The LNG Technology for the Development of the Arctic Gas Fields

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Abstract. The development of the Arctic offshore fields has difficulties today. The harsh climate and lack of infrastructure makes us look for rational ways to resolve the issue of hydrocarbon production in this place. One of the solutions is the construction of a floating LNG plant which can be operated in Arctic conditions. According to the experience of Arctic projects, a technology has been developed that can be helped with the implementation of projects both on the Arctic shelf and onshore. The technology, based on the nitrogen cycle, will be provided the highest liquefaction rate, a compact refrigeration unit with acceptable parameters for plant sea operation, low CAPEX and OPEX and safety at the production facility.

1. Introduction

Hydrocarbon reserves in the Arctic are estimated about 1/5 of the total reserves of world hydrocarbon resources, with natural gas in the structure of these reserves occupying the largest part and accounting for 73.8% of the total. About 17% of Arctic oil and 70% of Arctic natural gas are localized in the Russian Arctic [1].

Russia has already had experience in implementing LNG projects in the Arctic. LNG is one of the most suitable gas field development solutions in a harsh Arctic environment with a lack of infrastructure [2]. In the work [1] was described the economic efficiency of LNG transportation instead of pipeline transportation. Sea delivery of 1,000 m³ in the form of LNG is cheaper than pipeline delivery on average by 40.2%.

The absolute leader in the development of Arctic projects is Novatek [3]. The company has more than 60 licenses for the development of the Yamalo-Nenets Autonomous Okrug (YNAO). Proved hydrocarbon reserves are estimated to 16.3 billion boe [4]. Most of the fields are located on the shelf of the YNAO. The Arctic climate is meant the following difficulties: permafrost, low ambient temperatures, a short navigation period, and the absence of even coastal infrastructure. Therefore, many fields have not yet been developed [5]. The possible solution is creating of a floating LNG plant for Arctic conditions.

2. Floating LNG plant

At the last decade has been an active introduction of technological solutions in the field of LNG around the world [6]. Special attention should be given to the floating LNG plants: over the past 5 years, 6 projects have been implemented (Table 1) [7].
Table 1. Completed FLNG-projects.

| Liquefaction plant train | Liquefaction capacity (MTPA) | Infrastructure start year | Market | Owners | Contractors |
|--------------------------|------------------------------|----------------------------|--------|--------|-------------|
| Caribbean FLNG           | 0,5                          | 2016                       | -      | Pacific Rubiales Energy | Exmar/Wison/ Black&Veatch |
| Kanowit (PFLNG-1)        | 1,2                          | 2016                       | Malaysia | Petronas | Technip/DSME Tednhip/ Samsung |
| Prelude                  | 3,6                          | 2017                       | Australia | Shell | Golar/Keppel/ Black&Veatch |
| Kribi (GoFLNG Hilli)     | 1,2                          | 2017                       | Cameroon | SNH/ Perenco | Golar/Keppel/ Black&Veatch |
| Fortuna (GoFLNG Gimi)    | 2,2                          | 2019                       | Papua New Guinea | Ophir Energy | Golar/Keppel/ Black&Veatch |
| Rotan (PFLNG-2)          | 1,5                          | 2020                       | Malaysia | Petronas | JGC Corp./Samsung |

The technologies are used the same as on land project, but with several amendments - there are size limitations and climatic features. LNG production at sea is an extremely dangerous technological process that requires a detailed calculation of production risks [8], estimation of remoteness of the coastal infrastructure and the peculiarities of operating in marine conditions [9].

As shown in the table 1, among the projects are not factories which were designed for operation in the Arctic. These plants are used technologies the same as onshore projects. There are PRICO (Figure 2), AP-X (Figure 1) [10] and DMR. The only difference is the low number of units and a more compact arrangement of equipment in the technological block.

3. Decarbonization

Mixed refrigerants are often used in LNG plant. But in the future, the LNG industry is planning to replace mixed refrigerants with single component [11,12]. This is all related to the global decarbonization policy. Environmental organizations are determined to take radical action steps to
reduce emissions. For realization of this ecological politic, many countries have introduced a system of greenhouse gas emissions trading and a tax on carbon dioxide [13].

This program is worked by the cap-and-trade principle. A country's government sets an upper limit ('cap') on the total emissions in one or more sectors of the economy. Companies in these sectors must have a permission for each unit of emissions they make. They can obtain emission permits for free or buy them from the government and trade them with other companies. This corresponds to trade ("trade") in the cap-and-trade principle.

Restrictions are imposed on CO₂, methane, nitrogen oxide and various fluorinated gases. Fluorinated gases have a high ozone-depleting potential and, some also, have a global warming potential. Therefore, the use of mixed refrigerants containing fluorine should be excluded in the technological schemes of LNG production [14].

4. Problem of the research
There are many fields located on the shelf, the development of which by traditional methods is unprofitable due to their remoteness and small reserves. It is not profitable to build an offshore pipeline and an onshore LNG plant, since the fields are small and will be depleted rather quickly.

A floating LNG plant can provide monetization of such fields. These plants can also be used to monetize associated petroleum gas, as well as replace the LNG plant still under construction on the shore.

Existing technologies do not imply their use on the Arctic shelf due to the peculiarities of the equipment used and the conditions for the use of refrigerants. In addition, the issue of decarbonization in the world dictates changes in views on the use of refrigerants and the use of systems that prevent the release of hydrocarbons into the environment [15]. Therefore, the technological issue is now the most important.

