Environmental status of continental shelf in the Pechora Sea: analysis and recommendations

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Abstract. We have assessed the hydrocarbon reserves, including oil, in the waters of the Arctic seas of the Russian Federation. We have considered current projects for extraction of hydrocarbons in the Pechora Sea at the Prirazlomnoye field. We have carried out comprehensive analysis of environmental issues related to operation of oil exploration facilities, describing the prospects for development of offshore hydrocarbon fields on the continental shelf of the Pechora Sea. The valuable ecosystem components of the Pechora sea have been characterized. We have discussed the set of measures developed for reducing environmental risks: organizing a three-tier automated system for oil spill response in any situation, including emergency; using the “zero discharge” approach, in which all human and industrial waste is collected in special closed containers transported to the shore for disposal; vessels of the auxiliary fleet are equipped with the appropriate equipment enabling them to be directly eliminate emergency oil spills; annual oil spill response (OSR) exercises are held; since the terminal is located in a permafrost region, the oil storage tanks were built with double walls (the tank-in-tank principle), which virtually eliminates the risks of oil spills. We have formulated recommendations for maintaining sustainable environmental status of the continental shelf of the Pechora Sea.

1. Introduction

Issues connected to developing hydrocarbon resources such as oil are top of the agenda right now since, despite the advances made in renewable energy sources, consumption of these resources keeps increasing, particularly in the energy sector. As continental deposits are gradually exhausted, the development of the continental shelf of the Arctic seas keeps gathering pace. However, in view of the Arctic’s special status and harsh climate, environmental safety of developing shelf deposits of the Arctic seas is becoming increasingly urgent.

Problems related to developing offshore oil and gas fields and their impact on the environment are of vital importance for the global community. For example, Ref. [1] considered alternatives to the current practice of well tests with their expected impact on the offshore oil and gas industry in the UK. Development of hydrocarbons and minerals in federal waters along the Pacific coast of the United States has been a controversial issue for many years, with the Federal Agency for Mineral Resources trying various approaches to identifying and solving the problems arising from the proposed exploitation of mineral resources [2]. To sum up, there is currently increased effort from the government and from researchers in almost all countries to protect the Arctic environment [3].
This problem is relevant for Russia as well. For example, [4] discussed the high vulnerability of the marine environment in extreme climatic conditions with ongoing development of the Arctic shelf, leading to high risks of accidents and large-scale environmental consequences during extraction of resources on the continental shelf. Simulation of dynamics of environmental shocks was carried out in [5]. Legal aspects of economic regulation in the field of waste management were considered in [6]. Organization of the monitoring system during shelf development is discussed in [7]. Strategic maps were proposed in [8] for comprehensive assessment of competitiveness of the industry; this tool can be used to organize exploration and development of new fields. New technologies related to digitization of the country's economy were addressed in [9].

Currently, about 5% of oil reserves, 10% of condensate reserves and 18% of natural gas of the total proven reserves of the Russian Federation have been explored in the country's seas. The initial oil resources of the shelf seas are poorly explored (4.6%), which means that new deposits might be discovered in the process of further exploration.

Different amounts of geological data have been accumulated on different parts of Russian sea water: the coastal areas of the Barents and Pechora seas, the Azov and Caspian seas, and the Sea of Okhotsk (around the Sakhalin Island) are relatively well-studied. The largest reserves of oil (442.9 million tons) and condensate (62.4 million tons) are located on the Barents Sea shelf, with the main reserves of gas condensate found in the unique Shtokman gas field, and of oil in Prirazlomnoye, Dolginskoye and Medynskoe-More fields.

Fourteen of the forty-four shelf fields of natural gas discovered are large and thirteen are unique. Notably, natural gas reserves of the Shtokman gas field are estimated at about 6% of all Russian reserves. According to the Ministry of Natural Resources and Environment of the Russian Federation, approximately another 5% is explored in the Kara Sea waters, containing two large and seven unique fields (Rusanovskoye gas condensate field, Leningradskoye gas condensate field, Semakovskoye gas field, Yurkharovskoye oil and gas condensate field, Pobeda oil and gas field, Severno-Kamennomysskoye gas condensate field and Kamennomyskoye-More gas field).

According to the Energy Strategy of Russia for the Period up to 2030, if fields located at a relatively short distance from the coast (including Prirazlomnoye, Varandey-More, Medynskoye-More and Dolginskoye) are developed, oil production can be expected to increase in years up to 2020 following the moderate and optimistic scenarios with oil withdrawals from wells amounting to 50 and 60 million tons per year, respectively.

The Prirazlomnoye field is the most interesting object for the purposes of our study, as it is the only developed oil field both on the continental shelf of the Pechora Sea, and in the entire Arctic sea waters of the Russian Federation.

