

Optimal method of Arctic hydrocarbons production- and-supply system implementation

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Abstract. One of the most important issues in the development of the Arctic shelf is the rationality of transportation. Selection of the optimal method is an integral part of the project, in the framework of which this article is written. Earlier all possible methods and their advantages and disadvantages were evaluated. Within the framework of this article, the optimal method for the development of reserves on the Arctic shelf will be proposed, taking into account the possibilities of development and the effectiveness of subsequent transportation to the importing countries. The risks of gas hydrates were considered. The prospects of development of the Northern Sea Route between Russia and Asian countries are assessed; the cost of transportation of liquefied natural gas and compressed natural gas from the Barents Sea to Central Europe is compared. The hydraulic calculation of the selected section of the gas pipeline network is conducted. The economic calculation of the project as a whole is accomplished. The optimal location of the route in relation to the reserves in the Barents Sea has been chosen. Pressure losses in the selected zone were no more than 12.24 MPa with pipeline pressure from 8 to 16 MPa. In this case, condensation and subsequent formation of gas hydrates are not possible. Using only three sections of the network, the profit of the project will be 223 billion rubles per year. In accordance with this the best way of hydrocarbons realization in the Arctic is a combined method of transportation with modern methods of extraction and pipelaying laying.

1 Introduction

One of the main tasks for our country is the development of the Arctic shelf. The basis of the Russia's economy is the production and export of hydrocarbons. Russia's main oil and gas are located in Siberia and on the Arctic shelf. Most of the gas is concentrated in the Barents Sea (about 49%) in small and medium-sized fields [1]. Currently, there are 4 platforms on the Arctic shelf of Russia, the profitability of the projects of which is a big problem. Identification and assessment of the challenges of Arctic development is no less important among the economic and technological issues of existing projects to complete and optimally address them. The global goal of this research work is to identify possible ways to develop deposits on the Russian Arctic shelf, choose the optimal method of development and subsequent transportation of the extracted hydrocarbons. To estimate

recoverable reserves and highlight existing problems and possible solutions, we conducted hydraulic and economic calculations to justify the selected method of transportation. Depending on various factors, the transportation solution becomes significant, and its cost can reach billions of dollars.

Within the next decades, it will hardly make sense for Russia to switch to other types of power production, be it based on hydrogen or renewable energy sources since the country still has huge reserves of gas in the Arctic. As Litvinenko V.S. said at the conference: «It is necessary to find a way to economically realize the gas concentrated there» [2]. This global challenge needs to be broken down into subtasks, and this article raises the question of how best to transport and market the gas.

The purpose of this article is to choose the best way to sell reserves of the Arctic shelf, taking into account the possibilities of development and efficiency of subsequent transportation to the importing countries with an assessment of the risks of field development and economic and technological efficiency.

Based on the relevance and purpose of the work, we can identify the following objectives of this work:

- 1) Assess the risks and difficulties of field development on the Arctic shelf
- 2) Estimate the reserves of raw materials in the area and the demand for them
- 3) Choose the best way to sell and transport hydrocarbons
- 4) Evaluate the economic and technological aspects of the feasibility of the project
- 5) Conduct appropriate technological calculations for the selected method of transportation
- 6) Highlight the prospects for the development of the project
- 7) Emphasize the economic value of the project.

Currently, there are several problems associated with the development of the Arctic. The main ones are industrial safety and labor protection. The Arctic region has a number of specific climatic features. Oil and gas companies have not encountered such conditions before, therefore there is no normative document on labor protection, which would regulate the activities of workers. Currently, there are no methods to control and eliminate hazards associated with these features. Low temperatures and glaciers are the most common. Generally, lower temperatures result in very high risks, and icebergs result in critical risks. Transportation workers and drillers are at greatest risk. The greatest risk to the transport state is from waves up to 10 m high and glaciers, and to the drillers from high reservoir pressure [3].

One of the most cost-effective solutions in offshore development is to use the concept of ensuring a constant flow rate. Pipeline transport is statistically necessary, but there are no problems with it. This discussion disputes the nature of flow, pressure, and temperature distribution in various cases of hydrocarbon transportation. Due to the special environmental conditions in Arctic regions such as the Barents Sea, it is important to consider the risk of hydrate formation along the pipeline. To ensure reliable service life and safe operation when transporting multiphase flow, it is important to predict possible flow problems, such as hydrate formation, and to prepare a flow strategy and possible risk mitigation actions.

