Analysis of a new underwater LNG storage tank

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Abstract. The article presents the current disadvantages of onshore LNG tanks used in the Arctic. A critical analysis of the closest analogue – a floating LNG storage of gravity type - was carried out. On the basis of the results of the critical analysis a completely new design of an underwater LNG storage was offered. Also the principles of submergence and exploitation of the storage were described. The conclusion about the opportunity of application of underwater tank farms was made.

1. Introduction
The development of the Arctic has become practically a national idea. Of course, the importance of this region in life of country can be hardly overestimated. A lot of works have been published on the perspective hydrocarbon resources of the Arctic shelf. The interest in high latitudes is caused by considerable reserves of hydrocarbons in this region. It must be based on development of new technical solutions, taking into account the requirements of reliability and ecological safety for the World Ocean.

Currently liquefied natural gas (LNG) technologies are becoming more and more prominent. They are displacing the traditional Russian pipeline supplies segment. In our part of the Arctic the several plant have already been exploited. A number of other major natural gas liquefaction are planned to construct in shallow water. Increasing of production capacity on liquefaction of natural gas will require the construction of appropriate LNG storages. At the time, LNG storages will be in demand both in the areas of LNG production – as part of the LNG plants – and in the areas of LNG shipment to the consumer, where LNG storages with the addition of regasification complexes are again needed.

Ones of the famous LNG storages are the tanks, which were built as part of the Yamal LNG project. Construction of these cylindrical reinforced concrete structures with built-in insulated steel tanks was carried out in the Arctic conditions and was accompanied by the following difficulties:

- Lack of developed coastal infrastructure and the need to develop transport logistics to deliver raw materials.
- Severe climatic conditions.
- Difficult building works.
- Considerable CAPEX.
- Significant timeframe for putting the facility into operation.

All of the above considerably increase the final price per ton of liquefied gas, and often makes the project unprofitable. The objective of this article is, thus, to analyze existing technical solutions, justify the design of an underwater LNG storage tank in the Arctic shelf fields and create a design of a new underwater LNG storage tank.
2. Underwater hydrocarbons storage
The beginning of tank building in the Russian Empire was established in 1878 by Academician Shukhov. At the beginning of the 20th century the first projects of underwater oil storages also appeared and found wide application in the period of the Second World War for the purpose of storing strategic fuel reserves [1]. The same idea was proposed in Vietnam to eliminate intense evaporation of light fraction of oil which was caused by the hot climate in this region [2]. There are more than one hundred different designs of underwater tanks developed in Russia and abroad.

One of the first offshore oil storages was steel and was developed in the Russian Empire. Engineer Kirillov in 1906 got a patent for a floating tank in 1906. The construction didn’t have a bottom; the liquid was stored on water cushion. Later, such scientists and engineers as Ayrapetyan, Bunchuk, Alexi, Minakov and others contributed to the development of underwater tank construction.

Among the current developments is a steel underwater tank set up in the Solan field. A typical example of an underwater oil tank, the main material of which is reinforced concrete, is the tank at the Ecofisk field. It was built in the North Sea away from the cost of Norway. A currently known subsea flexible membrane tank design introduced by National Oilwell Varco (NOV) (Figure 1) [3]. NOV promotes its own subsea storage unit (SSU) solution to store crude oil, chemicals and produced water on the seafloor.

Horton and Maher [4] patented a deep-sea compressed natural gas storage system in 2006. Glaser in 1971 [5] proposed the idea of an underwater LNG tank. This idea was later developed in the underwater liquefied gas storage facilities developed in 2003 by the French company Technip [6].

3. Critical analysis of the nearest analogue
The patent analysis of existing technical solutions for storage LNG in the Arctic shelf conditions has shown that currently the most perspective alternative to onshore LNG storage is a floating LNG storage of gravity type as given in Figure 2.
This construction contains a polygonal ice-resistant reinforced concrete caisson, double bottom, double sides, inner bulkheads and decks, vertical cylindrical design with a dome-shaped roof and a built-in LNG isothermal tank with multilayer insulation [7].

The authors the invention presented above claim that the technical result from the use of their technical solution is:

- The possibility of building on a production site with a dry dock in an industrialized area.
- The technology of storage building simplifying.
- Reducing the cost and construction time.
- Increasing the reliability during exploitation.
- Improving ground stability.