2. General characteristics of the development project for the Prirazlomnoye field

The continental shelf of the Pechora Sea is located in its northern part and is included in the Timan-Pechora Basin province. The oil reserves in the continental shelf of the Pechora Sea with the coastal territory of the Nenets Autonomous Okrug are estimated at 1.1 billion tons and natural gas reserves at 0.55 trillion cubic meters. This region ranks in the top three constituent entities of the Russian Federation in terms of oil reserves (after the Khanty-Mansiysk Autonomous Okrug – Yugra and the Krasnoyarsk Krai). The recoverable oil resources in uplift zones of the Pechora Sea are estimated at 0.5 billion tons. The structures located within the eastern margin of the Khoreyver Depression, such as Varandey-More and Madachagskaya [10], are the most promising from the standpoint of exploratory drilling in the Pechora Sea.

The offshore natural gas deposits of the Pechora Sea are rather small and are not currently in industrial development. For this reason, we are going to focus on oil exploration, extraction and transportation.

The following oil fields discovered in the Pechora Sea shelf present the greatest interest (reserves as of January 1, 2017, categories A+ B1+C1 + B2+C2, million tons): Prirazlomnoye (56.9 + 21.3),
Dolginskoe (0.9 + 234.9), Medynskoe-More (63.5 + 33.9), Severo-Gulyaevskoe (13) and Varandey-More. The fields were discovered in 1989, 1999, 1997, 1986 and 1995, respectively.

Oil production in the field began in December 2013, with the first shipments to delivered consumers in April 2014. Projected peak oil production per year is estimated at 5.0 million toe. Maximum daily production rate is 20,748 cubic meters. The actual oil production amounted to 2.15 million tons in 2016 and to 2.64 million tons in 2017, while Gazprom Neft PJSC plans to exceed the volume of 3.0 million tons in 2018. Based on the volume of recoverable oil reserves in the Prirazlomnoye field, its planned life is estimated at 36 years.

Horizontal wells were drilled for oil extraction at the Prirazlomnoye field. By 2023, the total number of wells is planned to increase to 32 units, including nineteen producers, twelve injectors and one absorber. The lengths of the wells range from 4,132 to 8,100 m. According to the data from Gazprom Neft PJSC, eleven out of the total number of wells drilled will be inclined with a measured depth of more than 6000 m (horizontal sections up to 1,000 m, offset from the center of the wells to 4000 m).

Arctic Oil (ARCO), a new type of oil, is extracted at the Prirazlomnoye field. Compared with other varieties of oil exported by Russia, ARCO is relatively heavier, with high density (about 910 kg per cubic meter), its paraffin content is low, and sulfur content is high. This type of oil is delivered to countries of Northwestern Europe, where it undergoes deep processing to obtain specialized products for the chemical, pharmaceutical and space industries; the oil is also used in tire production.

Gazprom Neft PJSC (the parent company of the project operator, Gazprom Neft Shelf LLC) has developed a new scheme for delivering ARCO oil to European consumers, launching it in 2016. Umba, an offshore storage tanker with a cargo capacity of about 300,000 tons and capable of accommodating simultaneous berthing of vessels on both sides, is moored in the Kola Bay (Murmansk Oblast). The storage tanker consists of seventeen tanks for storing oil and is additionally equipped with a transload facility, providing separate storage of various oil grades (beside ARCO), the storage is used to transfer oil of the NovyPort grade produced at the Novoportovskoye field). Mooring a floating storage tank in the ice-free Kola Bay makes it possible to shorten the duration of round trips for special ice-class tankers, as well as to attract a fleet of standard tankers for further shipment of oil to consumers. The projected maximum cargo turnover for the transload facility is estimated at up to 15 million tons annually.

Drilling, extraction, storage, processing and shipment of oil from the Prirazlomnoye field to ships is carried out around the clock (construction of wells and oil production is also independent of weather conditions) using Prirazlomnaya, a specially constructed offshore ice-resistant fixed platform (OIRFP). This is the only fixed platform in the world used for field development in ice conditions (the ice remains around the station for up to 7 months a year, with the height of the pressure ridges reaching two meters). The OIRFP is located 60 km from the coastline (settlement of Varandey), the depth at its location reaches 19.2 meters [11]. The platform was designed to take into account the specifics of business practices in the Arctic conditions (climatic, environmental, ice) and compliance with stringent safety requirements. Prirazlomnaya independently provides itself with electrical and thermal energy and is intended for year-round stay of up to 200 people. Small depths allowed to install the platform (whose weight is about 0.5 million tons, and size is 126 by 126 meters) directly onto the seabed, reinforcing it with a crushed-stone safety berm (with a volume of more than 45,000 cubic meters and a weight of about 0.12 million tons ).