The amount of reserves in this region is amazing. The prospective and forecast hydrocarbon reserves of the Russian continental shelf amount to 98.7 billion tons of oil equivalent. At the same time, about 70% of reserves are accumulated in the shelf zones of the Kara Sea and the Barents Sea (including the Pechora Sea) (Figure 1). The share of oil and condensate in the total volume of resources does not exceed 10%. The structure of hydrocarbon resource potential is dominated by promising resources (about 90%), which

are very unevenly distributed on the shelves of certain seas. 84% of the known reserves of the entire Russian shelf are concentrated in the Barents and Kara Seas. 95% of the gas reserves of entire Russian shelf are concentrated on the neighboring shelf. On the shelf from the Barents and Kara Seas, the two largest oil and gas basins with a total area of 2 million square meters with potential resources of at least 50-60 billion tons of fuel equivalent and 10 fields were discovered and tested by drilling (Table 1).

Table 1. Initial geological gas reserves of the largest fields [25]

Field	Gas reserves
Murmansk	120 billion m^3
Ludlovskoe	211,6 billion m^3
Ledovoe	320 billion m^3
Rusanovskoe	780 billion m^3
Leningrad	3.0billion m^3
Harasavey	1.9 billion m^3
Kruzenshtern	965 billion m^3
Kamennomysk Sea	534.7 billion m^3
Yurkharovskoe	460 billion m^3
Antipayutinskoe	320 billion m^3

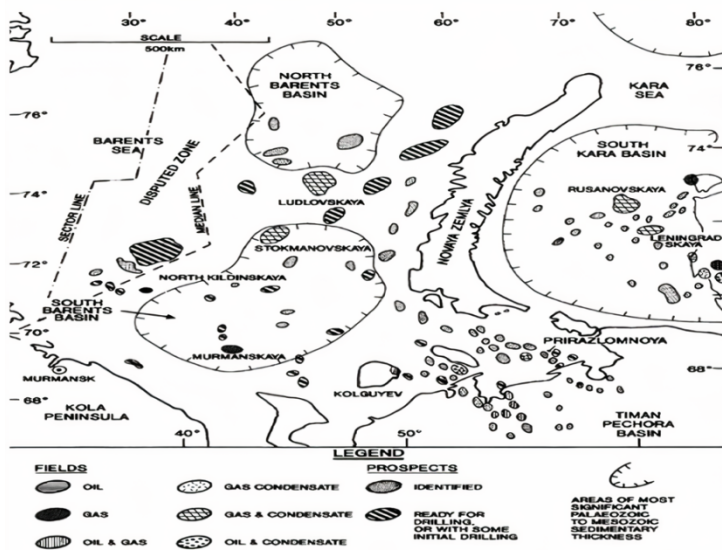


Fig. 1. Russian Barents and Kara Sea.

Figure 1 shows that most of the deposits with different reserves are located within a short distance from each other.

In the context of the realization of hydrocarbons, there are three major problems associated with gas hydrates, so it is necessary to determine ways to overcome them.

The first problem is, undoubtedly, the formation of hydrates under the Arctic conditions directly in the gas pipeline. The second problem is the development of fields with

extremely high reservoir pressure and, consequently, possible explosion. The third problem is the method of hydrocarbons extraction and dehydration for the following transportation.

Gas hydrates play a key role in field development. Both their formation and their evaporation can be a problem, depending on the context.

The problem of most deposits is the evaporation of gas hydrate interlayers at a depth of 10-15 meters, resulting in abnormally high pressure in the reservoir. Also, a large amount of sedimentary rocks in the upper layers contribute to the threat of soil undermining in the area of gas transportation. In the development of small and medium deposits this can be both an advantage and a disadvantage. Saving energy for extraction leads to catastrophic fracturing. A thorough preliminary assessment of the formation condition is necessary.

The use of electric heating technology together with partial oxidation of gas hydrates is considered the best option. The main advantages of this method are its simplicity and compactness. Many technologies have been proposed and are consistently used in the development of gas hydrate deposits.

