Advantages of Production and Operation of Innovational Storage Systems in Multimodal LNG-Transportation

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Abstract. The world gas consumption, as well as the needs in its transportation are growing constantly nowadays. Gas transportation in a liquid form has become a strong competitor for traditional pipelines. LNG can be transported by different transport means by sea, rivers, roads, railway. Tank-containers allow to transport LNG without its reloading into other tanks due to universal container construction. Traditional tank-containers are heavy, have limited lifespan and not sufficient durability. The innovational membrane tank-containers made of aluminum alloy with low scandium content solve the majority of the aforementioned technical problems. They provide the highest level of safety for dangerous cargo transportation, longer operation period and lower weight of the construction. The last two parameters influence positively the economic efficiency of using innovational tank-containers in multimodal LNG-transportation. The research compared the traditional steel and innovational aluminum-scandium tank-containers used in automobile and railway LNG-transportation. The innovational ones are more perspective for investment due to lower operational costs and lower depreciation rates. As an option the manufacturing could be also organized at shipbuilding yards, which are familiar with the technology of LNG-tankers construction. It allows to start new production without significant initial investments, to broaden the market and to increase the level of capacity usage.

1. Introduction

World gas consumption, trade and transportation are constantly growing. Most consumers are situated far from the gas extraction sites. The traditional way of gas transporting through pipelines on the one hand has limited destination points and can’t provide all consumers with gas, on the other hand it has become an expensive form of transportation both because of high initial investments and further operational costs. Therefore, transporting gas in a liquid form (LNG) has increased strongly and has still a very good potential of development. For instance, one of the main objectives for Russia nowadays is the exploration of the Arctic territories with its reach gas reserves. Exploration of the Yamal peninsular is connected directly with projects of LNG-production and transportation. Because of its extreme remoteness new innovative forms of transporting are needed to develop the region.

The presented research is dedicated to feasibility study of construction and operation of innovational tank-containers, which can be used for multimodal transporting of LNG by automobile,
railway and marine transport means. Their new design and innovational material allow to decrease the weight of the tank, to increase consequently the volume of the transported LNG and to decrease operational costs not increasing significantly initial investments. The objective of the review is to analyse total economic effect of implementing tank-containers of new construction.

2. Technical and economic advantages of innovational LNG-tank-containers production

While choosing the type of cargo tanks the following factors should be taken into consideration: reliability of the construction, its technological and economic effectiveness, the volume of the initial investments. That cargo storage system which shows the best combination of the aforementioned factors will become definitely a strong competitor at the LNG-transportation market. Such an example could be innovational tank-containers for multimodal LNG-transportation per railway, automobile and marine transport.

Using **tank-containers in LNG-transportation** has the following **advantages**:

- As the basic transport module is a 20 ft container (20'x8'x8.6’), the cargo (LNG in our case) should be **not reloaded** while changing the transport mean. It is a definite advantage of tank-containers comparing to railway and automobile tanks. This feature of tank-containers provides safety of cargo transportation and decreases definitely operational costs.
- Tank-containers are suitable for keeping liquids at **specially equipped sites** (container terminals), as well at **not equipped sites**.
- Tank-containers could be used **repeatedly**.
- The construction of tank-containers is **easy in operation**.

Tank-containers are produced under control of international classification societies: Bureau Veritas, ABS, Lloyd's Register, Det Norske Veritas, SGS, Germanyscher Lloyd, Russian Maritime Register of Shipping. Tank-containers correspond the International Convention of Safe Containers and Customs Convention of Containers.

Despite all the aforementioned advantages **usage of traditional steel tank-containers** has definite **disadvantages**:

- high weight of the construction;
- limited lifespan;
- low durability of the construction.

These disadvantages decrease the volume of the transported LNG, which leads to increase of cargo transportation costs, as well as to decrease of potential earnings, which could have been generated during longer lifecycle of the construction.

The study was focused on analysis of innovational technologies used in shipbuilding for constructing modern cargo tanks in LNG tank vessels, as well as in tank-containers for LNG transportation. [1] The following **innovational technological solutions** were proposed to increase operational and investment attractiveness of tank-containers construction:

- membrane technology;
- innovational aluminum-scandium alloy 1580.

