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Author: **Alexey O. Basov**	……………………………………… (signature of author)

Programme coordinator: **Professor Dimitrios Pavlou (University of Stavanger)**

Supervisor(s): **Professor Ove Tobias Gudmestad (Unversity of Stavanger)**
Professor Anatoly B. Zolotukhin (Gubkin Unversity)

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Abstract

Since the first oil and gas field was discovered the industry has changed and a lot and new challenges have appeared.

While the industry was developing related sciences like geology, geophysics, and others, companies started exploration and development offshore fields and further to the Arctic offshore. The Arctic is the special region where approaches for development and exploitation used elsewhere do not work.

A severe weather condition requires a large number of standards both for operations and material selection. Exactly a large number of standards is one of the biggest issues concerning development and operations in Arctic conditions because more than 3 countries have access to this region. This means that we have to develop only one standard system for all countries and companies who would work in this region.

Another challenge is product transport because ice covers most of the Arctic area during the winter period and this period could continue for more than half a year. There are a lot of solutions to this problem and some of them are presented in this Master thesis.

Also, this master thesis covers such aspects as choosing suitable facilities for the region’s conditions with an explanation of why exactly these types of production units are the best way to develop this field. At the same time, this paper discusses the possible location of these facilities based on technical, economic and environmental sides.

Acknowledgments

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Writing this master's thesis would have been impossible without the excellent support provided by my mentor and professor Owe Tobias Gudmestad. He was one of the few who believed in me and supported me in my studies at the University of Stavanger. He always worries and cares about his students. His deep and irreplaceable knowledge in the field of development and development of offshore fields was transferred to students in the most understandable form. His desire to convey this knowledge and classes with students, even outside the school hours, motivated me.

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Finally, and most importantly, I would like to thank my family, who gave me great support, believing in me.

Content

List of figures

List of tables

Chapter 1. Introduction

The Arctic is a very severe region with a lot of conditions that are dangerous not only for industrial facilities but also for human life. That's why a big amount of requirements for building and operation exist.

The main issue in Arctic region is weather namely all kinds of ice: 1) Ice that covers water surface could be cause of some facilities damage and as a result huge disaster and big money loss; 2) Ice that appears at the top of structures adds some mass on the structure and if this would not take into account in the structure calculations it could lead to failure of structure; 3) Icebergs that could slam the structure and destroy it.

This Master thesis presents one of the possible solutions for the development of the Leningradskoye gas-condensate field. This concept of development includes choosing types of operational facilities, their location, and protection as well as transportation of production and protection systems.

1.1 Scope of work

This Master thesis focuses on Leningradskoye gas-condensate field development concept in Arctic conditions which includes: environmental conditions analysis, choosing and location of the production system, analyzing and choosing of transportation system type, pipeline trajectories development, choosing protection system for subsea facilities.

Chapter 1 Introduction

Chapter 2 General information - gives an overview of the geographical location of the Leningradskoye gas-condensate field; climatic and ice conditions of the Kara Sea.

Chapter 3 Selection and location of development facilities – This chapter presents an analysis of possible solutions for development systems and its location on the geographical map.

Chapter 4 Transportation system design – This chapter presents a choice of transportation system and pipeline trajectories development.

Chapter 5 Impact of technical solutions on the environment – On this chapter impact from onshore and offshore facilities installation on the environment have analyzed.

Chapter 2. General information

2.1 Geographic location of Kara Sea

Leningradskoye gas-condensate field is located in the Kara Sea. The Kara Sea is a part of Arctic Ocean and located between Novaya Zemlya and Yamal islands in the north part of the Russian Federation.

Its northern border goes from the Cape of the Arctic (Komsomolets Island of the Northern Earth Archipelago) to Cape Kolsat (Father Graham Bell of the Franz Josef Land Archipelago). The western border of the sea runs from this cape to Cape Zhelaniya on Novaya Zemlya, further along, the eastern shores of Novaya Zemlya, along the western border of the Kara Strait, along the western shore of Vaigach Island and along the western border of the Yugorsky Shar to the mainland. The eastern border of the sea goes along the shores of the islands of the Severnaya Zemlya archipelago and the eastern borders of the straits of the Red Army, Shokalsky and Vilkitsky, and the southern border goes along the mainland coast from Cape White Nose to Cape Pronchishcheva.

Figure 2.1 Location of Kara Sea [15]

The Kara Sea is wide open to the Arctic basin of the Arctic Ocean. Most of its water area lies on the continental shelf, so it belongs to the type of continental marginal seas. Its area is 883 thousand km2, the volume is 98 thousand km3, the average depth is 111 m, the maximum depth is 600 m.

There are many islands in the Kara Sea. The vast majority of them are small and located along the Asian coast.

The coastline of the Kara Sea is very winding. The eastern shores of the Novaya Zemlya are carved by numerous fjords. The mainland coast is significantly dissected. The Baydaratskaya Bay and the Gulf of Ob stretch deep into the land, between which lies the Yamal Peninsula, and to the east, there are large bays: Gydansky, Yeniseysky, Pyasinsky.

The coastal areas of various forms and structures are of different morphological types. Abrasion coasts predominate, but accumulative and icy occur. The east coast of Novaya Zemlya is steep and hilly. The continental coast in some places is low and gentle, in places steep.

2.2 Climatic conditions

Located in the high latitudes of the Arctic and directly connected to the Arctic basin, the Kara Sea is characterized by a polar maritime climate. The relative proximity of the Atlantic Ocean somewhat softens the sea climate, but Novaya Zemlya serves as a barrier to the warm Atlantic air and waters, therefore the climate of the Kara Sea is more severe than the climate of the Arctic Barents Sea.

In the autumn-winter time, the Siberian anticyclone is formed and established over the Kara Sea, the Polar maximum increases, and the trough of the Icelandic minimum influences the atmospheric processes over the sea. At the beginning of the cold season, the north wind prevails in the northern part of the sea, and in the south, the winds are unstable in direction. Wind speed at this time is usually 5-7 m/s. The winter baric situation determines the prevalence of southerly, southwesterly and southeasterly winds over most of the sea. It is only in the northeast that the winds of northern rumba often blow. Wind speed is on average 7-8 m/s; often it reaches a storm force. The greatest number of storms is observed in the western part of the sea. A local hurricane wind, Novaya Zemlya bura, is often formed off the coast of Novaya Zemlya. It usually lasts several hours, but in winter it can last 2-3 days. The southern winds, as a rule, bring continental air strongly cooled over the mainland into the Kara Sea. The average monthly air temperature in March at Gulf of Chelyuskin is –28.6 °C, at Gulf of Desires –20 °C, and the minimum air temperature can reach –45–50 °C. However, with southerly winds, relatively warm sea polar air sometimes comes to the western part of the sea. It is brought by cyclones, which come from the west and, meeting on their way a chain of Novaya Zemlya Mountains, deviate to the south and south-east. Most often warm air flows occur in February, with which even a certain increase in average air temperature is connected. In addition, these invasions of warm air and Novaya Zemlya bura cause unstable winter weather in the western part of the sea, while in its northern and eastern regions there is relatively stable cold and clear weather.

In the warm season, the Siberian maximum is destroyed, the low-pressure trough disappears, and the polar maximum weakens. In this regard, in the spring winds blow, unstable in direction, the speed of which usually does not exceed 5-6 m/s. Cyclonic activity weakens. Spring heating occurs fairly quickly, but there is no significant increase in air temperature. In May, the average monthly air temperature is about –7 °C in the west and about –8 °C in the east of the sea.

In the warmest month, July, the average air temperature is 5-6 °C in the western part of the sea and 1-2 °C in the east and northeast. In some areas of the mainland coast, the temperature can rise to 18 and even to 20 °C. Snow can fall in any summer month.

The Kara Sea accounts for about 55% (1,290 km^3 / year) of the total flow to all the seas of the Soviet Arctic. Ob annually brings on average 450 km^3 of water, the Yenisei - about 600, the Pyasina - 80, the Pur and Taz - about 86 and other rivers up to $75km^3$. Approximately 80% of river water comes into the sea at the end of summer - beginning of autumn (June - September). In winter, in very small quantities only water from the largest rivers flows into the sea. Virtually the entire continental runoff enters the Kara Sea from the south. In general, almost 40% of the area of this sea is influenced by continental waters, which create a surface desalinated layer with a pronounced density gradient. For the Kara Sea, western, eastern and fan-shaped variants of the distribution of freshened waters are established. Stoke, concentrated in the area of. Dixon Island influences the development of the flow system. Thus, continental runoff is an important factor in the formation of the hydrological characteristics of the Kara Sea.

2.3 Temperature and salinity of seawater.

The structure of the waters of the Kara Sea is formed by the surface Arctic, mouth and deep Atlantic waters.

Most of the area of the sea is surface Arctic waters. They are formed as a result of the mixing of the waters coming from other basins and continental runoff, and their further transformation. The thickness of the surface of the Arctic waters in different areas of the sea depends mainly on the relief of the bottom. At large (200 m and more) depths, these waters lie to the horizons of 150–200 m, and in shallow areas, they spread from the surface to the bottom. In general, they are characterized by a temperature close to the freezing point, and slightly lower salinity (29–33.5 %). Arctic surface waters are divided into three layers. The upper (0–50 m) has a uniform temperature and salinity, which is explained by the active mixing of the waters during the winter vertical circulation. It is underlain by (from horizons 20–25 to 100 m) a layer with the same low temperature and sharply increasing (up to 34 % and more) salinity. Deeper (from a horizon of 100 m to 200

m) is a layer with characteristics intermediate between subsurface and deep Atlantic waters. In spring and summer, on ice-free spaces of the sea, a thin layer (5–10 m) of elevated temperature and low salinity is distinguished in the upper layer of surface Arctic water.

In the warm season, near the river mouths, river waters are mixed with cold and salty surface Arctic water. As a result, peculiar water with high temperature, low salinity and, accordingly, low density is formed here. It spreads over the surface of more dense arctic waters, on the border with which (horizons of 5–7 m) large salinity and density gradients are created. Desalinated surface water sometimes extends over considerable distances from the formation sites. Under the surface of the Arctic water in the St. Ann and Voronin gutters are relatively warm (0-1 °C) and saline (about 35) Atlantic waters. They come from the Central Arctic Basin and are transformed from north to south, and their upper boundary (0 °C isotherm) rises from a horizon of 100 m to a horizon of 75 m. The number and characteristics of the Atlantic waters entering the sea change from year to year.

Located in high latitudes and during the year completely or largely covered with ice, the Kara Sea warms very little. On the surface, the temperature generally decreases from southwest to northeast. In the autumn-winter season, the sea surface is intensively cooled, and in open spaces, the temperature of the water rapidly decreases. In winter, in the under-ice layer, it is everywhere close to the freezing point of water and is –1.5 - 1.7 °C.

In the spring, the sun's heat is spent primarily on the melting of ice, so the water temperature on the surface is practically the same as in winter. Only in the southern part of the sea, earlier than others freeing themselves from ice and experiencing the influence of continental runoff does the temperature at the sea surface gradually increase. In the summer, during the warmest months — July and August — on free ice-free spaces, the surface water temperature is 3-6 °C, and under ice, it is slightly above the freezing temperature.

The vertical distribution of water temperature varies by seasons. In winter, from the surface to bottom, almost everywhere the temperature is close to the freezing point. Only in the gutters St. Ann and Voronin, through which the deep Atlantic waters of the warm layer of the Arctic basin penetrate into the sea, it begins to rise from the horizons of 50–75 m and in the layer of 100–200 m reaches values of 1–1.5 °C, and goes deeper again. In the southernmost parts of these troughs, the temperature at horizons of 100–200 m rises slightly. In spring, in the southern regions of the sea that have become ice-free, water temperatures above 0°C are observed up to horizons of 15–18 m in the southwestern part of the sea and up to horizons of 10–15 m in the east. Deeper it drops sharply to the bottom. In the northern part of the sea, the winter temperature distribution of water temperature is maintained vertically. During the warmest summer months, the water temperature in the shallow waters in the southwestern part of the sea becomes above zero from the surface to the bottom. In the western regions, the relatively high temperature of the water is observed to 60–70 m, and the deeper it gradually decreases. In the east of the sea, the water temperature on the surface is 1.7 °C, with a depth it rapidly decreases and reaches 10.2 °C on the horizon 10 m, and 1.5 °C at the bottom. In the northern part of the sea covered with ice, the vertical distribution of temperature in summer is the same as in winter. At the beginning of the autumn cooling, the water temperature on the surface is slightly lower than in the subsurface (up to 12–15 m in the south-west and up to 10–12 m in the east) horizons, from which it decreases to the bottom. With autumn cooling, the temperature levels off throughout the entire water column, excluding areas where deep Atlantic waters spread.

Free communication with the Arctic basin, a large continental drain, the formation and melting of ice are factors that determine the magnitudes and distribution of salinity in the Kara Sea. The salinity of its surface waters varies from 3-5 % in the region of Dixon Island to 33 and even 34 % in the open sea.

In the cold season, when the river runoff is small and intense ice formation occurs, the salinity is relatively high.

As a result of the spring inflow of river waters, the surface salinity decreases in the mouth areas and in the coastal strip. In summer, due to the melting of ice and the maximum spread of river water, the surface layer is desalinated. The lowest salinity (less than 5 %) is observed in the areas of the mouths of the Ob, Yenisei and other major rivers. North of the Ob-Yenisei shoal, the salinity of surface waters increases to 15–20 %. For the northern regions of the Kara Sea (to the north and north-east of the Desires metro station), the salinity of the surface layers rapidly increases from south to north to 34 %.