5. Proposed technological solution
Novatek has developed a technological solution [16], which will be surpassed one of the most energy efficient technologies for medium and large-scale production: C3MR and Shell DMR (Table 2) [17].

| Liquefaction Technology/parameters | DMR | Novatek Arctic Cascade | C3MR |
|-----------------------------------|-----|------------------------|------|
| Energy consumption, kWt/h         | 0.215 | 0.21 | 0.214 |
| CAPEX, $/tone                     | 1177 | 450-500 | 1161 |
| Number of Cycles                  | 2 | 2 | 2+1 |

The solution is based on a high-pressure nitrogen cycle, which can be extracted ethane, cooled of natural gas and its own circuit in the reverse flow (Figure 3) [16]. According to Novatek’s data, this development will significantly reduce capital costs: the specific capital cost of the line will be 2 times cheaper (USD / ton 1100 / 400-500 in comparison with the C3MR technology) [3]. The climate characteristics of the region are taken in this technology; therefore, it has prospects for application in other Arctic projects.
Figure 3. Novatek Arctic Cascade liquefaction technology: NG – natural gas; GTE – gas-turbine engine; Exp – expander, CM – compressor; BOG – boil off gas.

However, capital investments and the scale of the refrigeration unit limit the implementation of this technology in offshore projects [18], making the onshore liquefaction process difficult due to the large number of units of heat exchange equipment.

To solve this problem, we offer our own version of this technology, which implies the use of nitrogen in the main cooling circuit (Figure 4). Ethane separation is a great idea in terms of improving the quality of the LNG outlet.

It is more rational to use ethane not to cool natural gas, but to cool the nitrogen circuit. The proposed scheme of the nitrogen circuit is shown in Figure 5. Nitrogen is compressed to a pressure of 20 MPa using compressors CM4 (process 1-2), CM5 (process 3-4), CM6 (process 5-6), cooling in air cooling or water in AC3 (process 2-3), AC4 (process 4-5), AC5 (process 6-7) up to +10 °C. Nitrogen acts as a refrigerant for natural gas, and the reverse flow will allow, by cooling the natural gas, to extract ethane from the HE1 heat exchanger (Figure 3). The ethane loop is used to cool the nitrogen loop to -40 °C (Figure 6): Process 2-3 is the cooling of natural gas to recover ethane to -92 °C in the HE1 heat exchanger.

Figure 4. Proposed technological scheme: NG – natural gas; HE – heat exchanger; AC – air cooling; CM – compressor, BOG – boil off gas.
Figure 5. $N_2$ refrigeration cycle in i-logP coordinates: 1-2, 3-4, 5-6 – compression of $N_2$ in CM4,5,6; 2-3, 4-5, 6-7 – cooling $N_2$ AC3,4,5; 7-8 – cooling $N_2$ circuit $C_2H_6$; 8-9 – expansion of $N_2$ in the Exp; 9-10 – cooling of the NG with a nitrogen circuit; 10-1 – cooling of the $C_2H_6$ and NG with a nitrogen circuit in HE1.

Figure 6. $C_2H_6$ refrigeration cycle in i-logP coordinates. 1-2 - compression of $C_2H_6$ in CM2; 2-2’ – cooling $C_2H_6$ AC2; 2’-3 – cooling $C_2H_6$ with a nitrogen circuit in HE1; 3-4 – throttling $C_2H_6$ in choke 1; 4-1 – cooling $N_2$ with a ethane circuit.

Nitrogen, cooled by an ethane loop, is expanded in an expander (process 8-9) to -165 °C (Figure 5). The underrecovery temperature is approximately 4 °C, so the natural gas in the MCHE will be cooled to -161 °C, then the flow will be throttled to the storage pressure (Figure 5).

After compression, natural gas, nitrogen and ethane can be cooled using both air coolers or water. Compression of natural gas, nitrogen and ethane is necessary because in this case, the issue of equipment compactness is resolved (compressed gas occupies a smaller volume).

Because of boil-off gas is always present during LNG production, especially during long-term storage, it was decided to equip the LNG storage tanks with a gas return system to the inlet line (Figure 4). This will avoid LNG losses as well as safeguard the floating LNG plant.
This solution makes it possible to reduce to a minimum the amount of equipment and, most importantly for a floating LNG plant, the area of the refrigeration unit, while maintaining the original solutions: ethane is separated and used as a refrigerant, and the main refrigeration circuit is nitrogen.

According to our calculations, the proposed technology will reduce capital costs by about 22.2%, considering the use of Russian equipment. Specific energy consumption will amount to 1.99 kW/h [19]. Reducing energy consumption occurs by reducing the number of equipment. In this case, the area occupied by the refrigeration unit can be reduced by about 2-2.5 times.

6. Conclusions
In the present work, an analysis of projects and prospects in the field of floating LNG plants was made mainly for Arctic. Because of the decarbonization policy, it is necessary to develop design solutions that do not contain environmentally hazardous refrigerants.

The proposed technological scheme fully complies with environmental and safety standards. The technology will show itself well in Arctic conditions due to the rational use of cold energy. Due to the compactness and relatively low weight of the refrigeration unit, the technology can be applied both onshore and on floating LNG plants.

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