The main task in this method is to correctly position the wells around the gas hydrate deposits. Then, it is necessary to use the technology of gas hydrate oxidation, which is due to the fact that the radius of impact on the formation is up to 4 meters. This will immediately make it possible to achieve a significant increase in gas production at the first stage. Then, when the amount of extracted gas stabilizes, the technology of electric heating of hydrates is introduced, which will significantly increase the radius of impact on the reservoir and increase gas production. Later it will be possible to introduce depressurization technology, increase the production rate and increase gas recovery [4]. This method is one of the simplest, since electrical energy can be easily regulated, and also the most environmentally friendly, since electricity is harmless and does not harm nature, unlike radiation waste.

An important parameter is the study of these resources, which require careful study to be successful in operation. This formation of the resource is a result of the regression that occurred at the end of the Miocene, during the formation of ice masses; the gas deposited in the ancient ages in this area froze. The layer, permanently frozen, contributed to the accumulation of this resource and became a reservoir in the late Pliocene. Today, tectonic structures support a less dynamic. One of the conditions necessary for the crystallization of gas is the low temperature (0 – 10°C) and high pressure (1 – 10 MPa), and high gas and water content. The bottom of the oceans, mainly on continental slopes, shelves, and abyssal plains, is 90% more favorable for hydrate formation due to adequate thermobaric conditions. In natural waters, the mass of gas is not dispersed, but is almost completely preserved and passes into the state of gas hydrate from about a depth of 100-250 meters in the polar regions. Also, for a natural environment with negative temperatures, the pressure range can be reduced. That is, at lower temperatures, the accumulation of gas hydrates is more likely to occur closer to the surface than at higher temperatures, this is due to the natural conditions of increasing pressure from the surface to the interior. These properties are characteristic of much of the Arctic region, so it is very important to study them. On the other hand, some gas hydrate deposits were found on water slopes in areas where these conditions are absent. From calculations performed in promising water areas of Arctic regions, the diagram shows the temperature range below 2°C, and the corresponding thermobaric conditions were drawn in the diagram [5].

The problem of transporting gas through the pipeline is the formation of gas hydrates due to low temperatures. Depending on certain concentrations of gas components, temperature, pressure, there is a transition from a single-phase liquefied flow to a two-phase flow and further formation of gas hydrates. The lower the temperature of the gas, the lower

its viscosity and, therefore, the rate of transportation. In offshore unstable temperature conditions, flow or other external influences on constant flow can significantly affect performance. Systems and technologies for temperature control are needed to monitor the transportation condition in real time [6].

Therefore, ensuring the reliable and safe transportation of hydrocarbons requires special attention and control [7].

2 Methodology

2.1 Resource Development Method

Among the main options for transportation by sea, it is possible to distinguish the transportation of natural gas both in compressed and in a liquefied state on special gas carriers. However, if we consider the long-term prospects of the development of the largest fields, the pipeline will be the most rational from the point of view of economy and technical equipment.

For the full-scale development of the Arctic shelf, the ideal operation is a network of gas pipelines for large and medium fields and gas carriers of compressed natural gas for small deposits.

As optimization of the route for gas transportation, it is proposed to create a link between large and medium-sized fields.

It is planned to create several key platforms equipped with primary gas treatment and dehydration units and compressors of different capacities necessary for its transfer to the next key platform [8].

Such platforms can be installed at the following fields: Ludovskoye, Shtokmanovskoye, Murmanskoye, Ledovoye, and Severno-Kildinskoye. Moreover, some of the platforms not only can maintain pressure for gas transportation but also serve as terminals for preparation of compressed gas to be transported on vessels in a compressed state.

Medium-sized fields will be connected to key gas pipelines. The development and supply of gas at the required pressure to the key platform will be carried out directly underwater using innovative underwater compressor stations and subsea development facilities.

The construction of offshore gas pipelines along the Arctic shelf and their subsequent operation is assumed guided by the regulatory legal documentation [9].

An offshore gas pipeline network was created in accordance with the selected location of key platforms and the most potentially profitable small and medium-sized fields.

After the depletion of key platform fields, additional medium and small fields can be brought into production, which will have positive effect on the economic component of the project.

The method of developing small and medium deposits - underwater drilling and subsequent exploitation is already being implemented today, in practice, in Norway. Although their conditions are different from ours, in a couple of years it will be possible to implement in an appropriate way.