The distribution of salinity is influenced by the process of melting ice. Among the ice, the salinity on the surface is 7-8 % - lower than on the ice-free parts of the sea. In the water column, salinity increases from the surface to bottom. In winter, in most parts of the sea, it rises relatively evenly from 30 % on the surface to almost 33 % of the bottom. Even near the mouths of rivers, bottom waters can have high salinity.

In the spring, especially at the beginning of the season, the vertical salinity distribution is similar to the winter one. Only at the coast, the increased inflow of continental waters desalinates the most superficial layer of the sea, and with depth, the salinity rises sharply to a horizon of 5–7 m, below which it gradually increases to the bottom.

In summer, the salinity from low values on the surface (10–20 %) increases sharply with depth and has 29–30 % at horizons of 10–15 m. From here, it increases more smoothly, and at the bottom, it reaches 34% and even higher.

This nature of the vertical salinity distribution in the summer months is especially pronounced in the eastern half of the sea - in the zone of distribution of river waters and among the drifting ice in the northern areas of the sea. In stormy weather, the wind mixes the upper 5-meter layer of water; therefore, a uniform, but somewhat higher salinity is established in it. Directly under the mixed layer, its value immediately increases dramatically, below it gradually increases with depth. Relatively homogeneous and saline Barents Sea waters flow into the western part of the sea, so the salinity here is slightly higher, and with the depth, it does not increase as sharply as in the east of the sea.

By the autumn the river runoff decreases and ice begins to form in the sea. As a result, the salinity on the surface increases, the salinity jump begins to smooth out, and vertically it changes more evenly.

2.4 Currents

The density of water in the southern and eastern parts of the Kara Sea is lower than in the northern and western regions. In autumn and winter, they are denser than in spring and especially in summer. Density increases with depth. In autumn, winter and early spring, the density gradually increases from the surface to bottom. In summer, during the maximum distribution of river waters into the sea and during the melting of ice, the density of the upper layer 5–10 m thick decreases and under it rises sharply.

Thus, the increase in density with depth occurs in a very sharp jump. The water column is divided into two layers. This is most pronounced in the east of the sea, in the zone of distribution of river waters, less brightly in the north, where a decrease in the density of surface waters is associated with desalination during the melting of ice. In the western part, the density gradually increases with depth, since homogeneous waters of the Barents Sea penetrate here.

Wind mixing of waters in open spaces of the sea occurs most intensely in the autumn, during frequent and strong storm winds. In the central and western regions, the mixing penetrates to horizons of 10–15 m, and in the Ob-Yenisei shoal, its depth does not exceed 5–7 m, which is associated with a sharp separation of water by density due to desalination.

Autumn-winter convection is much more developed. The most favorable conditions for density mixing are formed at the western shores of Severnaya Zemlya, where fairly weak stratification of waters, rapid cooling, and intensive ice formation are observed. Convection here penetrates to the horizons of 50–75 m. Similar conditions for the development of convection and about the same depth of its distribution are observed in the southwestern and northwestern parts of the sea. In the central regions and in the Ob-Yenisei shallow water, which is under the influence of continental runoff, convection develops only due to salinization during the formation of ice and reaches the bottom only towards the end of winter. Sliding of water on underwater slopes increases the vertical circulation in areas with rapidly changing depths.

A relatively stable system of currents is created in the sea, associated with the circulation of the waters of the Arctic basin and the neighboring seas. The continental drain maintains the stability of currents. The Kara Sea is characterized by a cyclonic gyre in the south-western part and multidirectional flows in the southern, central and northern regions. The western ring of currents is formed partly by the Barents Sea waters, which flow here through the southern Novaya Zemlya Straits and move toward Yamal and further north along its western shore. At the northern tip of the Yamal Peninsula, the Ob-Yenisei current intensifies, and further north it gives a branch to Novaya Zemlya. Here, this stream turns to the south and in the form of the East Novaya Zemlya current moves along the shores of Novaya Zemlya. At the Kara Gates, this current spurs a branch into the Barents Sea (Litke current), where it merges with the Barents Sea waters entering the Kara Sea and closes the cyclonic circulation. With a significant development of the Siberian maximum, atmospheric pressure and a relatively northern location of the Icelandic minimum, this ring of currents covers the entire western part of the sea. In cases of intensive development of the Polar maximum and displacements to the west of the Icelandic minimum, the cyclonic water cycle is limited to the extreme south-western part of the sea, and the currents in it are somewhat weakened.

In addition to the Ob-Yenisei Current in the Dixon region, the West-Taimyr Current begins, whose waters are mainly carried to the Vilkitsky Strait, and partly spread along the west coast of Northern Earth to the north.

Above the St. Anne chute is followed by the same course as a continuation of the Yamal (or Ob-Yenisei) flow. It is directed to the north and goes beyond the limits of the Kara Sea.

The velocities of currents in the sea, as a rule, are small, but with long and strong winds they increase. As for the patterns of movement of the deep waters, (with the exception of the patterns of distribution of the deep Atlantic waters penetrating from the Central Arctic Basin into the sea through underwater troughs) they are not yet sufficiently clear.

Within the Kara Sea, currents transfer relatively homogeneous in terms of thermohaline indices of water, therefore in it, the frontal sections are not clearly expressed. In the summer, areas of contact between the river and sea waters and border waters serve as original fronts. Their position and size often change during the warm season, and in the cold season, they are absent.

The tides in the Kara Sea are expressed very clearly. One tidal wave enters here from the Barents Sea between Franz Josef Land and Novaya Zemlya and spreads south along the eastern coast of Novaya Zemlya, the other from the Arctic Ocean goes south along the western shores of Northern Earth. Right semi-diurnal tides prevail in the sea, but diurnal and irregular tides are observed in some areas.

The rate of tidal currents reaches significant values. For example, about Beliy Island, in the Kara Gate, off the western coast of Taimyr, it significantly exceeds the speed of constant currents in the Kara Sea. The magnitude of the tides is relatively small. On all points of the coast, they are on average 0.5–0.8 m, but in the Ob Bay exceed 1 m. Often they are suppressed by surge-and-surge fluctuations of the level, which are more than 1 m on the continental sea, and in the depths of the bays and lips, iceless seasons reach 2 m and even more.

Frequent and strong winds develop significant waves in the Kara Sea. However, the size of the waves depends not only on the speed and duration of the wind but also on the ice cover. In connection with this, the strongest excitement is observed in the little icy years at the end of summer - the beginning of autumn. Waves with a height of 1.5–2.5 m have the greatest repeatability; waves of 3 m and more are less frequently observed. The maximum wave height is about 8 m. Most often, strong waves develop in the southwestern and northwestern parts of the sea, usually ice-free. In the central shallow areas, the waves are weaker. During storms, short and steep waves from here. In the north of the sea, the excitement is extinguished by ice.

2.5 Icing

The Kara Sea is completely covered with ice in autumn and winter, and in summer only part of its surface is freed from the ice. Ice formation begins in September in the northern areas of the sea and in October in the south. From October to May, almost all the sea is covered with ice of different types and ages.

The coastal zone is occupied by fast ice. In the northeastern part of the sea, fixed ice forms a continuous strip extending from about Beliy Island to the archipelago of Nordenskiöld and from there to Severnaya Zemlya. In the summertime, this fast ice band is cracked and broken up into separate fields. They persist for a long time in the form of the Northern Earth ice massif. In the south-western part of the sea, fast ice occupies small areas.

A zone of pure water or young ice is located more seaward from still ice. In open areas of the sea, drifting ice is common, among which one-year-olds of local origin predominate. Their maximum thickness (in May) is 1.5–2 m. In the south-west, the Novaya Zemlya massif is located, melting “in place” during the summer. In the northern regions of the ice is maintained constantly. Spurs of oceanic ice massifs descend here. The distribution of ice in spring and summer is very diverse and depends on winds and currents.

2.6 Seabed profile

The relief of the Kara Sea is very uneven, with depths of up to 100 m prevailing. In the shallow waters of the southern and eastern parts of the sea adjacent to the mainland, there are numerous small deepening separated by elevations of different height. The relatively flat bottom is in the central regions.

To the north of the mainland coastal shallow water lies the Central Kara High, extending to the continental slope. It separates two trenches: in the west, St. Anne's trench (here is the greatest depth of the sea), and in the east - Voronin's trench with depths of more than 200 m.

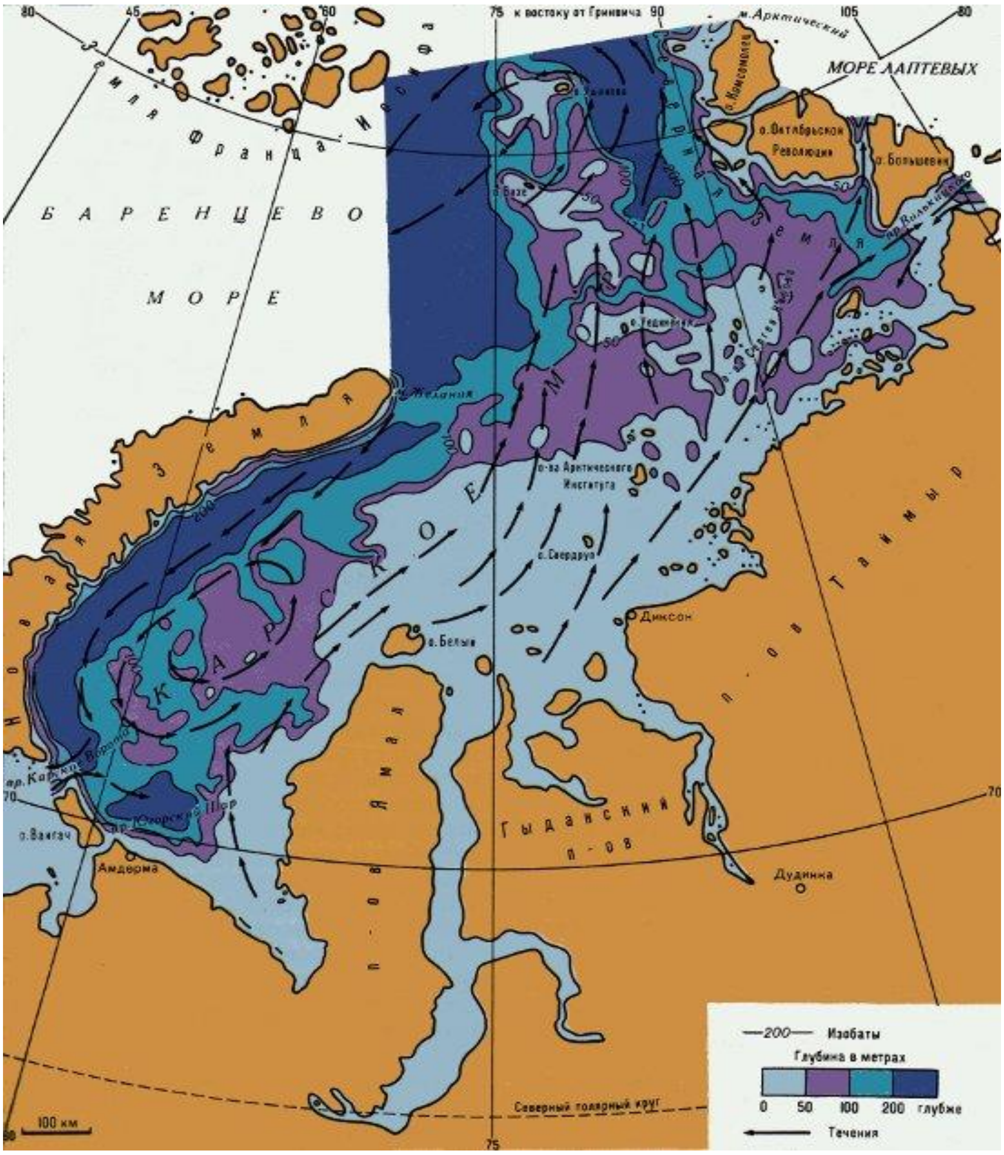

Figure 2.2 Depth distribution of Kara Sea [16]

2.7 General information about Leningradskoye field

Leningradskoye gas condensate field is located in Russia, in the Yamal-Nenets Autonomous District, in the Kara Sea, 125 km north of the village Harasavey. The gas content is 52.5 km2 included in the Yamal oil and gas region of the West Siberian oil and gas province. Gas deposits were discovered in 1990, condensate-containing - in 1994. Initial explored reserves of free gas 71 billion m3, condensate 0.2 million tons, in addition, preliminary estimated gas reserves 980.6 billion m3, condensate 2.8 million tons the explored reserves of condensate-containing gas are 13.5 billion m3. The field is located on the shelf of the Kara Sea and is confined to the brachyanticline, which complicates the continuation of the West-Siberian platform on the shelf of the South-Yamal swell. It includes 5 productive horizons, represented by Cretaceous sandstones. Gas-bearing lower and upper Cretaceous sandstones at a depth of 1099–1895 m, condensate contained in lower Cretaceous sandstones at a depth of approximate 1895 m. Main the gas-bearing horizon (27.1 billion m3 of explored and 388 billion m3 of preliminarily estimated reserves) lies in Upper Cretaceous sediments, the roof of which is at a depth of 1099 m. 8–36 m. Mostly methane gas. The density of the gas in the air is 0,558. The gas condensate contains up to 4.6% of heavy hydrocarbons and minor sulfur impurities. The initial content of stable condensate is 18.6 g / cm3, its density is 769 kg / m3.

