner post
4	Transverse racking	P	150 kN
5	Longitudinal racking	P	75 kN
6	Longitudinal restraint (static test)	Combined force of 2Rg	706 kN
7	Walkways strength	P	3 kN
8	Ladder strength	P	2 kN
9	Longitudinal inertia test	R	36 000 kg
10	Lateral inertia test	R	36 000 kg

8. Tests

Static tests

8. Tests

Static tests

Load case	Load combinations	Strength criteria of the tank	Conformity
Securing the container in the longitudinal direction	• Vertical load on the tank 1g from the cargo weight • Vertical load on the tank 1g from the tank weight • External tensile and compression forces of 353.2 kN applied to one corner fitting and 706.4 kN applied to two corner fittings.	$K>5.775$, $e_д \leq 0.2\%$	Conforms
Strength analysis of the container under longitudinal securing	ISO-1496	$K>5.775$, $e_д \leq 0.2\%$	Conforms
Strength analysis of the container under transverse securing	ISO-1496	$K>5.775$, $e_д \leq 0.2\%$	Conforms
Strength of contact areas	ISO-1496	$K>5.775$, $e_д \leq 0.2\%$	Conforms
Load moving towards the tank and its fastenings	ISO-1496	$K>5.775$, $e_д \leq 0.2\%$	Conforms
Horizontal load applied towards the tank and its fastenings under 90 degrees	ISO-1496	$K>5.775$, $e_д \leq 0.2\%$	Conforms
Vertical bottom-to-top load to the tank and its fastenings	ISO-1496	$K>5.775$, $e_д \leq 0.2\%$	Conforms
Vertical top-to-bottom load to the tank and its fastenings	ISO-1496	$K>5.775$, $e_д \leq 0.2\%$	Conforms