Another way of efficient production is to use mobile platforms, which can deliver gas to specialized vessels in the form of liquefied natural gas and/or compressed natural gas [10]. However, the disadvantage of this technology is that most of the deposits of small sizes have relatively short periods of experimental, while investments in transporting such a platform are quite substantial. And this already is an economic challenge [11].

2.2 Input data for the calculation

Based on the data obtained, it was concluded that most of the fields have abnormally large reservoir pressure. More than 100 wells have been drilled in the Barents Sea, which is marked in pink on the map. On average, the reservoir pressure reaches 50 MPa (Figure 2), and the coefficient of abnormal pressure is 1.4. The average depth of successful well drilling was 3000 m [12].

Arctic gas has high water content. Following statistical data, average data were chosen for hydraulic calculations (Table 2). High wellhead pressure and a large number of small and medium-sized fields allow efficient use of subsea production, which provides economic benefits due to the absence of huge platform construction costs.

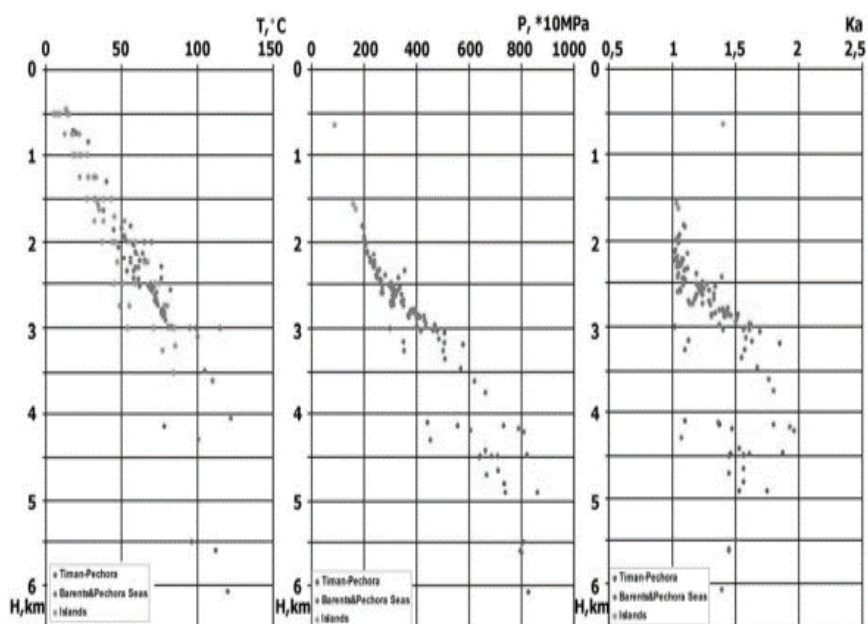


Fig. 2. The Barents Sea region. Graphs of reservoir temperatures, pressures, and their anomaly coefficients.

Table 2. Initial data for hydraulic calculations

Track / Parameter	L, km	D, m	$\rho_0, \text{kg/m}^3$	P_1^*, MPa	Current, m/h	T1**, K	T2***, K	
Ludlovskoye – Ledovoe	66.3	66.3	1.42	0.67	8.00	0.1	276	191
Ledovoe – Shtokman	107.7	107.7	1.42	0.67	7.77	0.05	278	191
Shtokman – Murmansk	580	580	1.42	0.67	16.00	0.12	281	191

Here

L – is the distance to the next platform;

D – is the diameter of pipeline; *P1 is the initial pressure;

**T1 – is the environmental temperature (Bratskikh et al. 2019.);

***T2 – is the critical temperature ($P_{cr}=4,62\text{MPa}$).

2.3 Method of the hydraulic calculations

Based on the selected route direction “Ludlovskoye - Ledovoe - Shtokman – Murmansk” (Figure 4), the hydraulic calculation was carried out at 3 sections of the gas pipeline. These sections were chosen due to their subsequent importance for the transportation of gas from small and medium fields. The input data for the calculation were selected based on the pumping performance of the existing Portovaya compressor station. Costs and diameters of pipelines were calculated based on the thermo baric conditions of the region. The calculations were carried out in accordance with STO Gazprom 2-3.5-051-2006 [13].