Figure 2.3 Location of Leningradskoye gas-condensate field [17]

2.8 Icebergs

It should be noticed that some islands partially consist of glaciers near the Kara Sea. These islands are possible places where icebergs can appear. Franz Josef Land and Severnaya Zemlya are highlighted as potential places where icebergs might be generated in the Kara Sea.

The water depth in the areas where icebergs appear is deep (over 400 m). Therefore, icebergs might be with a deep draft. However, bathymetric data in the direction of the Novaya Zemlya shows that the deepest draft of icebergs is about 250 meters in the north and the south of the Kara Sea. Such large icebergs can travel to the southern part of the Kara Sea just along the east coast of Novaya Zemlya, as the central area of the Kara Sea is shallower.

According to ice drifting and currents map (Figure 2.4) it can be seen that there are currents that can deliver icebergs to Leningradskoye field.

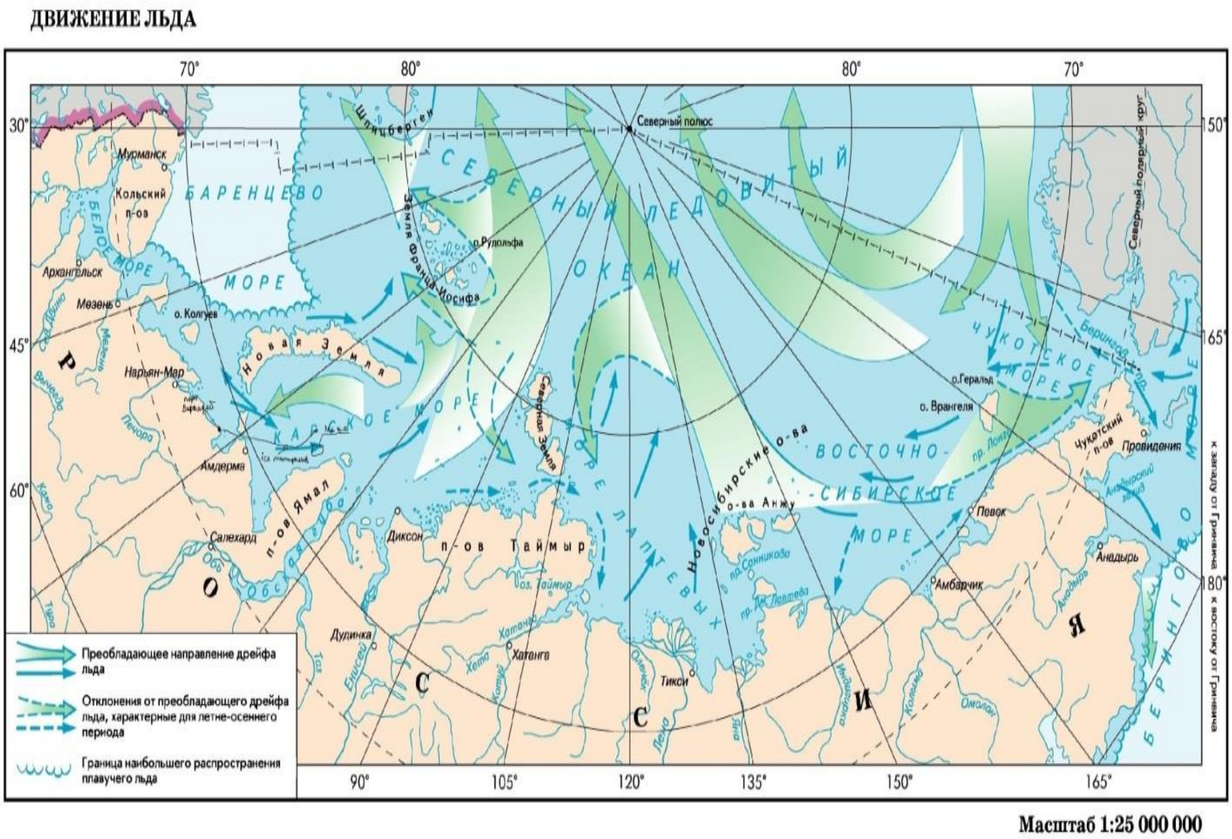

Figure 2.4 Ice drifting and currents map [18]

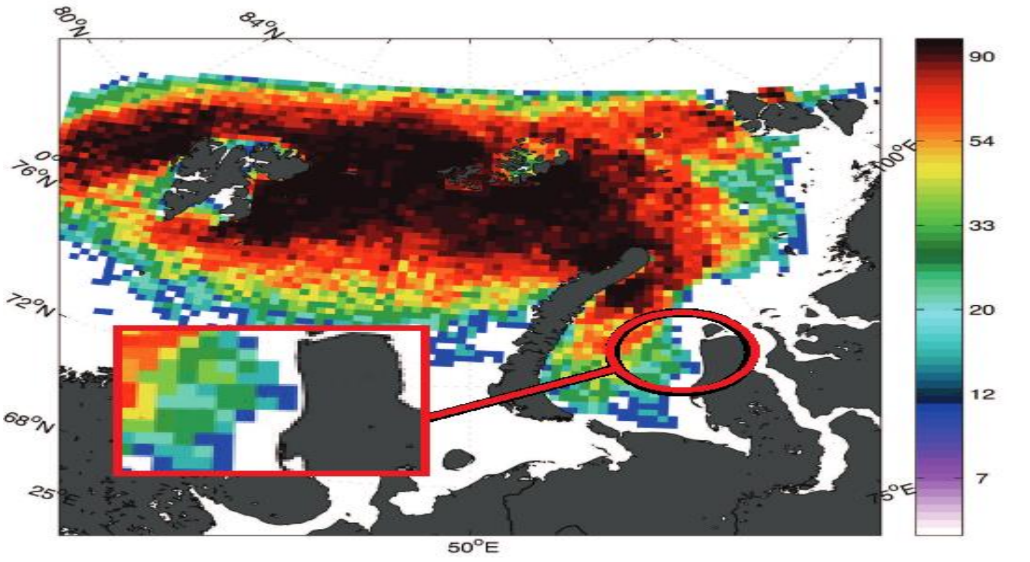

Figure 2.5 Probability of encountering an iceberg within the year on a 25 km×25 km grid cell. 1987-2005 Density distribution. [22]

From Figure 2.5 it could be seen that the probability of encountering an iceberg within the year nearby Leningradskoye field is 10-33%.

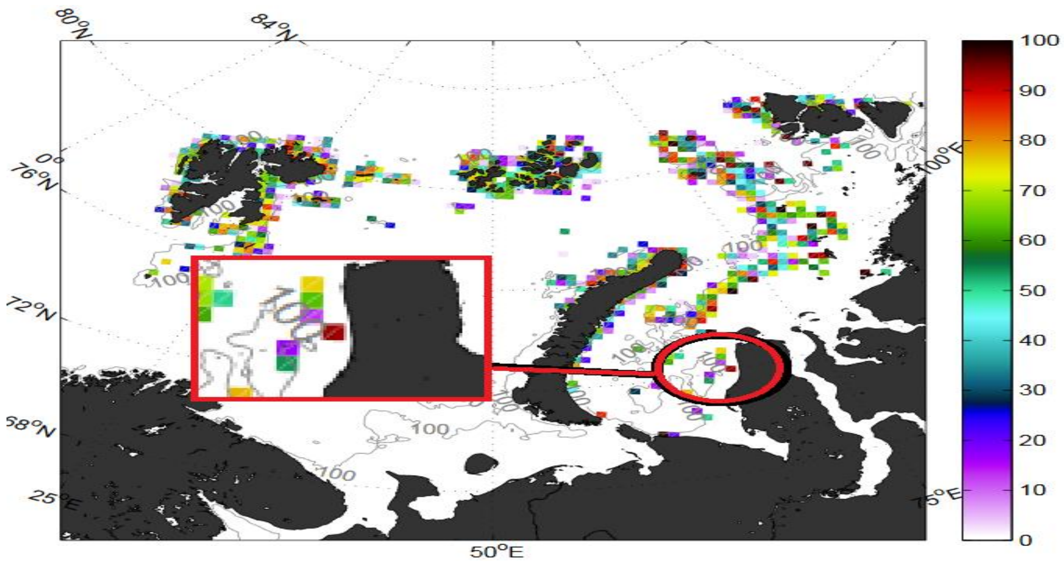

Figure 2.6 Probability of encountering having an iceberg grounded within a 25 km×25 km grid cell. [22]

From Figure 2.6 it could be concluded that the probability of encountering having an iceberg grounded nearby Leningradskoye field is from 20 to 90%.

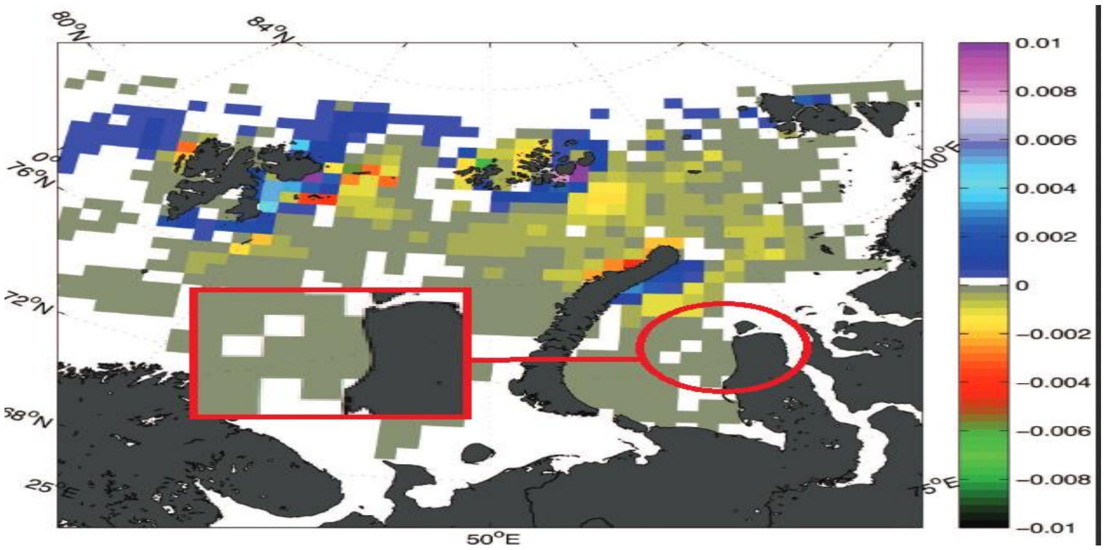

Figure 2.7 Winter - Summer density distribution. [22]

Chapter 3. Selection and location of development facilities

This chapter focuses on facilities selection that would be more technically and cost-effective for this field.

3.1 Gravity based ice-resistant platform

Platforms in general and their structural elements must be designed, built and maintained in such a way that they are suitable for their intended use.

The platform must meet the following operational requirements:

a) to withstand the stresses that may occur during construction and operation (basic ultimate state);

b) Provide appropriate performance characteristics for all possible loads (limit state according to the criterion of suitability for normal operation);

c) Withstand cyclic loads (fatigue limit state);

d) Structural elements must withstand anomalous (special) loads arising, for example, during accidents (a special limiting state);

e) Have the proper degree of reliability, which is determined by the following factors:

- Causes and types of failures (in particular, the nature of the damage);

- The possible consequences of failures in terms of risk to life, the environment, and property;

- Carrying out activities necessary to reduce the risk of damage;

- Various requirements at the state, regional and local levels;

f) Ensure the safety of personnel and the environment. [21]

Since the Leningradskoye field is located in an area without a permanent seabed profile it is hard to install such facilities as gravity based ice resistance platform. But we should take into account any possible solution for field development.

For zones sampling, some criteria should be used. For this purpose we have developed 2 criteria: 1) current criterion 2) distance criterion.

In the purpose of the economical efficient platform should be located no deeper than 100 meters. The area with such depth is shown in the map (Figure 3.1).