The main **advantages of applying membrane construction** for tank-containers are the following:

- durability as a result of the double-hull construction;
- strong impact resistance due to ability of the membrane material to elongate and to allocate homogeneously dynamic load;
- high adaptation level of tanks to rapid temperature change since membrane system is not affected by heat strokes;
- the formed secondary barrier allows to keep the cargo unlimited period, which provides the highest level of membrane systems safety;
- fuel consumption is lower by the same cargo capacity compared to analog constructions.

Using **innovational aluminum-scandium alloy** with low scandium content of not more than 0,10% of the total mass allows:
- to decrease the cost of semi-finished goods more than twice comparing to serial aluminum-scandium alloy 1570 with 0.22% content of scandium;
- to increase corrosion resistance by 100 times comparing to steel constructions;
- to decrease definitely the weight of the construction.

Both **innovational solutions allow to improve the main technical characteristics** in comparison to traditional steel ones:
- the tensile strength increases by 8%;
- the empty mass decreases by 19%;
- the load capacity increases by 5%;
- the lifetime increases by 50%.

Despite the slight increase in construction costs by 3% comparing to a steel tank-container mainly because of increase of labour intensity, the aforementioned advantages make the innovational tank-container construction more attractive for usage in LNG-transportation both from operational and economic points of view.

Manufacturing of innovational tank-containers could be organized at different production sites, but one of the most interesting solutions is their production at shipbuilding yards. This opportunity is detailly analysed in our previous research [1]. On the one hand, the capacities of a typical shipbuilding yard are enough to produce innovational tank-containers without significant additional investments. Shipbuilding yards are familiar with the technology of LNG-tanks manufacturing on the larger examples of LNG-tankers construction. On the other hand, Russian shipbuilding yards are strongly interested in increasing their volume of production because of unstable market of civil and military shipbuilding and consequently low level of capacity usage.

### 3. Perspectives and advantages of innovational tank-containers operation in multimodal LNG-transportation

LNG-transportation in tank-containers develop actively nowadays because of definite advantages in comparison to other types of the rolling stock. Tank-containers allow to decrease transport costs due to forming optimal routes using different transport means without reloading the cargo. It is a very important argument especially for transporting the cargo from new gas fields, as well as by dangerous cargo transportation to remote highly inaccessible areas where are neither railway, nor automobile routes, and all the transportation is held mainly during the summer period by the river.

**Table 1.** Comparison of different tank types for LNG-transportation.

| Barrel | Tank vehicles / Railway tanks | Innovational tank-containers |
|--------|-------------------------------|-----------------------------|
| Operation | 1. High cost of the barrel itself, cargo handling and storage comparing to the volume of the tank-container  
2. One-time usage  
3. Storage only at special warehouses | 1. Quick ware of the chassis  
2. Expensive maintenance  
3. Necessity of reloading cargo | 1. Transportation by all types of transport means  
2. Different volume  
3. Convenience of cargo handling  
4. Multiple usage  
5. Convenient and quick discharging of LNG  
6. No necessity of reloading cargo by changing the transport mean  
7. Convenient maintenance  
8. Compatibility with all transport means |
Safety
4. Easy to damage
5. Often leakage
4. No protective frame
9. Maximum safety construction

Storage
6. Repeated handling
7. Expensive marking
8. Necessity of a large warehouse for storage
5. No opportunity of stacking
6. Necessity of a large warehouse for storage
10. Storage is possible at different places
11. Stacking up to 6 levels is possible

The market growth of the temperature logistics is expected to increase by 25-30% during the next three years. Moreover, the segment of multimodal transportation is provided not only by the growing market demand, but also by the increasing number of disposal of obsolete specialized rail wagons.

The main advantages and disadvantages of using different tank types are shown in the table 1. Within the present research there was held a feasibility study of the tank-containers operation. The following characteristic features of tank-containers constructed from different materials were considered:

• carrying capacity;
• fuel consumption;
• operational costs;
• cash flows;
• investment effectiveness.