Pressure drop in the gas network can be found by the following formula:

$$q = 3,32 \cdot 10^{-6} \cdot d^{2,5} \sqrt{\frac{P_i^2 - P_j^2}{\lambda \Delta T_{av} z_{av} L}} \tag{1}$$

- λ – is the coefficient of hydraulic resistance of the gas pipeline section;
- L – is the pipeline section length, km;
- T_{av} – is the average temperature of the transported gas along the length of the gas pipeline section, K;
- z_{av} – is the average gas compressibility factor along the length of the gas pipeline;
- Δ – is the relative density of gas to air;
- P_i, P_j – is the absolute pressures at the beginning and end of the gas pipeline section, respectively, MPa;
- d – is the pipe inner diameter, mm;
- K – is the equivalent pipe roughness.

The coefficient of hydraulic friction λ is determined depending on the mode of gas flow mode in the pipeline, characterized by the Reynolds number:

$$Re = 17,75 \cdot 10^3 \frac{q \Delta}{d \mu} \tag{2}$$

where μ – is the dynamic viscosity of natural gases, Pa·s.

The hydraulic friction coefficient λ is determined for rough walls at $Re > 4000$ by the formula:

$$\lambda = 0,067 \left(\frac{2K}{d} + \frac{158}{Re} \right)^{0,2} \tag{3}$$

The average coefficient of gas compressibility along the length of the gas pipeline should be determined by the formulas:

$$z_{av} = 1 + A_1 P_{pr} + A_1 P_{pr}^2 \tag{4}$$

$$A_1 = -0,39 + \frac{2,03}{T_{pr}} - \frac{3,16}{T_{pr}^2} + \frac{1,09}{T_{pr}^2} \tag{5}$$

$$A_2 = 0,423 - \frac{0,1812}{T_{pr}} + \frac{0,2124}{T_{pr}^2} \tag{6}$$

$$P_{pr} = \frac{P_{av}}{P_{cr}}, T_{pr} = \frac{T_{av}}{T_{cr}} \tag{6}$$

Where T_{cr}, P_{cr} – critical values of pressure and temperature of the gas mixture.

2.4 Transportation of liquefied natural gas to Asian countries

To implement its interests in the Arctic region, Russia is developing a fleet of atomic icebreakers, infrastructure for bunkering, including tankers for liquefied gas of the Arctic class. The disadvantages of the Northern Sea Route (NSR) are the difficulty of passage in the winter, lack of infrastructure, shortage of icebreakers, and administrative difficulties in obtaining permits for passage. The remoteness of the fields from the mainland, the high cost of organization and operation, special requirements for labor and the environmental protection, as well as increasingly complex and technologically advanced wells are aspects that must be taken into account.

The main environmental threat to the Arctic Ocean is pollution by spent fuel from ships passing through the NSR. During the construction of gas wells, a technological scheme of drilling waste processing by vulcanization with obtaining building material should be introduced. Meanwhile, the only cost-effective way to develop small deposits is a floating liquefied natural gas production unit. It can be relocated relatively easily and cheaply to the next license site anywhere in the world. Offshore production can reduce costs and minimize the political and environmental risks associated with the construction of long subsea pipelines and onshore liquefied natural gas plants. It is also an important step for the global energy industry at a time when the development of problematic deposits is seen as the most reliable source of energy in the near future. The first projects to deliver liquefied natural gas to China via the Northern Sea Route have already changed the geopolitical situation in the world [14].

Today, cooperation between China and Russia in the gas industry is not limited to gas that runs through the onshore pipeline. New fuel supply channels from Russia are now being expanded. Therefore, now the North Sea Stream is one of the promising directions for the development of intercontinental energy relations between Russia and China [15].

2.5 Piping

In Arctic and subarctic conditions, the most urgent problem is the construction and laying of pipelines, since this method is the most profitable and expedient in the future. When designing those, it is necessary to take into account a number of unique factors: ice plowing, ice bed erosion, soil type, its shear strength, and environmental conditions, from temperature to the condition of marine fauna. The risks of economic loss are too high due to poorly understood necessary technical arrangement and optimal implementation of technical equipment. Here, more than anywhere else, a set of engineering solutions is important for many complex issues. There are many ways to lay offshore pipelines, but given the unique construction conditions (mostly weather conditions), as well as the experience of successfully implemented projects, the most optimal is the use of J- and S-laying methods [15].