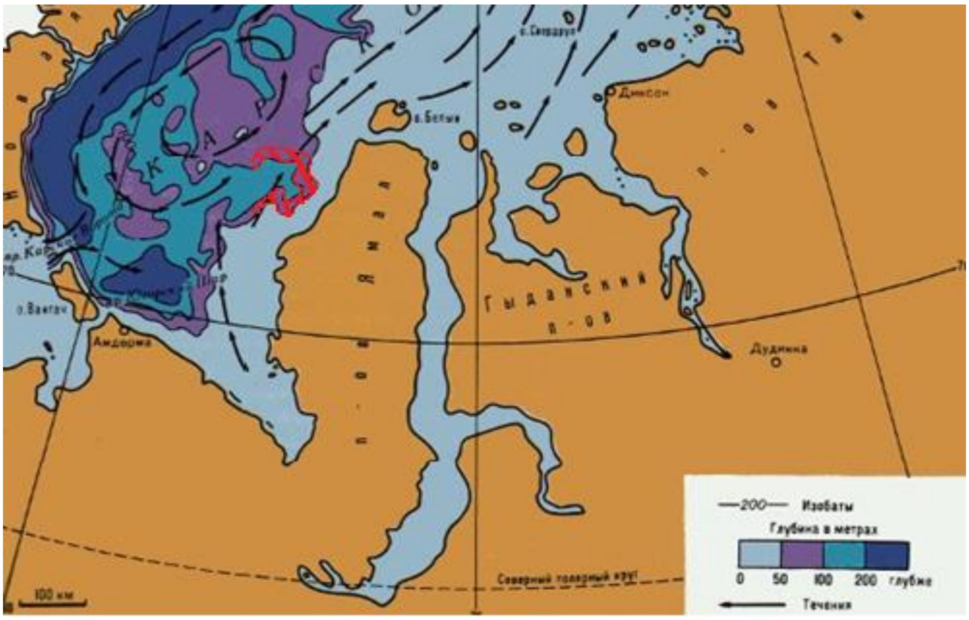

Figure 3.1 Favorable area for platform installation [16]

Next stage of selection is to minimize this area according to currents which exist nearby Leningradskoye field. This criterion must be entered because the current that crosses the field could deliver icebergs and create a dangerous situation for structures. The safest distance from current is more than 15 kilometers. This distance provides enough time to react to any situation which may arise. As it can be seen from Figure 3.2, the big area is divided by 2 areas because of the current criterion.

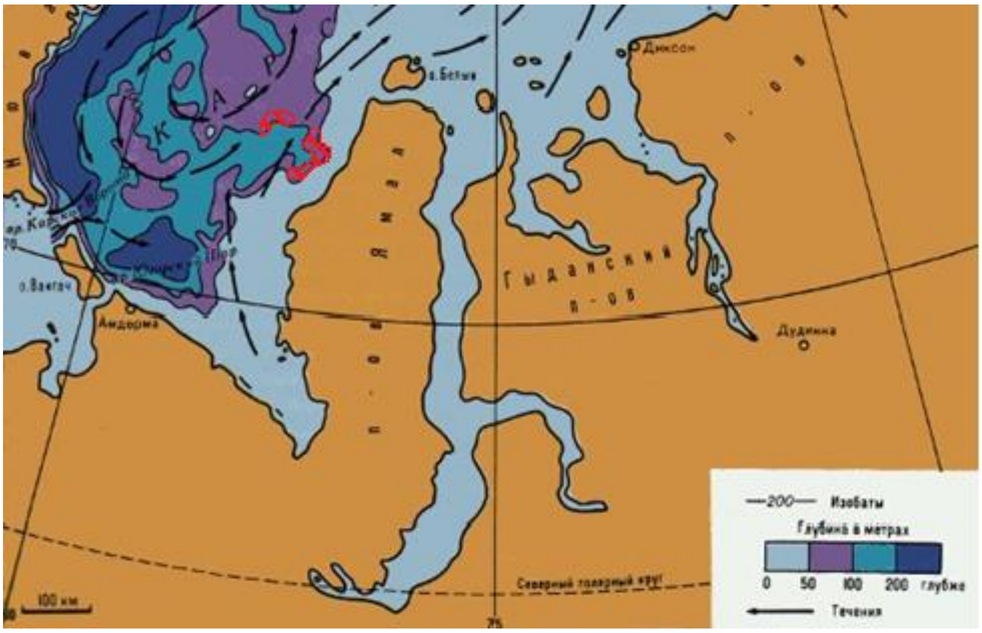

Figure 3.2 Favorable area for platform installation using current criterion [16]

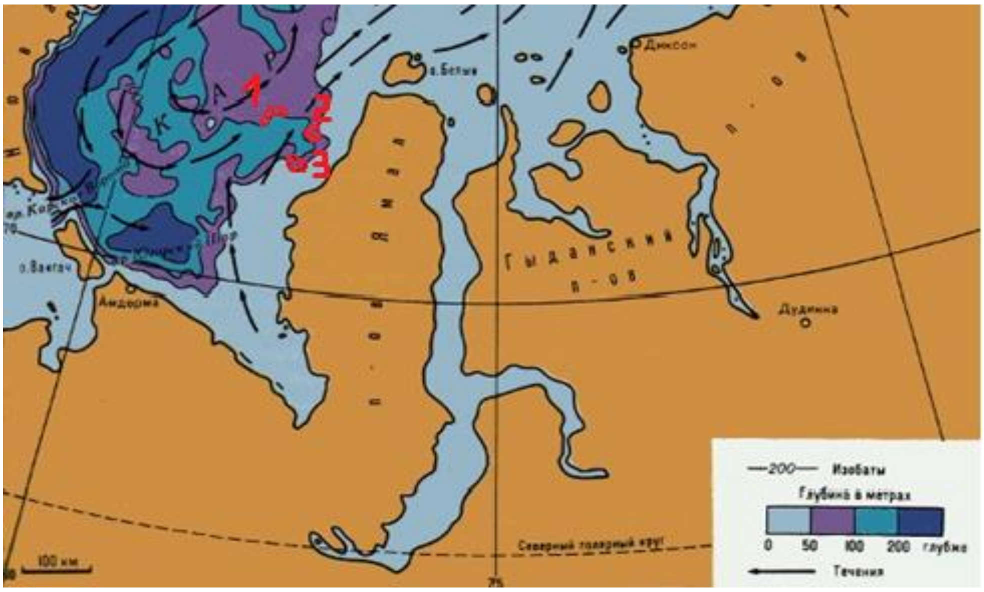

Figure 3.3 Favorable area for platform installation using distance criterion [16]

The last stage of choosing zones is using distance criterion. Principle of this criterion is to exclude zones which are far from the field. One more condition in this criterion is the distance from the edge of the slope which must be more than 600 meters. From Figure 3.3 it could be seen that zones decrease.

From Figure 3.3 we can conclude that there are only 3 zones around the edges of the field which satisfy the conditions for safe development and costeffectiveness. But production at field scale requires the installation of at least two platforms which makes this solution not economically viable. Also from Figure 3.3, we can conclude that for future main and on-field pipelines it will be more profitable if we would use zones 1 and 2 or 2 and 3 in the purpose of cost reducing.

Also, this scheme can't provide full coverage of reserves even if we put both platforms in deep places so as to get maximum coverage. That's why this scheme couldn't be accepted.

3.2 Subsea Production System

Arctic Subsea production has a number of technical issues. To make the good design the Integrated Template Structures (ITS) we should list design criteria (Table 3.1).

Table 3.1. Arctic ITS design criteria [24]

Input	Output
Bottom Conditions - Soil shear strength is the ability of the seabed to support the load of a template or a manifold and how a template could be buried (ISO, 2002).	ITS sizing, number of templates, jumpers, connectors
Geohazard Analysis	ITS arrangement selection
Seismic wave propagation analysis	Selection of the Leak Detection System (LDS) and applications
Planned product properties and content	Stability analysis and determination type of foundations and/or trenching/buried requirements
Production volumes	Cost Estimates
Water depth	Determine the most cost-effective method to install ITS in this very dynamic region and provide the necessary protection
Number of Wells - The number of wells served by a template will determine its size.	ITS installation studies to verify multiple installation options, which can be maintained for cost and contractor

	competitiveness (templates are commonly installed by a drilling rig as the first step prior to drilling)
Bottom hole zone locations	Risk analysis due to external influences, and definition of risk reduction measures
Interferences due to another pipeline (not so relevant)	Material Specifications

Offshore module installations are challenging operations both when the modules are in the air and in the splash zone [24]. Figure 3.4 presents the 5 stages of lifting operations.

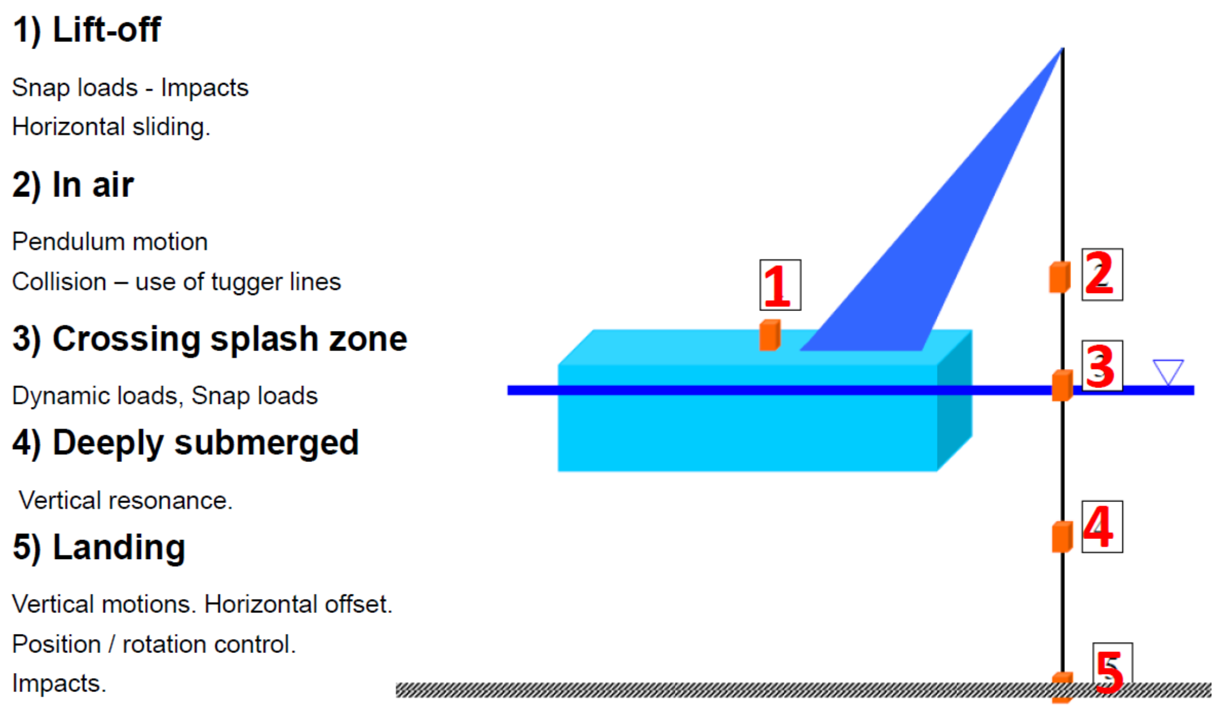

Figure 3.4 Five stages of offshore lifting operations [25]

On Figure 3.5 time history of tension in the lift wire during lift-off are presented.

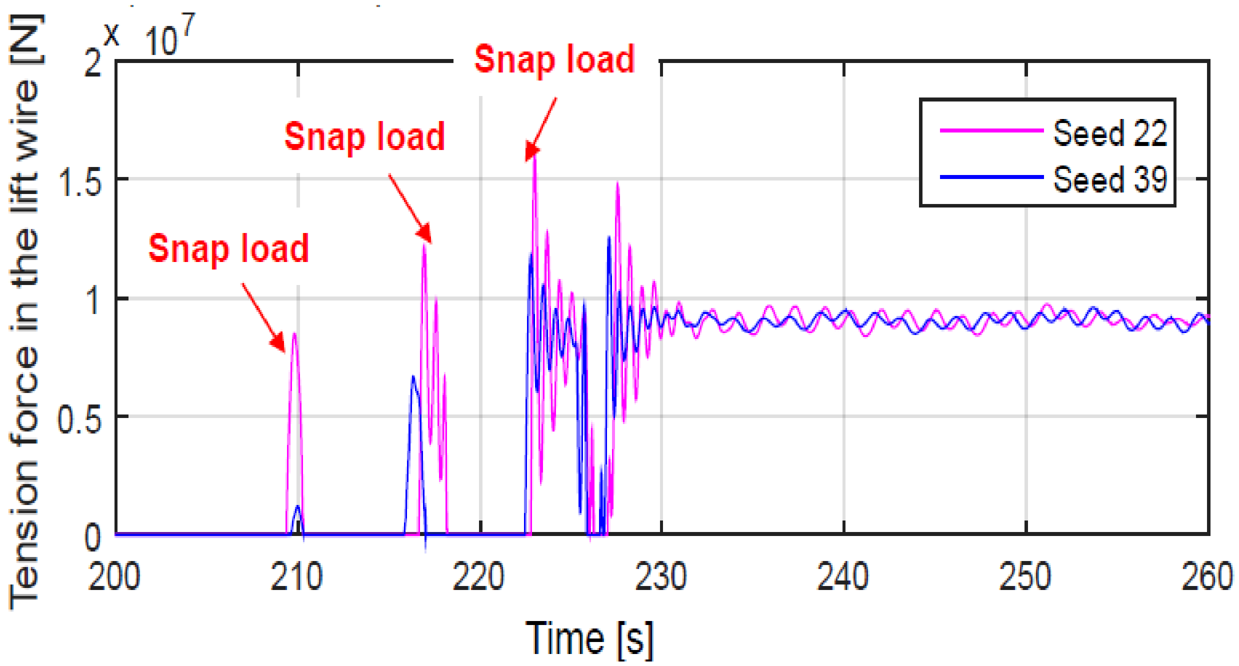

Figure 3.5 Time history of tension in the lift wire during lift-off a tripod from a barge [25]

As it was discussed above crossing splash zone while lifting operations makes some challenges:

•Large dynamic loads

•Impact force on the structure

•Snap load in the wire

•Stability of the lifted object

•Structural integrity

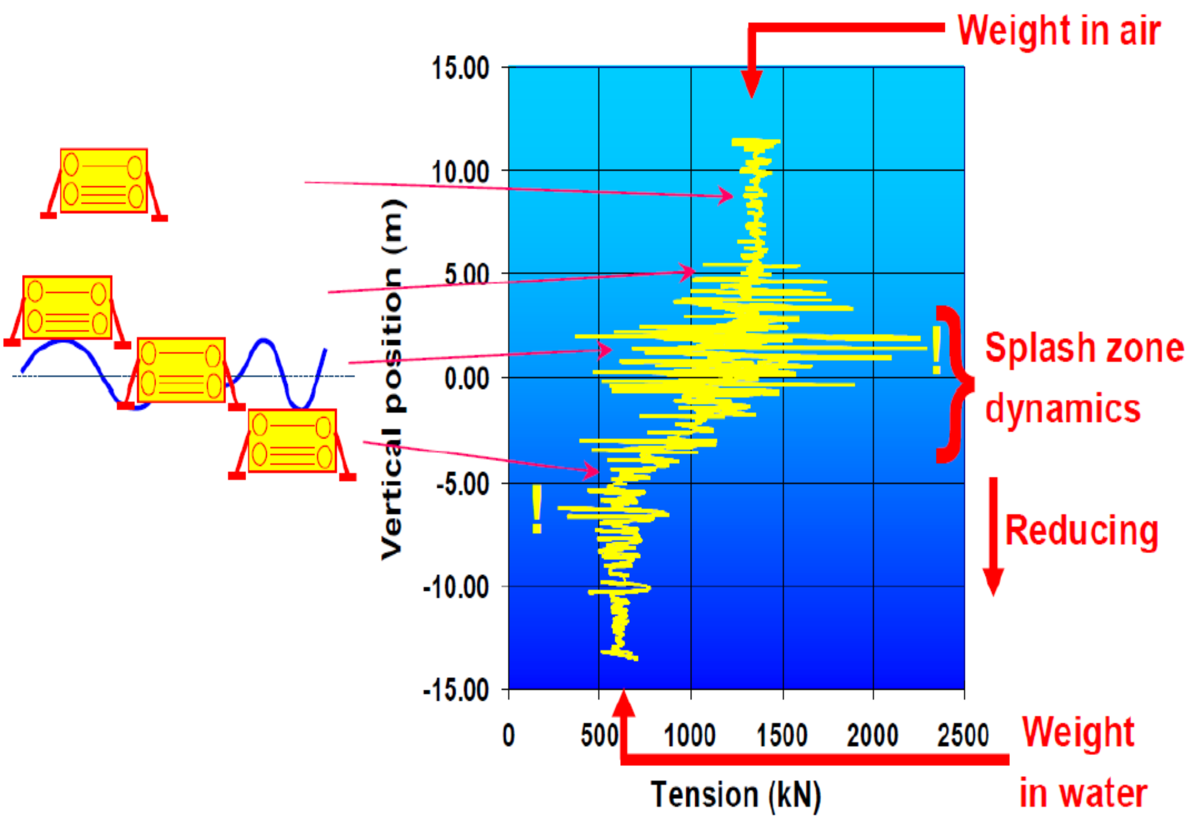

Figure 3.6 Typical time history of sling force for lifting a subsea template when crossing the splash zone [25]

From Figure 3.6 it could be seen that the template and wire have the biggest tension in splash zone which means high risk of accidents appearing.

According to Gazprom investigation, Leningradskoye gas-condensate field must have 29 pads with 4-spots templates [23]. All pads should be equipped by on-field pipelines and manifolds.

The manifold is a system of receiving / distribution collectors and pipelines with branches used to collect reservoir products from wells, distribute reagents / injected gas to maintain reservoir pressure, as well as gas-lift gas through wells [27].

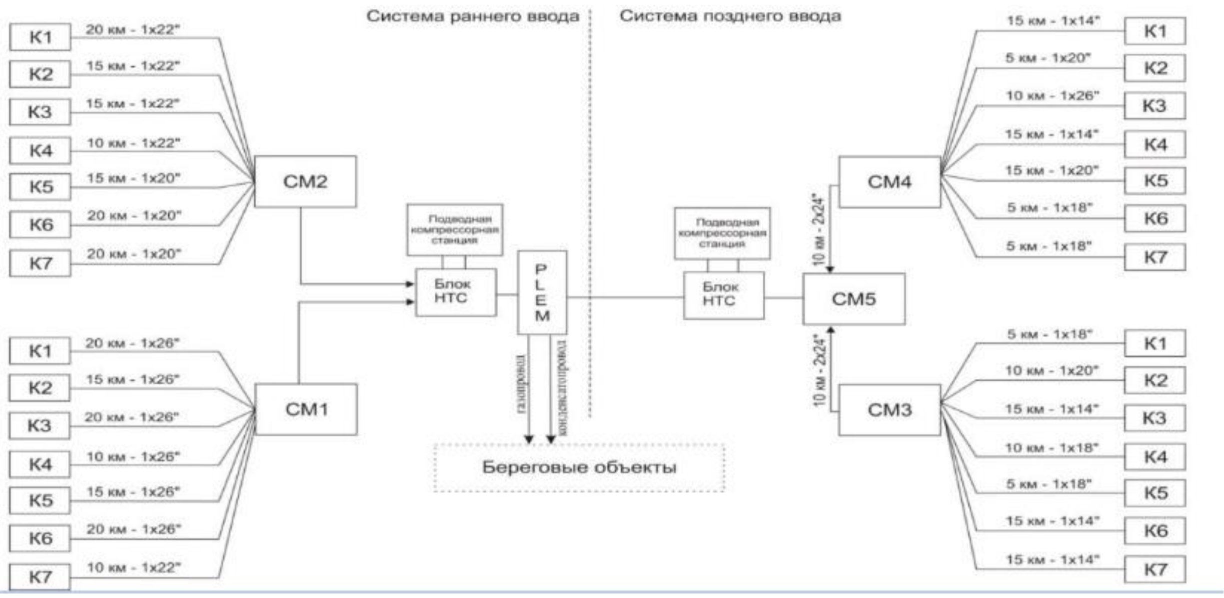

Figure 3.7 Schematic diagram of the arrangement of the Leningradskoye field using Subsea systems [23]

Main facilities:

- Subsea production complex consisting of 29 pads with 4 wells each

-2 early and late entry collection systems, 5 prefabricated manifolds

-2 underwater stations (installations) for gas treatment (early and late entry)

-2 subsea compressor stations

In the purpose of cost-reducing, we can abandon the 4 wells system in favor of the 6 wells system. This decision will save us about 400 million dollars (Figure 3.7) [24]. But it will increase drilling costs more than 1300 million dollars and its complexity (Table 3.2) which means inefficiency of this solution.

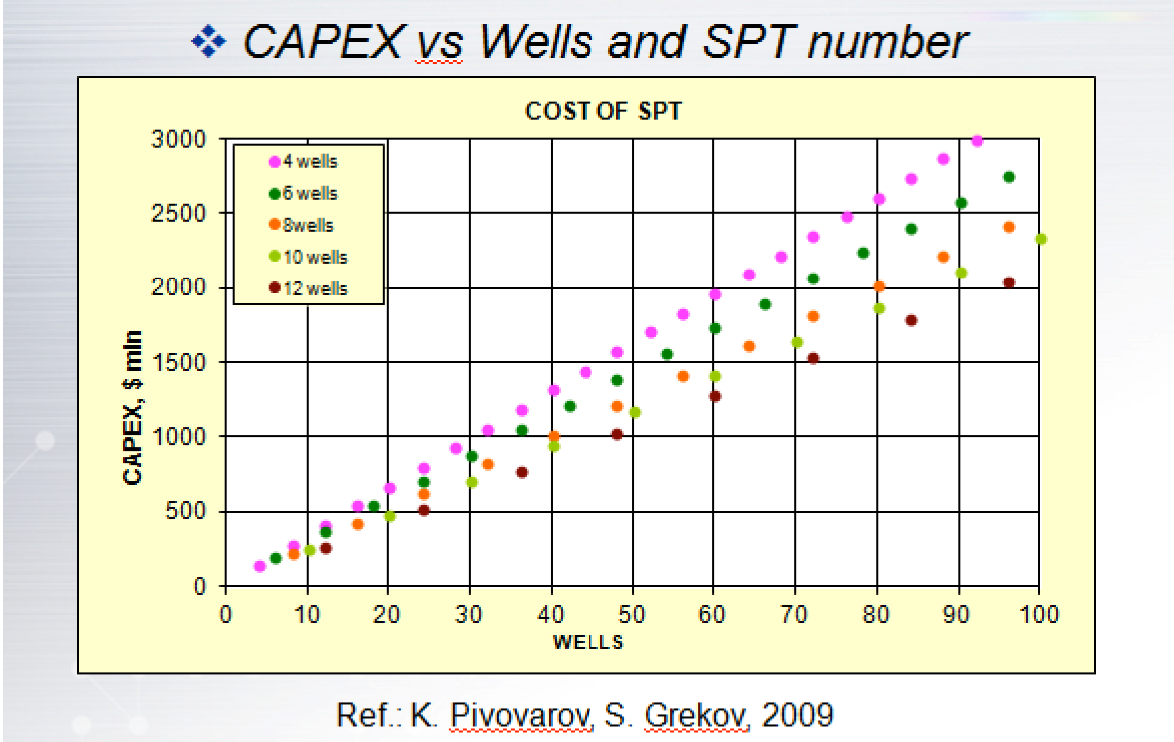

Figure 3.8 ITS costs (mln = Million, wells = wellslots)

We can find the dependence of the template costs from the slope angles. So, we can easily get the cost for the predefined template's number. The solutions which have a bigger number of wellslots in the ITS have lower total capital expenditures (Grekov and Kornienko, 2007) [24].

Table 3.2: Total costs for the subsea development, drilling included [24]

Scenario	Number of templates	Total costs, $M
A12	2	2104
A8	3	1990
A6	4	1957
A4	6	1850

Since the scheme of subsea field development imply lack of gas treatment facilities above the water, technological schemes for the underwater gas treatment were developed (Figures 3.9, 3.10) [23].

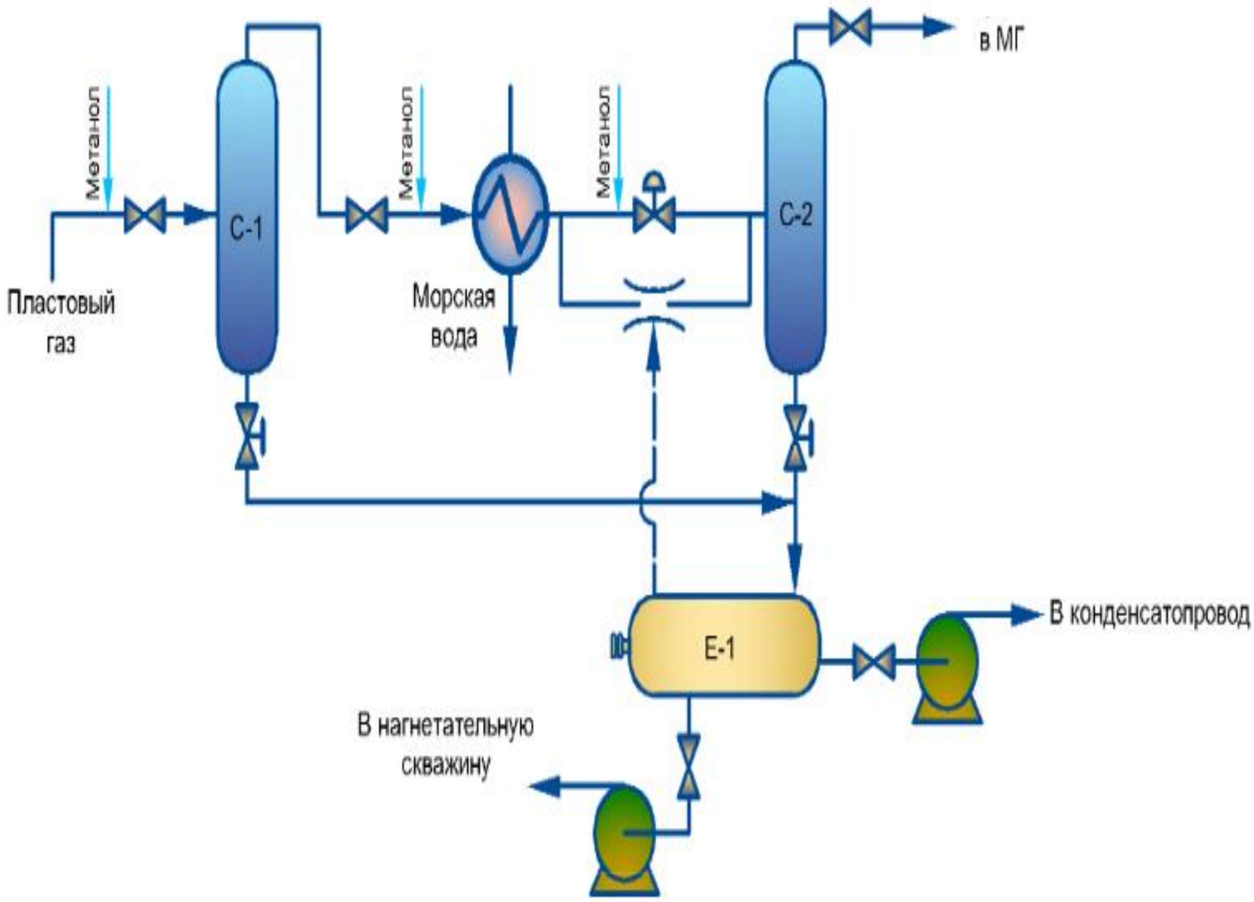

Figure 3.9 Technological scheme of underwater gas treatment before the compressor period of field operation [23]

Features of the developed technological scheme (Figure 3.9):

1) The possibility of preparing products of gas and gas condensate wells.