The carried load and cost for its carriage were calculated for one transport cycle of 1000 km. The analyzed route for railway transportation is Moscow – Arkhangelsk; the analyzed route for automobile transportation is Moscow – Örebro (Sweden). The structure of the operational costs calculated for typical operational conditions is the following:

1. **Inspections and current repairs.** Inspections and current repairs for tank-containers should be held once in three years. The cost of the works are assumed at the level of 6-10% of the construction cost of the tank-container.
2. **Major repairs.** Major repairs should be performed once during the lifecycle, which is about after 12 year of operation of the tank-container. The costs constitute 25-50% of its construction cost.
3. **Maintenance.** Maintenance costs include preventive and repair works. They are set consolidated on the average for one year of operation. Mainly these costs are fixed as a percentage of the construction cost at the level of 0.5%.
4. **Overhead costs.** Overhead expenses include administrative and commercial expenses, medical and sanitary activities, communication means, navigation and other costal expenses (in case of marine transportation). The recommended rate is 10-15% of the direct costs for tank-container operation (except fuel and lubricants), which is almost the same for all types of tanks for LNG-transportation.
5. **Fuel and lubricants.** Expenses for fuel and lubricants depend on the operation regime and norms of lubricants consumption. The fuel cost is taken as the average market price. The fuel consumption is assumed at the level of 30 liter per 100 km.
6. **Truck maintenance and logistics costs** (in case of automobile transportation). A tank-container is carried by a truck with its standard costs for maintenance and different logistics costs including costs for standard procedures of cargo handling.
7. **Cost of railway transportation** (in case of railway transportation). A tank-container is carried by railway with its standard tariffs for transportation and different logistics costs including costs for standard procedures of cargo handling.
8. **Depreciation.** Depreciation costs are calculated by depreciation norms considering percentage of the tank-container construction cost, economically purposeful operation lifetime, major repairs and modernization during the operation period. Application of the innovational
aluminum-scandium alloy 1580 in tank-construction allows to increase the lifecycle to 30 years.

The earnings are calculated for one voyage or for the total year. They depend on the volume of the transported LNG and the level of the freight charges. Total economic effect should be assessed during whole lifecycle of the tank. Considering high corrosion resistance of the innovational aluminum-scandium alloy 1580 the lifecycle of the innovational tank-containers increases by 35-40% or up to 30-35 years compared to steel 09G2S. Total operational costs are about 5% less by using 1580 alloy in tank-container construction, which proves its higher economic efficiency comparing to steel constructions.

The potential revenues are calculated in two variants. The first variant supposes that the standard tariff set for transporting LNG in steel tank-containers calculated on the basis of cost for their operation could be also applied for the innovational ones to provide customers with the same conditions. In this variant the revenue while using an innovational tank-container increases by 6%.

The second variant supposes that the transportation company has opportunity to decrease its tariffs by 11% due to decrease in operational costs and offer customers better conditions. In this variant the revenue decreases by 4%, but the lower tariffs should lead to the following increase of the volume of transportation and to the increase of the market share.

The comparison of economic efficiency of using tank-containers made of steel and of innovational alloy 1580 for LNG-transportation is presented in table 2. The innovational material shows better characteristics almost by all parameters, except initial investment and maintenance cost (which are only 3% higher).

**Table 2.** Economic parameters of using tank-containers in automobile LNG-transportation.

| Technical/economic parameter | Material of tank-container shell | Variance |
|------------------------------|---------------------------------|----------|
|                              | 09G2S                          | 1580     | 1709 576 | 1 762 912 | +3% (U)* |
| Technical parameters         |                                 |          |          |          |         |
| 1.Volume of LNG transportation, m³ | 20.4  | 21.6 | +6% (F)* |
| 2. Length of a standard voyage | 1 000 | 1 000 |          |
| 3. Number of voyages per year   | 90   | 90   |          |
| 4. Volume of LNG transportation per year, m³ | 1 836 | 1 944 | +6% (F) |
| 5. Diesel consumption of a truck, l/km | 30   | 25.5 | -15% (F) |
| 6. Tank-container lifecycle, yrs   | 20   | 30   | +50% (F) |
| 7. Frequency of inspections and repairs, yrs | 3    | 3    |          |
| 8. Frequency of major repairs, yrs   | 8    | 12   | +50% (F) |
| Investment                      |                                 |          |          |          |         |
| 9. Initial investment in tank-container construction, RUR | 1 709 576 | 1 762 912 | +3% (U)* |
| Operational costs               |                                 |          |          |          |         |
| 10. Annual cost of inspections and repairs, RUR | 6 838 | 4 701 | -31% (F) |
| (8% of the construction cost totally) |      |      |          |
| 11. Annual cost of major repairs, RUR | 29 917 | 20 567 | -31% (F) |
| (35% of the construction cost totally) |      |      |          |
| 12. Annual maintenance costs, RUR | 8 547 | 8 814 | +3% (U) |
| (0.5% of the construction cost totally) |      |      |          |
| 13. Overhead costs, RUR         | 5 662 | 4 260 | -25% (F) |
| (12.5% of the construction cost totally) |      |      |          |
| 14. Fuel and lubricants for automobile transportation, RUR | 1 215 000 | 1 032 750 | -15% (F) |
15. Annual truck maintenance and logistics costs, RUR (without fuel and lubricants)  
2 385 000 2 385 000 0