After analyzing the advantages and disadvantages of these methods, it can be concluded that the J-method (Figure 3) is more optimal in terms of structural safety. Compressive and tensile stresses play an essential role in selecting the desired method. Considering the negative temperatures in the laying areas, special attention should be paid to the choice of steel (optimal parameters of frost resistance, high resistance to brittle fracture, reliability and compliance with the required service life). At the same time, it is impossible to exclude the S-method. For example, in places where the pipeline reaches the shore, it is much more convenient to use the latter method, since the reduction of the

working depth and simplification of control over the shore zone makes the application the J-method inefficient in terms of costs [16].

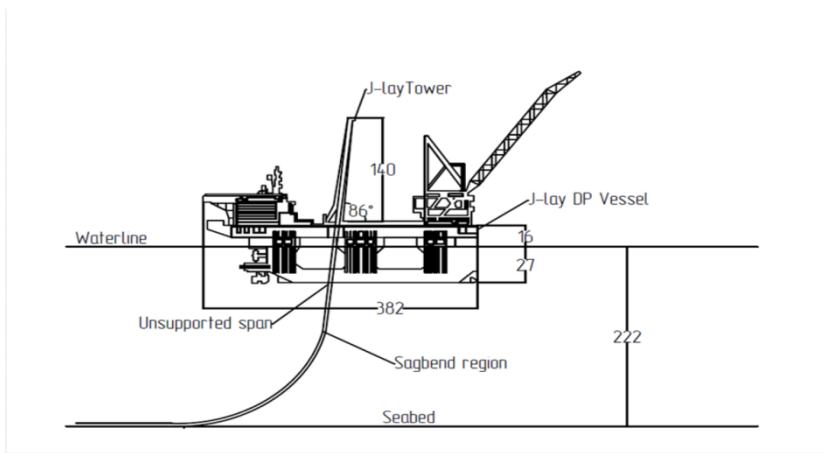


Fig. 3 - EMA of pipeline laying by J-method.

2.6 Transportation of compressed / liquefied natural gas to Europe

One of the most promising areas of the Arctic continental shelf for the production of natural gas is the territory of the Barents Sea with the Shtokmanovskoye, Ludlovsky and Ledovoye fields. Central Europe is expected to become the main consumer [18, 29]. To decide on choosing the most profitable technology for transporting natural gas from the Barents Sea to Central Europe, it is necessary to compare the cost of transporting liquefied natural gas and compressed natural gas. To do this, we need to perform the following tasks:

- 1) Compare the technology of transportation of liquefied natural gas and compressed natural gas in Arctic conditions
- 2) Using the proposed methodology, calculate the required number of ships and voyages for transportation of both types of gas to transport the same volume of natural gas from the Barents Sea to the port of Rotterdam
- 3) Estimate the cost of fuel for the transportation of liquefied natural gas and compressed natural gas.

As the research method to do this, the authors used comparative analysis of existing projects and study of natural gas transportation technology for liquefied and compressed natural gas [19, 23].

The whole data for economic calculation is presented in the paper *The construction of offshore gas pipeline systems in the Arctic zone* [20, 24, 28] along with the comparison of the cost for LNG and CNG transportation from Barents Sea to Central Europe.

3 Results and discussion

3.1 Hydraulic calculation

One of the most significant and more reliable solutions to this problem is the creation of a gas pipeline system connecting large and medium-sized fields. This solution provides for ongoing gas supplies to Central Europe.

In selecting right pipeline network (Figure 4), large fields were taken as the basis since more accurate data on the reservoir and topographic data on the possibility of their exploitation are available for them. The map shows geological zones and structures that have undergone seismic surveys, which are also a guarantee of subsequent potential implementation, but for which there is currently no accurate information.

The Murmanskoye, Shtokmanovskoye, and Ludlovskoye fields were chosen as collection points.

Compressor stations will be installed at assembly points as needed. In the event of insufficient pressure and/or throughput in the pipeline, additional compressor stations will have to be installed.