2) Using seawater to cool the gas before separating it.

3) Using the ambient temperature of water to heat the gas in the offshore pipeline.

4) Using proven gas separation principles.

5) Disposal of selected water through its injection at the field in the injection well.

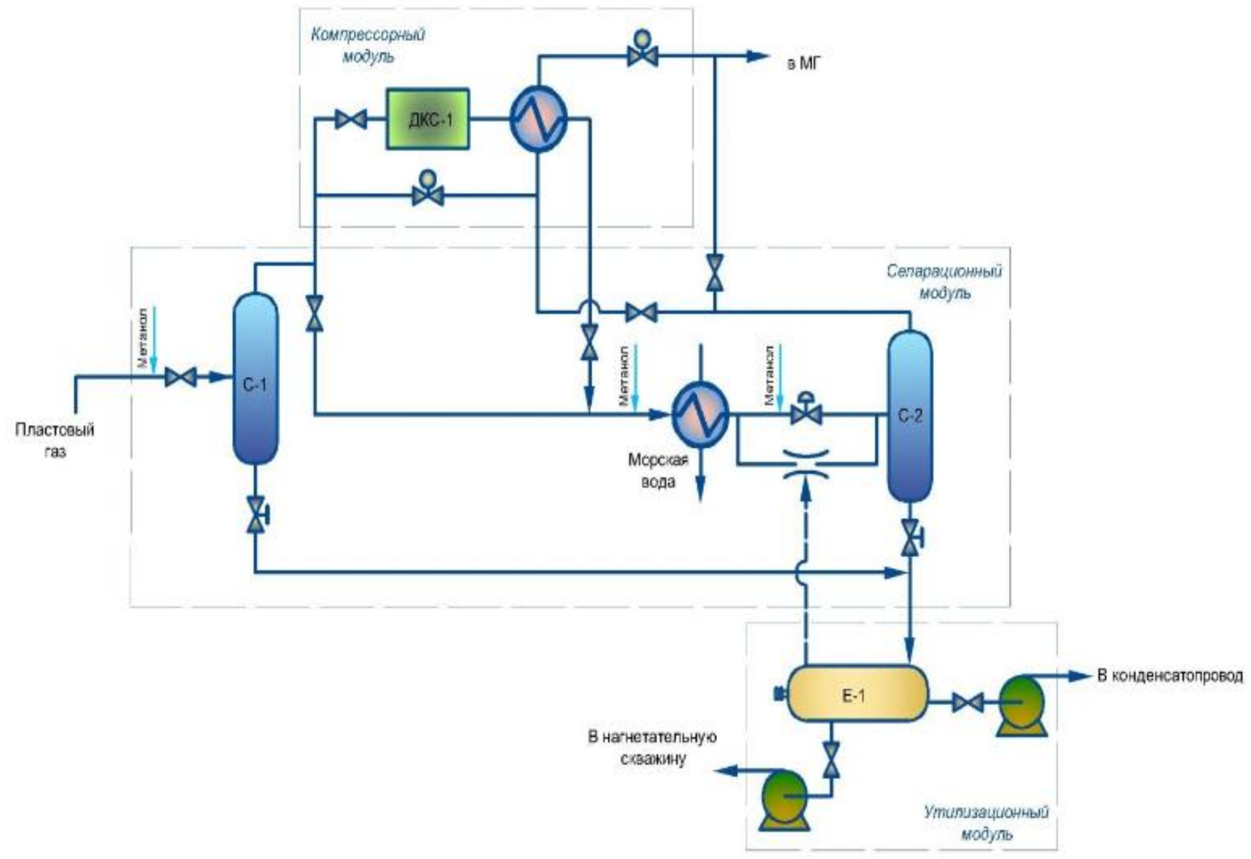

Figure 3.10 Technological scheme of underwater preparation of gas in the compressor period of field operation [23]

Features of the developed technological scheme (Figure 3.10):

1) The compressor module is installed in a later period (7–18 years from the start of field development).

2) Using a regenerative heat exchanger to cool the gas after compression and heating of the gas supplied to the export pipeline to the onshore facilities allow:

- raise the temperature of the gas supplied to the export pipeline;

- use the gas supplied to the export pipeline as a coolant and avoid local heating of water (environment) on the heat exchanger sea water gas.

4) The piping scheme allows using one heat exchanger gas - sea water to cool the gas in front of the throttle and before the bypass line.

3.3 Gravity based ice-resistant platform with a subsea production system

In case of using a gravity based ice-resistant platform with subsea production system scheme, we need only 1 platform and 23 4-spots templates for the whole field. [23]

But this scheme does not suit us because of some reasons:

1) Cost of this project will be equal to the project in which subsea production systems are used in combination with the new onshore factory;

2) Risk of accidents during exploitation of platform;

3) Environmental risk.

Chapter 4. Transportation system design

Hydrocarbon transportation systems in the Arctic include local and main oil and gas pipeline systems, freight transport systems by rail and sea transport fleet. Among the eight countries whose territories - fully or partially - are located above the Arctic Circle (Canada, Russia, USA, Iceland, Norway, the Kingdom of Denmark, Sweden, Finland), only five have access to the Arctic Ocean (Russia, Norway, Denmark, Canada, and the USA), and only four actively implement oil and gas projects (Russia, USA, Canada, and Norway).

4.1 Types of offshore gas and gas-condensate transportation systems

4.1.1 Pipeline transportation system

Pipelines, depending on the hydrocarbon that is being pumped, are called oil pipelines or gas pipelines. In the shelf conditions, we will consider only oil and gas pipelines.

Pipelines according to their purpose are divided into the following groups:

· Internal - connect various objects of arrangement in the fields;

· Local - in comparison with internal ones, they are longer and connect the fields with the main station of the main pipeline;

Trunk lines are characterized by a large extent (hundreds and thousands of kilometers), therefore pumping is conducted not by one, but by several stations located on the highway.

According to regulatory documents, trunk pipelines are divided into four classes depending on the nominal diameter of pipes (in mm):

Grade 1 - 1000-1200 mm;

Grade 2 - 500-1000 mm;

Grade 3 - 300-500 mm;

Grade 4 - <300 mm.

The main gas pipelines are divided into two classes depending on the working pressure in the gas pipeline:

Grade 1 - 2.5-10 MPa;

Grade 2 - 1.2-2.5 MPa.

The principal difference in the design of offshore oil and gas pipelines lies in the fact that land pipelines are calculated mainly on the impact of internal pressures of pumped hydrocarbon products, and sea pipelines are calculated on both internal and external pressures. In deep-sea conditions, external pressures can be commensurate with internal ones. In addition, the presence of negative temperatures in gas pipelines can lead to icing of pipelines, which will create additional forces of their ejection due to the force of Archimedes, etc.

However onshore and offshore pipeline installation is different. Waves, currents, and the need for special facilities make difficulties. There are a lot of challenges for which solving many methods were developed.

The most common are the following methods:

1. For sections of laying the pipeline in a trench at the intersection of the coastline:

1) Dragging ashore from a barge anchored to the sea along a pre-designed trench using shore winches.

2) Installation of lashes on the shore and dragging the pipeline into the sea through the developed trench using winches of a working barge or tugs.

3) Installation of the pipeline on the barge and dragging ashore from the barge through a pre-designed trench. The traction force is transmitted from the winch

mounted on the barge through the rope passing through the block on the shore and back to the winch of the barge.

The last method is optimal in terms of minimizing preparatory work and the cost of organizing and operating onshore facilities.

2. For laying the pipeline in deep water areas:

1) The usual S-method;

2) The method of laying with the vertical position of the pipes (J-method);

3) Laying of the pipeline from the drum (G-method);

4) Towing over the bottom;

5) Dragging along the bottom;

6) Towing at a given depth;

7) Towing on the surface [32].

Towing methods are usually applied only when working with very short pipelines.

For the construction of underwater main oil and gas pipelines, the length of which can reach tens and hundreds of kilometers, they are currently using the technology to build up the sea using special pipe-laying vessels. At the same time, all welding operations, non-destructive testing and application of insulation to the assembly joints are carried out on board the vessel at several work posts at the same time. As the pipeline is extended to one pipe or section, the pipe-laying vessel moves forward, and the pipeline comes to the bottom by free immersion. For a smooth descent of the pipeline from the stern and reducing the stresses that occur, the vessel is equipped with a special supporting device, the stinger. The control of the stress-strain state of the pipeline on the stinger and the sagging area between the stinger and the seabed is carried out by applying a longitudinal tensile force on them. Keeping the ship itself in a stationary position is carried out using an anchor system or dynamic positioning.

Modern technology for the construction of large-diameter offshore pipelines using pipe-laying vessels is based on the use of two main methods of production laying - the S method and the J-method of laying the pipeline. In practice, a combination of both technologies is used, namely, coastal areas are built with the help of vessels implementing the S-method, and they continue their installation into the sea using the J-method.

Pipeline layouts in deep water areas can be classified as follows:

1. dragging along the bottom of the sea;

2. dive from the sea;

3. descent to the seabed from pipelaying vessels [32],

When choosing a method of transporting the extracted products to onshore facilities, each time the question arises which of the best meets the investment and environmental requirements for the development of offshore fields, also in the conditions of the Arctic freezing seas. Year-round tanker transportation of oil and gas condensate from the transshipment terminal to the onshore terminals is impossible due to the presence of ice, which also determines the environmental hazard of using the tanker fleet. With this in mind, it is often the only possible method of transportation to transport products through offshore pipelines. As the experience of Canadian and American oil and gas companies has shown, it is the absence of offshore pipelines that has become one of the determining factors holding back the further development of hydrocarbon production in the North American Arctic.

4.1.2 LNG tankers transportation system

When creating infrastructure for the transportation of natural gas in Russia, until recently, they focused mainly on pipeline systems, as a result of which the longest trunk pipeline network in the world was created, and production of equipment for pipeline systems was completely localized in Russia. However, transportation of natural gas by water means has a number of important advantages, which include: lack of technical binding of the supplier to the recipient, less dependence on geographical obstacles on the delivery route, high economic efficiency during long-distance transportation, less vulnerability to geopolitical factors and regional instability, scalability supplies.

Liquefied natural gas - natural gas artificially liquefied by cooling to −160 ° C, to facilitate storage and transportation.

LNG is a colorless, odorless liquid whose density is 2 times less than the density of water.

75-99% consists of methane. The boiling point is –158… –163 ° C.

In the liquid state is not flammable, non-toxic, and not aggressive.

For use, it is subjected to evaporation to its original state.

During the combustion of vapor, carbon dioxide and water vapor are formed. In industry, gas is liquefied both for use as a final product, and for use in combination with low-temperature fractionation of associated petroleum gas and natural gases, allowing to separate gas gasoline, butane, propane and ethane, and helium from these gases.

LNG is obtained from natural gas by compression followed by cooling. During liquefaction, natural gas decreases about 600 times in volume. 1 ton of LNG is about 1.38 thousand m3 of natural gas.

The liquefaction process is carried out in steps, at each of which the gas is compressed 5–12 times, then cooled and transferred to the next step.

Actually, liquefaction occurs when cooled after the last stage of compression.

The liquefaction process in this way requires a considerable expenditure of energy - up to 25% of its amount contained in liquefied gas.

Now 2 technical processes are applied:

- condensation at constant pressure (compression), which is rather inefficient due to energy intensity

- heat exchange processes: refrigerated - using a cooler and turbo expander/throttling to obtain the required temperature with a sharp expansion of the gas.

In gas liquefaction processes, the efficiency of heat exchange equipment and thermal insulation materials is important.

During heat exchange in the cryogenic region, an increase in the difference in temperature difference between the flows of just 0.5 ° C can lead to additional power consumption in the range of 2–5 kW for compressing every 100 thousand m3 of gas.

The lack of throttling technology is a low liquefaction coefficient - up to 4%, which implies multiple distillations.

The use of the compressor-expander circuit allows increasing the gas cooling efficiency up to 14% by performing work on turbine blades.

Thermodynamic schemes allow achieving 100% efficiency of natural gas liquefaction:

- cascade cycle with successive use of propane, ethylene, and methane as refrigerants by successively lowering their boiling point,

- double refrigerant cycle - a mixture of ethane and methane,

- broad liquefaction cycles.

There are 7 different technologies and methods for liquefying natural gas.

- AP-SMR ™, AP-C3MR ™, and AP-X ™ are leading in the production of large volumes of LNG, with an 82% market share of Air Products;

- technology Optimized Cascade, developed by ConocoPhillips;

- the use of compact GTL-installations intended for internal use in industrial enterprises;

- local installations of LNG production can be widely used for the production of gas engine fuel (HMT);

- the use of ships with a liquefaction facility of natural gas (FLNG), which provide access to gas fields inaccessible to gas pipeline infrastructure facilities.