16. Total annual operational costs, RUR  
3 650 966 3 456 093 -5% (F)

17. Annual depreciation, RUR  
85 478 58 763 -31% (F)

18. Total annual costs, RUR  
3 736 445 3 514 857 -6% (F)

Revenue  
19. Annual revenue (variant 1), RUR (calculated on the basis of costs per traditional tank-containers plus 20% of profit)  
4 483 734 4 747 483 +6% (F)

20. Transportation tariff per 1 m³ (variant 1), RUR (calculated on the basis of using steel tank-container)  
2 442 2 442 -

21. Annual revenue (variant 2), RUR (calculated on the basis of costs per steel and innovational tank-containers plus 20% of profit)  
4 483 734 4 217 828 -4% (U)

22. Transportation tariff per 1 m³ (variant 2), RUR (calculated on the basis of using steel and innovational tank-container)  
2 442 2 169 -11% (F)

* (U) unfavourable variance for 1580 alloy  
** (F) favourable variance for 1580 alloy

Investment attractiveness of applying innovational aluminum-scandium alloy in LNG membrane tank-containers is analysed in table 3. The feasibility study shows that investing into innovational tank-containers for use in automobile transportation has very short payback period (table 3). It allows to develop different non-standard logistic routes, which gives opportunity to increase the market share by acquiring new customers, especially in far situated territories with difficult transport accessibility.

**Table 3.** Investment effectiveness of applying innovational tank-containers in LNG automobile transportation.

| Parameter                                               | Period (year) |
|----------------------------------------------------------|---------------|
|                                                          | 0             | 1           | 2           | 3           |
| Construction costs, RUR                                  | 1 762 912     |             |             |             |
| Operational revenue, RUR                                 | 4 497 882     | 4 497 882   | 4 497 882   |             |
| Operational costs, RUR                                   | 3 456 093     | 3 456 093   | 3 456 093   |             |
| Profit tax (20%), RUR                                    | 208 358       | 208 358     | 208 358     |             |
| Net cash flow, RUR                                        | -1 762 912    | 833 431     | 833 431     | 833 431     |
| Net cash flow cumulative, RUR                            | -1 762 912    | -929 482    | -96 050     | 737 381     |
| Discounted cash flow, RUR                                | -1 762 912    | 757 665     | 688 786     | 626 169     |
| Discounted cash flow cumulative, RUR                     | -1 762 912    | -1 005 248  | -240 695    | 530 119     |
| Payback period, years                                    | 2,1           |             |             |             |
| Discounted payback period, years                         | 2,5           |             |             |             |
The analog calculations were done to assess investment effectiveness of applying innovational tank-containers for LNG transportation by the railway (table 4). The innovational material shows the same good result almost by all parameters, except initial investment and maintenance cost (which are only 3% higher). Total operation costs are about 23% less by using 1580 alloy in tank-container construction, which proves its higher economic efficiency comparing to steel constructions. The revenues were also calculated in two variants as by automobile transportation. The first variant allows to increase revenue by 6%; the second allows to decrease the tariffs by 23% and to offer potential customer better transporting conditions.

### Table 4. Economic parameters of using tank-containers in railway LNG-transportation for 1000 km.

| Technical parameter | Material of tank-container shell | Variance |
|---------------------|----------------------------------|----------|
| 1. Volume of LNG transportation, m³ | 20.4 | 21.6 | +6% (F)* |
| 2. Length of a standard voyage | 1 000 | 1 000 | - |
| 3. Number of voyages per year | 45 | 945 | - |
| 4. Number of 20 ft tank-containers on one railway platform | 2 | 2 | - |
| 5. Volume of LNG transportation per year, m³ | 1 836 | 1 944 | +6% (F) |
| 6. Tank-container lifecycle, yrs | 20 | 30 | +50% (F) |
| 7. Frequency of inspections and repairs, yrs | 3 | 3 | - |
| 8. Frequency of major repairs, yrs | 8 | 12 | +50% (F) |