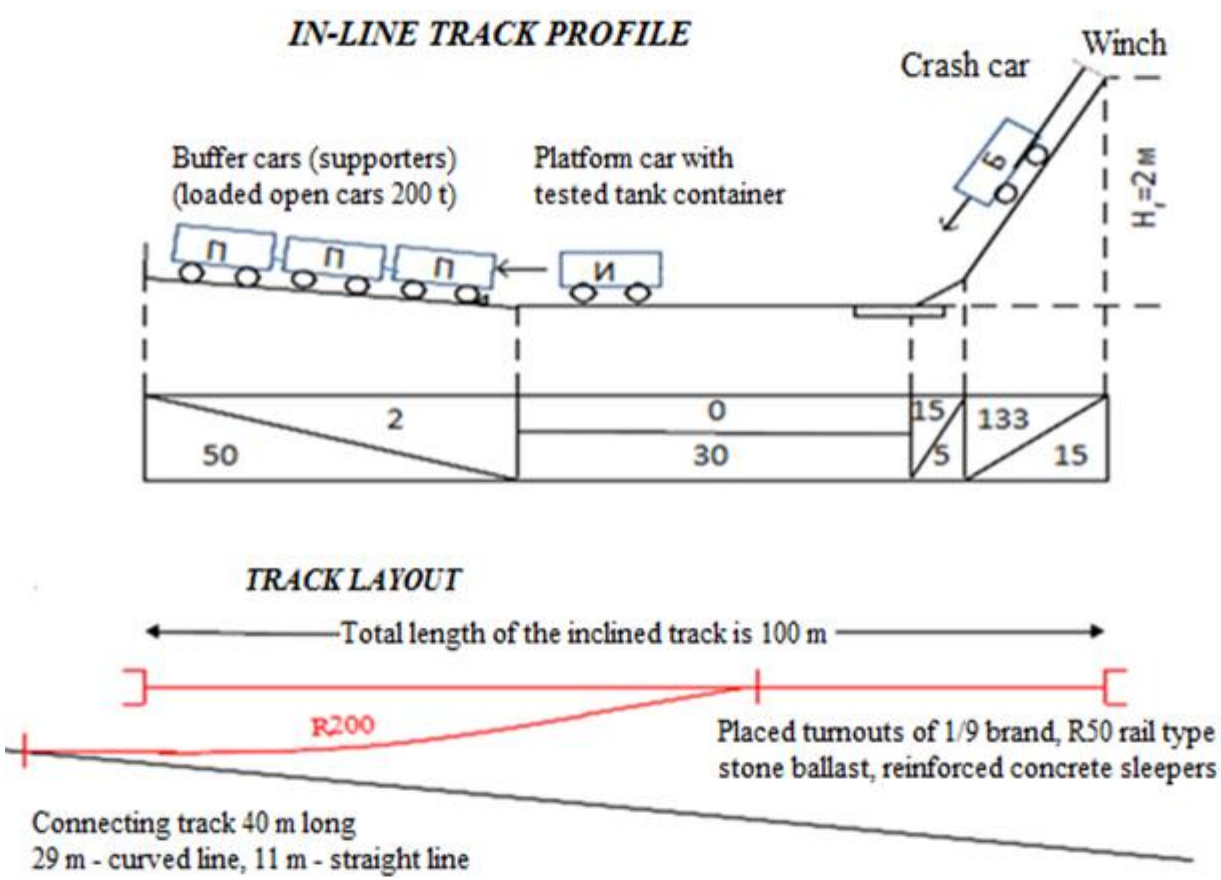
Our Achievements

8. Tests

- Dynamic tests

8. Tests

Dynamic tests



Dynamic Test Scheme

According to the Manual of Tests and Criteria, UN, Section 41, Part IV

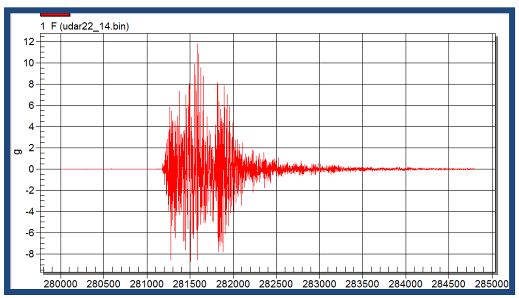
8. Tests

Dynamic tests

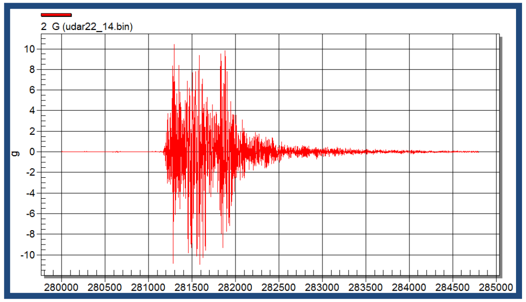
8. Tests

Dynamic tests

Speed of crash car, km/h	Max longitudinal acceleration, g	
	Fitting G	Fitting F
5,2	3,1	2,9
7	4,4	5
9,1	8,3	6,8
10	9,2	10,3
13,5	9,7	10,2
14	10,4	11,8



Oscillogram of acceleration in the fitting G at the impact speed 14 km/h



Oscillogram of acceleration in the fitting F at the impact speed 14 km/h

fitting G

fitting F

Our Achievements

8. Tests

- Hydraulic tests

8. Tests

Hydraulic tests

Design pressure 0,4 MPa **Test pressure 0,6 MPa**

After reaching the test pressure 0,6 MPa the tank container stayed under the load for 30 minutes.

Our Achievements

8. Tests

- Fire resistance tests

8. Tests
- Fire resistance tests

Summary

March 2014: Start of development

The tank container is designed for transportation of dangerous goods by road, rail and sea

December 2015: Approval by the Competent authority for transportation by road and rail transport

Technical data

Parameter	Value
Tank container ADR code	**L4DN**
Dimension type	**1CC**
Dimension code and container type	**22K2**
Max gross mass R, kg	**36 000**
Total capacity of the tank barrel, m3	**24±0,48**
Design pressure, MPa	**0,4**

Our Achievements

9. Pilot operation

9. Pilot operation

List of goods allowed for transportation

No.	Name	Hazard class	UN No.
1	**Phosphoric acid solution**	8	1805
2	**Hydrochloric acid (up to 37%)**	8	1789
3	**Sodium hydroxide solution**	8	1824

Parameters checked during inspection of the chemically resistant layer and fire resistant coating of the FRP shell

1. **Inner Surface macrodefects;**
2. **Color in the inspection surfaces;**
   (Shell surface area for measurements);
3. **Appearance in the inspection surfaces;**
4. **Roughness in the inspection surfaces;**
5. **Thickness in the inspection points;**