- the use of offshore floating platforms LNG, for example, which is being built by Shell 25 kilometers from the west coast of Australia [33].

4.1.3 Other transportation systems

Also, there are 3 more possible systems of gas transportation:

1) Railway transportation system;

2) Road transportation system;

3) Gas hydrates transportation system.

However, these systems are ineffective for our case because of their cost and time of transportation.

4.1.4 Summary

According to the description of the transportation systems given above we can conclude that three systems are suitable for the development of Leningradskoye field: 1) pipeline transportation system 2) LNG transportation system 3) Combination of that 2 systems.

For LNG system we need to build FLNG with ice resistance that could be the perfect solution for the region but not for one field because of its cost.

The pipeline system is the best solution for this project because of its cost and time of transportation. Also, the combined system could be used in this project but only in case of laying pipelines to the nearest LNG factory (Yamal LNG plant).

4.2 Pipeline trajectory choosing

Both the price of the entire project and safety for the environment depends on the correctness of the choice of the pipeline trajectory.

For pipeline trajectory design we have to use local standards. Such standards provide the safest installation and exportation of the pipeline:

1) Selection of the route should be in accordance with the requirements of SP 36.13330.

2) Selection of the route and location of the offshore pipeline facilities should be based on analyzes of climatic, geological and relief features of the onshore section and seabed, navigation conditions, the presence of closely located settlements and production facilities, transport routes, and communications taking into account pipeline safety.

3) The route of the offshore pipeline should be selected on the basis of a variant assessment of the economic feasibility and environmental acceptability of construction.

4) As the criteria for optimality, we should take the cost indicators for the construction of the offshore pipeline, its maintenance, and repair during operation, including the costs of environmental safety measures, as well as the metal consumption, structural design plans, safety, specified construction time, the presence of roads.

5) The norms of environmental acceptability of impacts in the construction and operation of the offshore pipeline should contribute to the preservation of the marine ecosystem and be based on the environmental constraints of the construction area on the use of water resources, fish stocks, forest resources, and the development of economic activities.

6) The engineering assessment of the offshore pipeline construction area should be carried out along the general route of the trunk pipeline based on the analysis of available literature data and stock cartographic materials, topographic plans, aerial photographs, engineering geological, navigation maps and other data. the whole complex of engineering surveys.

7) Engineering surveys for the construction of offshore pipelines should be performed in accordance with the requirements of SP 47.13330, SP 11-114, SP 11-102, SP 11-103, SP 11-104, SP 11-105, and other applicable regulatory documents.

The survey includes engineering-geodesic, engineering-geological, engineering-hydrometeorological, engineering-environmental surveys and lithodynamic studies.

8) Engineering survey materials should provide a comprehensive study of the natural and environmental conditions of the construction site, being the basis for selecting the offshore pipeline route and developing the technically sound design and technological solutions for its construction.

9) For the design and construction of offshore pipelines, plans of scales of 1: 1000, 1: 2000, 1: 5000 and maps of scale 1: 10000 ÷ 1: 25000 should be used.

10) When determining the bathymetric data of the offshore pipeline route, the average errors, including measurement and depth errors in the Baltic system of heights, when determining the seabed elevations should not exceed:

–0.2 m at a depth of 5 m;

–0.3 m at a depth of 5 to 30 m;

–1% of the depth at depths greater than 30 m.

11) The height of the cross-section of the relief horizontals and isobaths at depths of the sea up to 40 m should be from 0.5 m - with slopes up to 2 degrees and 1.0 m with slopes more than 2 degrees for scales up to 1: 5000. On topographic maps of the continental shelf should be displayed:

- Reference points of the high-rise and planned geodetic base, as well as permanent level posts;

–Standard visual and hydroacoustic means of navigation equipment of the seas and navigation reference points;

–Saving and drying boundaries;

–The boundary of regular wind surges of water, if the width of the coastline subject to this phenomenon exceeds 10 mm on the scale of a plan or map (on a scale of 1: 25000 and smaller than 5 mm);

–Engineering facilities and communications;

–Sea channels, leading and recommended fairways and paths;

–Bottom vegetation (phytobenthos) and coastal zone vegetation - according to life forms, as well as characteristic representatives of immobile and sedentary benthic animals (zoobenthos);

— boundaries and special areas on the water;

–Places of oil and gas, the remains of sunken ships, various underwater obstacles.

12) Engineering surveys should perform survey (design and survey) organizations that have licenses to perform engineering surveys in the territory of the Russian Federation, the experience of survey work in the construction of offshore facilities.

13) When choosing the route of the offshore pipeline, consider:

– Shipping in the area of the pipeline's passage — geotechnical conditions;

– The topography of the seacoast and the seabed;

– Fishing activity;

– The presence of hydraulic structures;

– The presence of previously constructed pipelines and communications;

– The place of economic activity of other sea users and the disposal of waste, including the interests of the navy;

– Ground discharge areas;

– Areas with increased environmental risk

14) When choosing an offshore pipeline alignment, one should be guided by the following basic requirements: a smaller category of engineering and geological conditions, the shortest length of the offshore pipeline, the availability of a suitable area for the placement of construction sites. Must also take into account: economic infrastructure, convenient driveways in the construction area, the possibility of delivery and storage of materials and equipment for the production of works.

15) When choosing an offshore pipeline section, it is necessary to cross the coastal zone at a right angle, or at an angle, providing favorable geotechnical conditions and reducing the length of the pipeline.

16) The piping of the offshore pipeline should be chosen so that the longitudinal axis of the pipe coincides with the energy resultant wave, i.e. with the predominant direction of movement of the waves.

17) The offshore pipeline should be selected on a section with a stable bottom and shore, the least exposed to waves, preferably in straight sections, where there are no islands and channels. When choosing the alignment, difficult sections should be avoided:

– Compiled with rocky soil;

– Intensive destruction of the coast as a result of erosion activity;

– A wooded or very steep, steep bank, it is preferable to select a section of the bank that has a smooth outline in terms of, without sharp fluctuations and deep bottom depressions in the construction site;

– Development of landslide phenomena and active karst formation;

– Intensive wave action, as well as in the areas affected by the broken wave of the wave reflected from the barrier structures located closer than 200 m from the pipeline

– The formation of congestion and ice jamming [31].

According to these rules, we can make such trajectories to Yamal LNG plant and Bovanencovo field (Figures 4.1, 4.2):

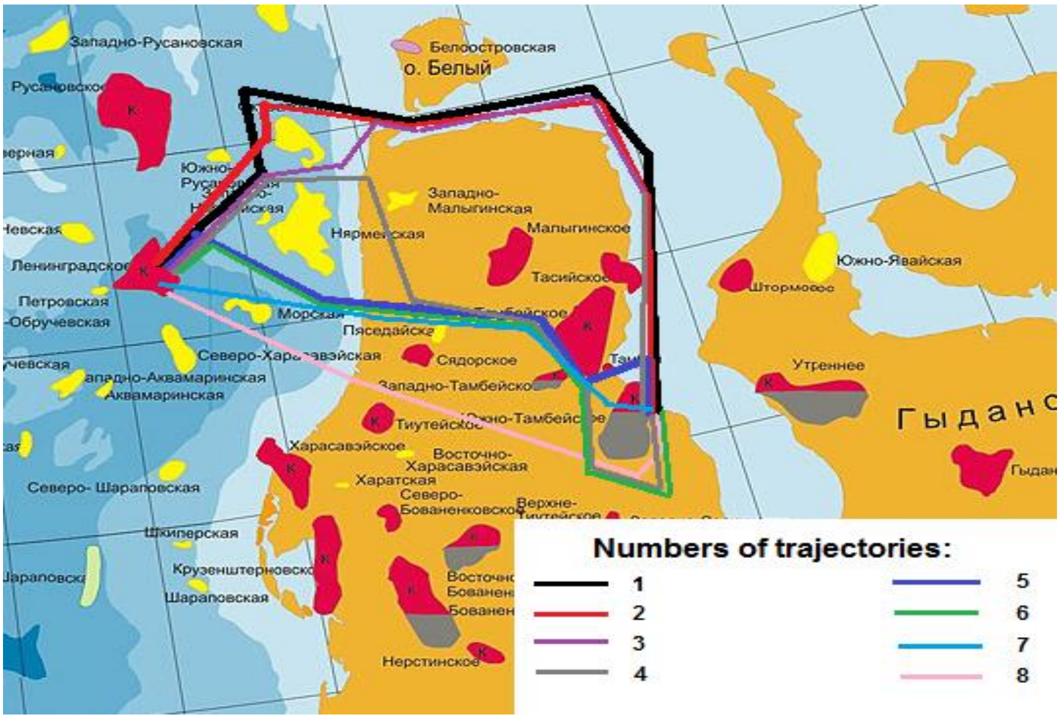

Figure 4.1 Possible pipeline trajectories to the Yamal LNG plant

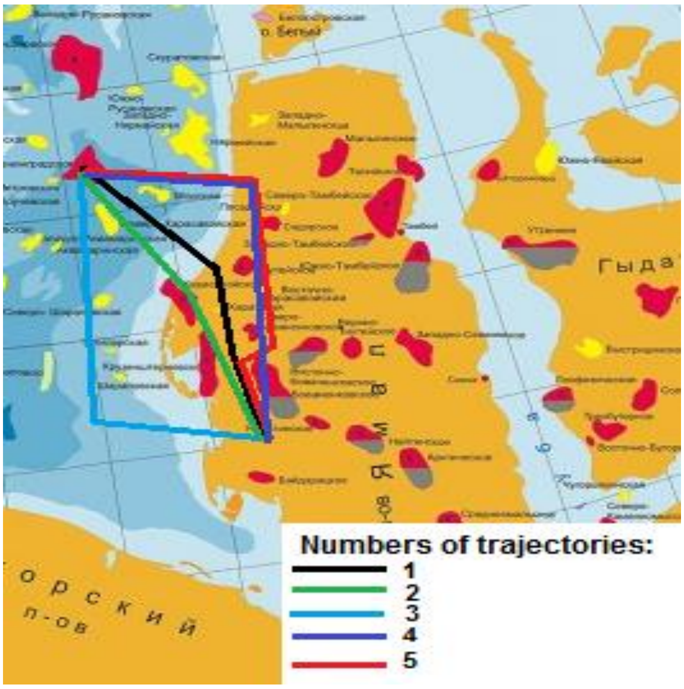

Figure 4.2 Possible pipeline trajectories to the Bovanencovskoye field

According to Figures 4.1, 4.2 there are 8 trajectories to the Yamal LNG plant and 5 to the Bovanencovo field. Each trajectory has advantages and disadvantages that’s why we need to choose only one for each variant and then choose the most suitable option.

4.2.1 Trajectory choosing to the Yamal LNG

From Figure 18 we can see that trajectories 1, 2 and 3 lay only through the water. This method solves a lot of challenges concerning the transition of the offshore pipeline to the onshore. But the solution of these problems leads to the appearance of other, associated with an increase in the number of sections of the pipeline that require protection from dropped objects and icebergs. We couldn't accept these trajectories because they are the longest and most expensive.

If we compare the trajectories of 4, 5, 6 and 7, 8, we can conclude that 4, 5, 6 are longer, which means their higher cost.

Trajectories 7 and 8 remain. Trajectory 7 is shortest but it goes through the other field. It means that we can accept trajectory 7 only in case if it wouldn't interfere with the development of this field. That's why trajectory 8 is more suitable for our case.

On Figure 4.3 the distance from Leningradskoye field to the Yamal LNG plant using trajectory 8 is shown.

Figure 4.3 Distance from Leningradskoye field to the Yamal LNG plant using trajectory 8

According to Figure 4.3 the length of the offshore part of the pipeline is equal to 99.2 km and the length of the pipeline on land equal to 195.8 km.

Long distances require compressors installation. In case of Leningradskoye field, the only one solution could be accepted for both trajectories, to the Yamal LNG and Bovanenkovskoye field: installation subsea compressor as used in Asgard field and building compressor station onshore.

4.2.2 Trajectory choosing to the Bovanenkovskoye field

In contrast to the variant with the transportation of products to Yamal LNG and the further preparation and transportation in the form of LNG to consumers, the variant with the transportation of products to the Bovanenkovskoye field assumes the subsequent preparation of gas and condensate for subsequent transportation via pipelines.

A project of domestic Russian gas pipelines in the Arctic region is the Bovanenkovskoye - Ukhta gas pipeline launched in October 2012 (the first line was commissioned in October 2012; in 2017 the gas pipeline was commissioned). It is planned that after the full implementation of the project for the construction of the Bovanenkovskoye - Ukhta - Torzhok gas pipeline, this branch will link the gas fields of the Yamal Peninsula with the territories of central Russia. In addition, it is assumed that later, after start other gas fields of the Yamal Peninsula, the land-sea transit zone (for example, the Kharasawayskoye and Kruzenshternskoye fields) and the adjacent offshore fields in Kara Sea (for example, the Leningradskoye, Rusanovskoye), this system will form an integrated regional infrastructure for the transport of gas from the YNAO. As for the technical characteristics, according to the project, the cumulative length of the branch should be over 2500 km (Bovanenkovskoye - Ukhta - 1200 km, Ukhta - Torzhok - 1300 km), and the carrying capacity at the Bovanenkovskoye - Ukhta section is 115 billion m^3 / year, at the Ukhta section - Torzhok: 90 billion m^3 / year [29].