| Investment |
|------------|
| 9. Initial investment in tank-container construction, RUR | 1 709 576 | 1 762 912 | +3% (U)* |

| Operational costs |
|-------------------|
| 10. Annual cost of inspections and repairs, RUR (8% of the construction cost totally) | 6 838 | 4 701 | -31% (F) |
| 11. Annual cost of major repairs, RUR (35% of the construction cost totally) | 29 917 | 20 567 | -31% (F) |
| 12. Annual maintenance costs, RUR (0.5% of the construction cost totally) | 8 547 | 8 814 | +3% (U) |
| 13. Annual overhead costs, RUR (12.5% of the construction cost totally) | 5 662 | 4 260 | -25% (F) |
| 14. Annual cost of railway transportation, RUR | 5 045 085 | 3 871 971 | -23% (F) |
| 15. Total annual operational costs, RUR | 5 096 051 | 3 910 314 | -23% (F) |
| 16. Annual depreciation, RUR | 85 478 | 58 763 | -31% (F) |
| 17. Total annual costs, RUR | 5 208 819 | 3 988 499 | -23% (F) |

| Revenue |
|---------|
| 19. Annual revenue (variant 1), RUR (calculated on the basis of costs per traditional tank-containers plus 20% of profit) | 5 208 819 | 5 515 220 | +6% (F) |
| 20. Transportation tariff per 1 m³ (variant 1), RUR (calculated on the basis of using steel tank-container) | 2 827 | 2 837 | - |
| 21. Annual revenue (variant 2), RUR (calculated on the basis of costs per steel and innovational tank-containers plus 20% of profit) | 5 208 819 | 3 988 499 | -23% (U) |
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The feasibility study of applying new innovational tank-containers were also done for railway transportation. The results are presented in table 5. They prove investment attractiveness of innovational tank-containers because of good payback period, which is even shorter than by the automobile LNG-transportation. The research showed that railway LNG transportation becomes more efficient while transporting high volumes of LNG 400 km and more during longer period of time.

Table 5. Investment effectiveness of applying innovational tank-containers in LNG railway transportation.

| Parameter                              | Period (year) | 0          | 1          | 2          |
|----------------------------------------|---------------|------------|------------|------------|
| Construction costs, RUR                |               | 1 762 912  |            |            |
| Operational revenue, RUR               |               | 5 515 220  | 5 515 220  |            |
| Operational costs, RUR                 |               | 3 910 314  | 3 910 314  |            |
| Profit tax (20%), RUR                  |               | 320 981    | 320 981    |            |
| Net cash flow, RUR                      | -1 762 912    | 1 283 925  | 1 283 925  |            |
| Net cash flow cumulative, RUR           | -1 762 912    | -478 988   | 804 938    |            |
| Discounted cash flow, RUR               | -1 762 912    | 1 167 205  | 1 061 095  |            |
| Discounted cash flow cumulative, RUR    | -1 762 912    | -595 708   | 583 108    |            |
| Payback period, years                   |               | 1,5        |            |            |
| Discounted payback period, years        |               | 1,7        |            |            |

4. Conclusion

The presented research was held to assess application of the innovational mean for LNG-transportation in membrane tank-containers constructed from new generation aluminum-scandium alloy 1580 containing low volume of scandium. The corrugated membrane of the primary barrier made of 1580 alloy prove its higher durability level compared to traditional steel constructions, where cracks of the welding seams may appear in zones of thermal influence. It is very unfavorable by transporting LNG, because it may lead to LNG leakage and corresponding risk of explosion. In this aspect, the innovational tank-containers are better applicable for temperature cargo transportation. The innovational tank-containers solve also another problem of steel tank-containers connected with sloshing of the transported liquid. Steel containers use special breakwaters inside, which increase the mass of the tank by 18-25%. Lower weight of the construction of innovational tank-containers allows to transport more cargo and to increase the operational revenue and its investment attractiveness. Moreover, the stainless steel used for traditional LNG tank-containers needs more complicated and longer processing compared to aluminum alloys, which increase its construction costs and the volume
of the necessary investment. The innovational tank-containers could be produced at shipbuilding yards which are familiar with the technology and are interested in increasing the volume of production. Thus, both technical and economic parameters of investing into innovational tank-containers construction prove that it is not only perspective from the market point of view, but also an interesting investing object which can bring high earnings to the investor.

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