On the basis our critical analysis we found the next disadvantages of the construction that do not allow this construction to be used safely in the Arctic shelf conditions. Ground stability causes great doubts due the processes of swelling of the bottom ground, the formation of ice lenses, the impact of waves, flows and wind on the construction because of the not streamlined shape. The huge mass of the storage may contribute to the subsidence of the sea soil.

The impact of ice on the construction can violate the «correctness» of the polygon and destroy the construction, forcing to increase the thickness of the walls of the caisson. The area at the waterline level is subjected to intensive corrosion and gradual abrasion. Additionally, the changing harsh climatic conditions of the Arctic will have an impact on the exploitation of the storage. It is also necessary to carry out preparatory work for levelling the seabed before submerging the construction, which can increase the cost of the project. The possibility of relocation described by the authors is practically excluded because of the cumbersomeness of the construction and the impracticality of the idea of moving an already installed tank to other locations, given that the ballast tanks have already filled with solid ballast. This work will cause additional difficulties.

The result associated with better resistance to global ice impacts is also not fully understood: with the existing alternative of not having to fight the ice 1-2 meters thick, but simply to install this construction just under the water below the ice exposure.

Lack of data on the exploitation of the storage indicates that the authors have not worked through the issues related to technological support of the LNG loading and unloading processes, control of excess pressure during tank return gas formation and vacuumization of gas space during storage emptying, control of the rollover phenomenon, provision of control and measuring instruments, and the possibility of safe mooring of tankers.

All of the above puts into question the reliability and safety of the proposed technical solution. The idea of placing the storage in the area of ice exposure is clearly irrational. The safety of the zone of
variable wetting during ice exposure is highly questionable, and so the designed structure must completely exclude the possibility of ice exposure, that is, it must be below the level of their impacts.

4. Underwater LNG storage

The disadvantages described above we propose to solve with a significantly different design of the underwater LNG storage (Figure 3). It contains a double-walled body 1 in the form of a hemisphere with a flat bottom 2 to form a sealed volume.

![Figure 3](image1.png)

**Figure 3.** General view of the proposed underwater LNG storage.

The underwater storage is fixed by means of submerged piles 3 on the ground of the seabed 4. The submersible piles 3 cemented in the eyelets 5 (Figure 4) of the flat bottom 2 in the form of a tripod, are submerged into the ground by means of suction devices 6 (Figure 5) with a gap 7 between the body bottom 2 and the seabed 4. The lower part of the double-walled body 1 contains the LNG connections 8 and a tray sump 9 for complete pumping of seawater or LNG.

![Figure 4](image2.png)

**Figure 4.** Top view of the underwater LNG storage.
Figure 5. The process of submerging an LNG underwater storage and fixing it using suction devices.

In the cavity of the body 1 there is an agitator 10 (Figure 6) with a drive and a cooling system 11. Instead of an agitator, you can install a constant "bottom-up" pumping of a small volume with a small pump, which will eliminate the occurrence of rollover.

The cooling system 11 is designed in the form of a coil with the height of the turns increasing from the periphery of the housing to the center which increased the efficiency of the cooling system 11, which is connected to the feed lines 12 of liquid air and its outlet 13. The cupola part of the body 14 connects with the nitrogen gas feed line and the outlet line 15 of the nitrogen gas and tank return gas mixture 16. On the cupola part of the body there is an adjustable valve 17, which is connected to the pressure sensor 18.

There is a gas collector 19 close to the underwater LNG storage, fixed by means of piles 20 on the ground of the seabed 4. The inner wall of the body 21 is made of cryogenic steel, lined outside by successive layers of thermal insulation 22 and polyurethane foam 23, and the outer wall 24 is made of reinforced concrete, faced outside a layer of waterproofing 25 in the form of a polymer coating.

The calculated wall thickness of reinforced concrete must be several times bigger than the wall thickness of cryogenic steel [8]. This is explained by the fact that the hydrostatic pressure of water on the outer wall 24 is much more than the excess pressure of the gas mixture 16 over the LNG surface and hydrostatic pressure of the LNG on the inner wall of the housing 21.