1.1 Cracking;

1.2 Delamination;

1.3 Pinholes;

1.4 Bubbles;

3.1 Luster;

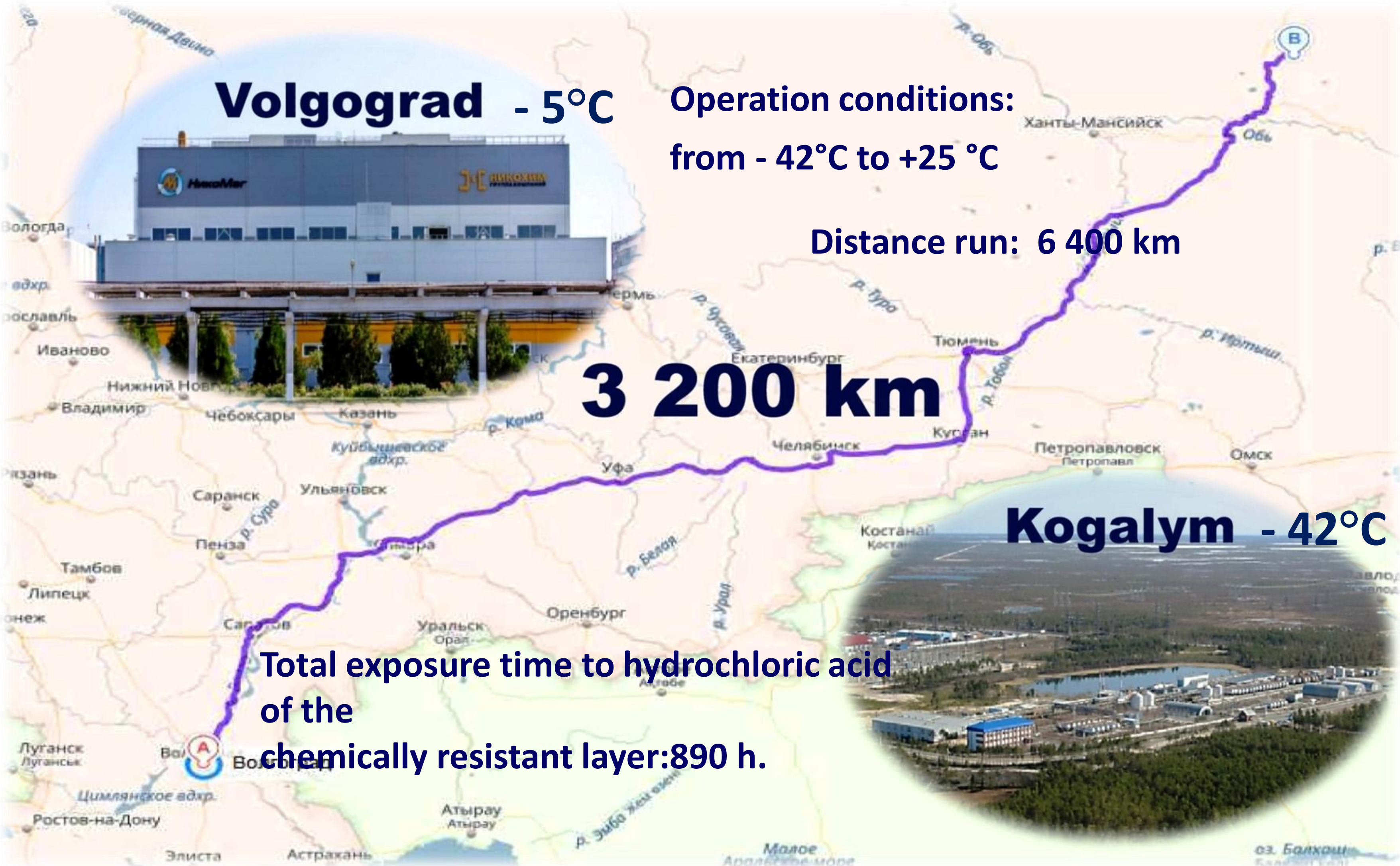
3.2 Mud retention

3.3 Chalking;

9. Pilot operation

9. Pilot operation

Operation route



Implementation

1. Transport equipment with shells made of FRP materials is already operated;
2. Such situation constrains use of tank containers with FRP shells in multimodal use (only for road and railway transport);
3. Considering the work performed it seems reasonable to establish similar requirements for use of transport equipment with FRP shells for maritime transport.

What is Next?

1. Development of the following standard requirements for all tank containers with FRP shells in partnership with all IMO member countries:
   - **Design;**
   - **Manufacture;**
   - **Testing;**
   - **Certification.**
2. Approval of tank containers with FRP shells for international maritime transportation.

Who Benefits?

1. **Safe transportation** (technical and environmental aspects);
2. **Consignee** (receives higher quality end product);
3. **Transport industry** (transportation of larger cargo quantities in one freight transportation unit, extended service life of tank containers and increased handling frequency);
4. **IMO** (promotion of innovations improving maritime transportation efficiency and safety).

What is Next?

INTERNATIONAL MARITIME ORGANIZATION

E

MARITIME SAFETY COMMITTEE
98th session
Agenda item 20

MSC 98/20/11
7 March 2017
Original: ENGLISH

WORK PROGRAMME

Proposal for a new output to amend the IMDG Code on portable tanks with shells made of Fibre Reinforced Plastics (FRP)

Submitted by the Russian Federation

SUMMARY

Executive summary:	This document proposes a new output to consider amendments to the IMDG Code on portable tanks with shells made of Fibre Reinforced Plastics (FRP) for multimodal transportation of dangerous goods. The Russian Federation believes that portable tanks with FRP shells to be cost effective, safe and environmentally friendly
Strategic direction:	5.2
High-level action:	5.2.3
Output:	None
Action to be taken:	Paragraph 34
Related documents:	None

Introduction

1 This document is submitted in accordance with MSC-MEPC.1/Circ.5 on *Organization and method of work of the Maritime Safety Committee and the Marine Environment Protection Committee and their subsidiary bodies*, taking into account resolution A.1099(29) on *Application of the Strategic Plan and High-level Action Plan of the Organization*, and proposes a new output to consider amendments to the IMDG Code on portable tanks with FRP shells. This document presents information and documentation on the technological findings of their design, construction and testing, and draft amendments to the IMDG Code.

Background

2 Multimodal transportation of portable tanks (including tank containers) plays a significant role in the global transport industry. Maritime transportation is the key part of it.

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IMO CONNECTING SHIPS, PORTS AND PEOPLE

Keeping in mind the information presented the Russian Federation has submitted to the IMO the Draft of the New Chapter for the IMDG Code on FRP matters (MSC98/20/11).

All interested Parties are invited to support the paper and to take part in the development of requirements for tank containers with FRP shells.

Thank you!