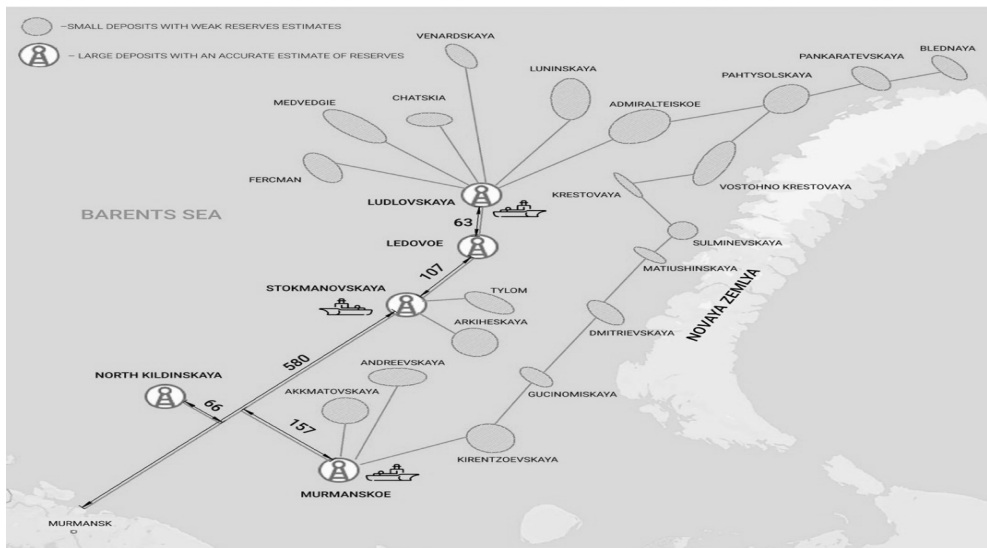


Fig. 4. Pipeline networks

3.2 Results of hydraulic calculation of pressure losses in the 3 selected sections of the pipeline

The pressure drop in local resistances (elbows, tees, stop valves, etc.) can be compensated by increasing the actual length of the gas pipeline by 5-10%. In general, after carrying out calculations (Table 3), it has been established that in these conditions losses are not so essential and are optimal for the given flow rate

Table 3. Results of hydraulic calculation

Track / Parameter	$Q_0 \cdot 10^5, \text{ m}^3/\text{h}$	$Re \cdot 10^6 \lambda$	P_1, MPa	P_2, MPa	$\Delta P, \text{MPa}$	
Ludlovskoye – Ledovoe	0.40	1.09	0.03	8.00	7.77	0.23
Ledovoe – Shtokman	0.76	2.05	0.03	7.77	6.17	1.60
Shtokman – Murmansk	1.04	28.08	0.03	16.00	5.58	10.41

The meanings of parameters are presented in section 2.3.

Thus, the total losses on the gas pipeline from the Ludlovskoye field to the city of Murmansk will be: $\Delta P = 12.24 \text{ MPa}$. As result, at the section from Shtokmanovskoye field to the city of Murmansk the initial pressure should be increased from 6.17 MPa to 16.00 MPa, i.e., by 9.83 MPa.

3.3 Results of economic calculation

In a simplified economic calculation, the profitability of the project was calculated without taking into account passive costs, taxes, discount rates over time and, approximately, with them. In both cases, the profitability of the project is positive. The main buyers of Russian gas transported through the pipeline will be the countries of Western Europe. The main buyers of compressed natural gas delivered by gas carriers along the Northern Sea will be Asian countries.

According to the calculations (Table 4), it will take 2 vessels to transport liquefied natural gas from the port of Murmansk to the port of Rotterdam, and 8 vessels for compressed natural gas, but it is worth considering that the cost of one liquefied natural gas tanker is higher due to complex construction of liquefying facilities. Although the fuel consumption and cost per voyage for compressed natural gas tankers is lower than for liquefied natural gas tankers, when transporting the same volume of natural gas the fuel cost per year for compressed natural gas tankers is 17% higher due to the higher number of voyages. In addition, it should be taken into account that 65% of the cost of transporting liquefied natural gas is spent on liquefaction, storage and regasification at the liquefied natural gas plant. Meanwhile, compressed natural gas vessels can receive and return gas on their own, the process does not require pre-treatment, filters and compressors are placed on the vessel. This advantage will save on infrastructure costs that are typical for liquefied natural gas transportation. From an environmental point of view, the use of compressed natural gas technology is preferable due to the low losses of gas during transportation.