Figure 6. Sectional view of the underwater LNG storage.
5. Principle of submergence of the storage on the seabed
The storage facility is placed on the seabed. For this purpose, controlled submergence is used by gradually pumping a certain, calculated volume of seawater into the underwater LNG storage facility to give negative floatation to the construction [9].

The underwater LNG storage tank is submerged uniformly on the seabed by powerful winches mounted on opposing tugs. The underwater LNG storage is submerged and placed on the seabed. The piles are submerged by pumping seawater out of them with suction devices.

Submerged piles protect the structure from underwater flows and prevent it from floating to the surface of the water area when it is emptied. And a predetermined gap between the flat bottom and the seabed is necessary to prevent soil swelling and ice lens formation, which also simplifies seabed surface preparation work. A slope towards the tray sump is needed to completely empty the underwater storage tank of seawater or LNG. Next, the process of submerging and connecting the gas collector with the cupola body part.

6. Principle of exploitation of the underwater LNG storage
When the underwater LNG storage facility is filled with a stream of liquefied natural gas using a cryogenic centrifugal pump through an inlet pipeline, the gas mixture above the LNG mirror is compressed. Liquefied natural gas moves upward as it fills the volume and compresses the gas mixture like a piston. As soon as the excessive gas pressure reaches the set value, which is fixed by the pressure sensors installed in the body cavity, the valve is opened, and the gas mixture flows into the gas collector, which has a high carrying capacity.

A cooling system is used to reduce the intensity of tank return gas formation inside the tank and to maintain the cryogenic temperature.

The LNG is fed into the submarine tanker under overpressure of the gas mixture from the gas collector. The gas mixture enters the underwater LNG storage and displaces the LNG. The LNG is emptied via a tray sump.

The volume of storage tanks must be at least equal to the displacement of the shuttle tanker intended for the removal of the accumulated product. In turn, during the period when the tanker is absent, an appropriate volume of LNG must accumulate in the underwater tank farm so that the tanker is fully loaded.

7. Conclusions
Thus, the underwater LNG storage facility will help as to solve problems in the absence of onshore industrial infrastructure, reduce the time of commissioning the facility, increase the reliability of the reservoir due to the construction in the dry dock in developed areas of the country, and reduce capital costs.

The achievable technical result consists of a complex simultaneous provision of conditions to increase the bearing capacity of the storage under the influence of external hydrostatic pressure, to prevent the occurrence of "rollover", to reduce the intensity of evaporation gas formation inside the tank and maintain cryogenic temperature (to prevent the ground swelling and ice lenses formation), as well as to create a negative buoyancy of the structure. The proposed tank can be constructed either as a single tank or as part of a group of similar tanks, forming an underwater LNG tank farm.

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References

[1] Bunchuk V A 1969 Podvodnoye khraneniye nefti i nefteproduktov za rubezhom [Underwater storage of oil and oil products abroad]. Moscow, VNIIOENG Pub.

[2] Nguyen C N and Guseynov C S 2000 Rol’ solnechnoy radiatsii v isparenii logkikh fraktsiy [The role of solar radiation in the evaporation of light fractions]. Neftyanoye khozyaystvo [Oil Industry]. 4, 54-56.

[3] Kaalstad J P, and Kristoffersen A 2013 Flexible subsea storage unit development and applications. OTC Brasil (Rio de Janeiro, October 2013).

[4] Horton E E and Maher J V 2010 Deep water gas storage system (Patent 7654279 US, B65 D88/78, F17 C1/100, № 11/506, 288).

[5] Glazier F F 1973 Sub-aqueous storage of liquefied gases (Patent № 165,234).

[6] Bihorel P E 2009 Liquid storage installation (Patent 7553107 US, E02 D27/38, № WO2004/059205).

[7] Volkov V A, Molyayev A A and Klyanchenkov A I 2016 Underwater oil storage tank (Patent 163720 RU, B 65D, № 2016112541/03).

[8] Guseynov Ch S, Zemlyanovskiy V A 2021 Calculation of strength and thermal insulation of an underwater LNG tank, Burenie & Neft. 6, 42-46.

[9] Guseynov C S and Zemlyanovskiy V A 2021 A technology for seabed installation of an underwater massive tank, Actual Probl. Oil Gas. 2(33), 38–51.