According to Figure 4.2 trajectories 3, 4, 5 have the biggest length what makes them not suitable for implementation.

Trajectory 2 could be accepted but it crosses two other fields which make this solution not suitable according to the technical development of those fields. It means that only trajectory 1 remains.

On Figure 4.4 the distance from Leningradskoye field to the Bovanenkovskoye field using trajectory 1 is shown.

Figure 4.4 Distance from Leningradskoye field to the Bovanenkovskoye field using trajectory 1.

According to Figure 4.4, the subsea length of the pipeline is 97.8 km and onshore part equal to 164.2 km.

4.2.3 Single path selection

Based on the above we can conclude that pipeline to the Bovanenkovskoye field will have less cost in contrast to the pipeline to Yamal LNG plant because of length both for the subsea and onshore part. This allows us to choose the trajectory to the Bovanenkovskoye field.

However, before Leningradskoye field begins to be developed we need to decide how the company will conveniently sell products as LNG or common gas. This will affect the choice of transportation scheme.

4.3 Pipelines design and calculation

According to the preliminary estimations, the recoverable gas and gas-condensate reserves in Leningradskoye gas-condensate field will be equal to 1.05 trillion m^3 of gas and 3 million tons of gas-condensate. According to the conceptual development strategy of the Leningradskoye gas-condensate field, the whole production will take 49 years (Figure 4.5) [23].

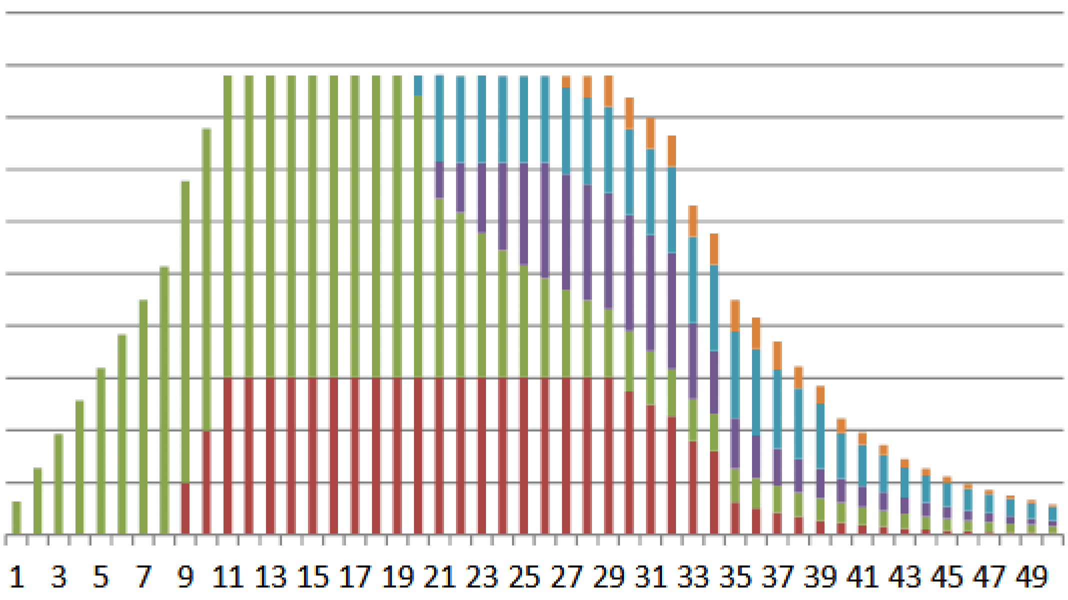

Figure 4.5. Conceptual flow chart of Leningradskoye gas-condensate field development [23]

Annual production rate might be taken in a range of 5 – 8 % of recoverable reserves (Aliev & Bondarenko, 2002). Assume that for Leningradskoye field annual production rate will be 6% of recoverable reserves.

The annual production rate:

$$Q_{agas} = Recoverable\ reserves\ \times 0.06 = 1.05\ trillion\ m^3 \times 0.06 = 63\ billion\ {m^3}/{year}\ of\ gas \quad (4.1)$$

$$Q_{agas-condensate} = Recoverable\ reserves\ \times 0.06 = 3\ million\ tones \times 0.06 = 180000\ {tons}/{year}\ of\ gas - condensate$$

The daily production rate:

$$Q_{dgas} = \frac{Q_{agas}}{365} = \frac{63\ billion\ {m^3}/{year}}{365} = 172.6\ million\ {m^3}/{day}\ of\ gas \quad (4.2)$$

$$Q_{d\ gas-condensate} = \frac{Q_{agas-condensate}}{365} = \frac{180000\ {tons}/{year}}{365} = 493.15\ {tons}/{day} => 493.15 \div 0.7 = 704.5\ {m^3}/{day} \quad (4.3)$$

Production rate in seconds:

$$Q_{sgas} = \frac{Q_{dgas}}{86400} = 2000\ {m^3}/{sec}\ of\ gas \quad (4.4)$$

$$Q_{sgas-condensate} = \frac{Q_{dgas-condensate}}{86400} = 0.00815\ {m^3}/{sec}\ of\ gas - condensate \quad (4.5)$$

Let's assume according to calculations above and standards that the inner diameter of the pipeline is 1220 mm. The value of this internal diameter corresponds to 1284 mm standard outer diameter if we will assume that wall thickness is 32 mm.

Table 4.1. Initial data about the pipeline

Pipe Data	**SI Units**
Pipeline Length, L	262 km

Internal roughness, k	0.03 mm
Flowline wellhead pressure	12 MPa
Constant Operating temperature	50 deg Celsius
Installation temperature	5 deg Celsius

Table 4.2. Additional parameters

Operating Data	**SI Units**
Gas flow rate, Q	2000 m^3/s
Dynamic Viscosity	0.0000016 Pa*s
Contents Density	0,7 kg/m^3

The aim is to find the diameter and wall thickness of the pipeline which will provide the required pressure conditions. Initial data for calculation presented in Tables 4.1-4.2.

1. Wall thickness calculation

Hoop stress (DnV 1996):

$$\sigma_h = \frac{(p_i - p_o)(D_o - t)}{2t} \quad (4.6)$$

Where,

σ_h –Hoop stress

p_i –Internal pressure

p_o – Outer pressure

D_o – Outer diameter

t – Wall thickness

Also, hoop stress should be less than a prescribed fraction:

$$\sigma_h \leq f_1 \sigma_y \tag{4.7}$$

Where,

σ_y –Yield stress,

f_1 – Design factor (for pipelines commonly used as 0.72).

$$f_1 \sigma_y \geq \sigma_h = \frac{p_i(D_o - 2t) - p_o D_o}{2t} \tag{4.8}$$

$$\sigma_h = \frac{12 \times 10^6 \times 1220 - 1025 \times 9.81 \times 100 \times 1284}{2 \times 32} = 208.57\ MPa$$

2. Wall thickness optimization

To check should we change wall thickness or not we need to check this inequality:

$$\sigma_h \leq f_1 \sigma_y$$

$$0.72 \times 448 > 208.57$$

$322.56\ MPa > 208.57\ MPa$ It is acceptable; the wall thickness shouldn’t be optimized.

4.4 Subsea facilities protection from icebergs

Offshore pipelines located in places with ice presence must be protected from possible ice gouging (also referred to as “extraction” (cutting)) that occurs when the ice keel is moved along the Pomeranian bottom. The integrity and operability of the pipeline can be broken either as a result of direct contact between the ice keel and the pipeline or as a result of the load acting on the pipeline during soil deformation caused by ice plowing. A typical way to protect against the risk of pipeline damage caused by ice plowing is to carefully deepen the pipeline [36].

Currently, there are two floating vessels in the Grand Banks on the Newfoundland shelf for the production, storage, and unloading of products. Terra Nova was installed in 2001, and White Rose - in 2005. Underwater modules are located in dug holes in the seabed, often referred to as excavated drilling centers. The excavated centers were deepened using excavation equipment at a depth of about 101 meters to obtain large depths that would allow subsea wellheads to remain below the seabed to protect against icebergs.

This technology is also suitable for the Leningrad field. However, to implement this protection technique, it will be necessary to strengthen the walls of the drilling centers in order to avoid their washing out.

The depth of the drilling centers will be calculated depending on the historical data on the movement of icebergs in the Kara Sea, their directions and sizes.

By analogy with the underwater module protection system, the pipeline protection system includes the deepening of the pipeline into the seabed.

The most simple and widespread method of pipeline burial throughout the world consists of pre-pulling out a trench along a pipeline route, laying a pipeline into it and backfilling a trench. However, this method has its drawbacks. The use of this method adversely affects the flexibility of the installation schedule, since all the installation steps must be carried out in strict order. Secondly, in each trenching process, the loss of soil averages 19%. This means that after the removal of soil and its movement, soil intake and backfilling of the trench, more than 41% of the original soil is lost, which leads to its incomplete backfilling. This aspect is of paramount importance if the constraints imposed by environmental considerations require a complete backfill.

In addition to the loss of 41% of the soil, environmental issues also become acute in cases where the terms of the contract indicate the limits of soil dispersion, the turbidity of the water, preservation of marine flora and fauna and soil removal.

If the work should be carried out in environmentally protected areas, the technical limitations of the process of embedding itself imply an even stricter observance of environmental requirements. For such cases, the most effective solution is to deepen the pipeline after laying it in a previously prepared trench with simultaneous backfilling.

This technique is recommended for use in the development of the Leningrad gas condensate field.

Chapter 5. Impact of technical solutions on the environment

Laying and subsequent operation of the pipeline, like any other production facility, is accompanied by a certain environmental impact. However, it is in the power of both builders and operators to make this impact minimal. The pipeline, ideally, should be for the nature of "barely noticeable" object. To achieve this, it is necessary to represent all possible types of environmental impacts at each stage of the construction and operation of the highway.

All impacts associated with the laying and operation of the pipeline can be divided into temporary and permanent. Temporary impacts are inevitable during the pipeline construction process. This is actually the work on the route itself laying or installing the pipeline, the creation of access roads, areas for storage, production facilities and construction villages.

At this time, the natural soil layer, natural drainage paths are disturbed, the soil is polluted with technical and household waste, the condition of soils is disturbed due to the operation of heavy machinery, forests are cut down. However, after the completion of construction work, the stage of land reclamation begins. As a result, the soil layer is largely restored, grasses and perennials are planted, and water drainage is improved. Modern technologies allow to almost completely compensating for violations caused during the construction of the pipeline.

A special situation develops during the construction and operation of pipelines on permafrost. The danger is a violation of the upper, very vulnerable plant and soil layer, which provokes the melting of permafrost, with the subsequent development of such processes as thermokarst, landslides, solifluction. The degradation of permafrost is also possible during the operation of pipelines, due to the heat transfer of heated oil. These phenomena are dangerous because they are irreversible, leading to the complete destruction of the natural environment.

Constant impacts are associated with the loss of land resources, the emergence of new inconveniences for agricultural and other activities. However, these impacts are one-time, as opposed to recurring impacts, which include emissions to the atmosphere as a result of oil heating installations, pumps, and power plants, ensuring the functioning of the pipeline, transport, housing and utilities in the places of work and residence of pipeline system operators.

The impact of man-made accidents associated with oil spills and fires, in which crude oil or petroleum products burn, stand apart. These are extraordinary, extremely rare incidents that cause not only physical but also great reputational damage to the pipeline operator. Therefore, companies are constantly working to improve preventive measures designed to prevent such incidents, and also equip their special services with various technical systems for combating pollution of the environment, in particular, cleaning it from spilled oil products.

Concerning the subsea pipeline, we have decided to choose microtunneling method in order to decrease coastal erosion effect. Most impacts and solutions mentioned above fit both onshore and offshore pipelines.

In order to minimize damage to the environment during the construction and operation of pipelines, a lot of attention is currently being paid to the study of this environment, natural biocenoses, and their interaction. Computer modeling at the design stage of pipelines and choosing a route makes it possible to evaluate the risks of one or another option in order to choose the most optimal one.

Conclusions

In this master's thesis, the main design aspects of the development concept of the Leningradskoye field were considered. Based on the analysis of methods and technologies applicable in the Arctic conditions, the choice was made economically, environmentally and technically suitable for the conditions of this field. The selection matrix of systems for the development and transportation of products presented in Appendix 1 was also developed and compiled.

According to the results of the work done, the following decisions were made:

1) For the development of the Leningrad gas-condensate field, choose a development scheme using an underwater mining complex consisting of 29 modules with 4 wells in each.

2) For the transportation of products, choose the direction to the Bovanenkovskoye field using the proposed trajectory with a duration of 262 km.

3) Based on the estimated flow rates, the appropriate diameter and a wall thickness of the pipeline were proposed. The calculation confirms the correctness of the choice of the diameter values and thickness of the wall for the pipeline.

4) A protection system was proposed for subsea modules and pipelines.

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Appendix A. Solution matrix

Type of development scheme	IRGBS	SPS	IRGBS+SPS
Type of transportation system	LNG tankers	Pipeline	Other
Method of transporting	One-phase flow	Multiphase flow	
Pipeline end point	Sabbeta port	Bovanenkovskoye field	Kharasavey village
Subsea facilities protection	Drilling centers+ pipeline trenching	Protection shields	

Solutions category: green – acceptable, orange – could be implemented, red – unprofitable/technically inefficient.