Thus, to make the final choice between liquefied natural gas and compressed natural gas technologies for transporting natural gas from the fields of the Barents Sea to the European market, it is necessary to continue research on this issue and make an economic assessment with the account of depreciation, operating and freight costs, port charges, and customs duties.

The possibility of combining the gas pipelines with the Nord Stream simplifies the task and guarantees gas supplies to European countries up until 2100.

With stable deliveries to Europe by the three sections described in 3.2, the profit will be about 3.24 trillion rubles a year (Table 5). The project implementation time is 10 years.

Table 4. Calculation results for the case of transportation to the port of Rotterdam

Parameter	LNG	CNG	Unit
The estimated number of the carrier ship	2		8
The cost of fuel for one voyage	96.4	41.07	Thsnd Euro.
The estimated number of the voyages	56		160
The estimated annual fuel cost	5.4	6.5	Mln Euro

Table 5. Results of economic calculation

Parameter	Result	Unit	Parameter	Result	Unit
The cost of laying 900 all gas pipelines to the shore**		Bln rub	Profit on export to Europe per year****	50-223	BlnRub
The amount of initial 607 costs for the creation of 3 platforms***		Bln rub	Payback period	15.8	years
Price per 1 km in a marshy area	100	Mln rub	Total cost	1.70	tril rub
Construction cost to reach the nearest gas pipeline	120	Bln rub	Payback period will increase in*	2.5	times

*All additional costs included

** 10 Bln Euros were spent on the construction of the Nord Stream. [27] The length under consideration is about the same.

*** Based on the cost of the Prirazlomnaya platform

**** Depends on the year of the project development. The peak profitability point of for the 15th year of the project implementation is 223 billion rub

4 Conclusion

Thus, in the course of this work, the requirements to design, construction, operation, and environmental safety necessary for organization of pipeline gas transportation on the Arctic shelf were studied; a rough estimation of structural parameters of the gas pipeline was made; , the scheme for its construction was proposed taking into account open gas fields, and hydraulic calculation and economic analysis were carried out.

Offshore gas pipelines in the Russian Federation are designed mainly for special technical conditions with due consideration of many design features. In this project, it is necessary to use a J-type pipe laying vessel. In coastal zones, the pipeline is laid in trenches, and the sections remote from the shore are on the bottom.

The pipe must be steel, seamless, with an inner diameter of 1420 mm, with epoxy coating on both inner and outer surfaces, and have a concrete casing of 60-110 mm for ballasting. Total losses of pressure along the gas pipeline from the Ludlovskoye field to the city of Murmansk will be 12.24 MPa. As a result of the economic analysis, the

following values were obtained that characterize the profitability and prospects of this project. Profit per year for deliveries to Europe via the Nord Stream amounts to 223 billion rubles (excluding taxes). Initial costs (excluding cleaning units, electricity, time elongation, and production costs) amount to 600 billion rubles. The payback period is 15.8 years.

According to the work, we can conclude that the project is not only realistic but also profitable. At the same time, according to the TESCIMP-methodology, the project is profitable for everyone [21, 22, 26]. Difficulties in both development and transportation in such conditions are many, but everything is realistic to be accomplished.

As a conclusion about the long-term work in the framework of the Arctic project, the following proven arguments can be highlighted:

1. Economic and technological aspects confirm the success of the combined method of transporting hydrocarbons, namely a network of gas pipelines with key platforms that serve as terminals, to transport compressed natural gas from platforms in the Barents Sea around the world.

2. Gas hydrates are a big problem, both during development and during transportation. The most reliable way to develop gas hydrates is partial oxidation. The solution to the problem of gas hydrates in the pipeline is digital technology and reliable pipe laying

3. The payback period of the project is confirmed by economic calculation and calculations of transportation to Rotterdam

4. According to calculations, promising opportunities for development of the project taking into account the depletion of reserves – is the development of methods of underwater drilling of smaller fields

5. Average pressure losses during transportation along the selected route due to the presented thermodynamic conditions amount to 12.24 MPa.

6. There are a wide range of threats to humans and surrounding countries.

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