The initial plan was to build a completely new platform; the first sections of the Pechora platform were laid at JSC PO Sevmash in 1995. However, the project's documentation was changed in 1996, and construction of the Prirazlomnaya platform began, stopping almost immediately due to lack of funding. In 2002, in order to reduce the cost of the platform, it was decided to get the top part (containing the drilling, residential and technical modules) from a decommissioned foreign drilling platform; the Hutton platform built in 1984 was acquired from the Norwegian company Monitor TLP Ltd for this purpose. In 2003, after being transported to the Murmansk region, the platform was divided into two parts, and its upper part, Hutton TLP, was delivered to Sevmash. The lower part of
the Prirazlomnaya platform, the caisson, was built during 2004–2005; both parts were joined in 2006, and construction continued afloat, lasting until 2010. In 2011, the platform was transported to the 35th Ship Repair Plant (Muransk Region), where outfitting and commissioning operations were completed. By the end of that year, Prirazlomnaya was installed in the field and reinforced. The OIRFP was commissioned in 2013 [12].

3. Environmental risks of the project

The first concerns about the environmental risks of the project were voiced by environmental organizations in 2004. The greatest controversy surrounded the final stages of construction and preparation of the platform for operation in 2011–2013. A number of organizations, including the Russian Bird Conservation Union, Greenpeace Russia, WWF Russia, and Bellona Foundation, jointly declared in 2011 that the project was unacceptable. In 2012-2013, Greenpeace Russia activists held a number of provocative protests, for example, attempting to organize a picket right on the sheer wall of the Prirazlomnaya platform [13].

The following measures were introduced to ensure environmental safety of the platform and the project as a whole:
- the platform is installed directly on the seabed and reinforced with a berm, so that there is no direct contact of the production well with water;
- the upper part of the platform is protected with high (16.4 m) sloping walls, called ice and wave deflectors;
- the platform has a two-tier protection against the risk of blowout oil spills, using a slam-shut valve located at a depth of 100–150 m from the wellhead, and a backup hydraulic valve which is part of the wellhead equipment;
- the oil is stored in tanks with a total volume of 124,000 cubic meters, located in the caisson whose walls are made of a three-meter layer of concrete, covered with clad steel (4-centimeter layer) for greater resistance to wear and corrosion;
- the tanks use a wet- sump storage approach, eliminating oxygen ingress and thus preventing virtually any risk of an explosion;
- oil is pumped from the platform's tanks directly to vessels via two sets of offloading systems (KUPON), equipped with an emergency shutdown system with a maximum 7-second response time;
- automated oil flow through KUPON only starts after 30 parameters of this operation are checked;
- shuttle tankers Mikhail Ulyanov and Kirill Lavrov were built specifically for the project (deadweight 70,000 tons each; ice class Arc6);
- all systems are controlled remotely via an automatic control and safety system minimizing the risks of the human error;
- a zero discharge system is employed, preventing the drilling and production waste from getting into the sea: drilling fluid, sludge and other wastes are either delivered to the shore for further disposal or pumped into special absorption wells;
- process water is pumped to the platform using fish protection devices;
- helicopters fly over the sea at a height of at least 500 meters to reduce noise impacts;
- the platform has a special birdlife protection facility broadcasting sounds that prevent birds from nesting and forming permanent flocks in the protected area;
- multifunctional icebreakers Yuri Topchev and Vladislav Strizhov responsible for delivery of cargo to Prirazlomnaya and its bunkering with fuel, equipped with special oil-gathering systems, are on permanent standby around the platform to provide fast oil-spill response;
- additional oil-spill response equipment ensuring full protection of the coastline is also in place onshore near the settlement of Varandey;
- annual oil spill response (OSR) exercises are held;
- since 2012, there has been ongoing research on the habitats and breeding grounds of Atlantic walruses living around the Prirazlomnaya platform. Studies around the Matveev, Vaigach, Maly
Zelenets, Bolshoy Zelenets, Golets and Dolgy islands found no significant fluctuations in migration patterns and distribution of marine mammals in the Pechora Sea.

Thus, the Prirazlomnaya OIFRP is equipped with a fairly impressive range of protective mechanisms and systems for disaster prevention, and resources have been prepared for emergency oil spill response. A special system consisting of more than 60 sensors that instantly react to changes in operation provides 24-hour monitoring of platform. Fish protection devices are used during the platform’s operation.

No disasters, including oil spills, have been recorded for the entire period of oil extraction and processing at the Prirazlomnoye field, which indicates high environmental safety of the project.

The Varandey Oil Terminal project, launched by LUKOIL in 2000 for handling the oil extracted from the company's fields in the Nenets Autonomous District, also confirms that development of hydrocarbon resources in the Pechora Sea is possible without endangering the vulnerable environment of the region. No disasters have occurred for the entire period of the terminal’s operation. Environmental safety at the terminal is ensured by a three-tier automated protection system.

4. Reducing the environmental risks of field development projects

While the project is safe enough from an environmental standpoint, a set of additional measures has been developed to reduce environmental risks:

- organizing a three-tier automated system for oil spill response in any situation, including emergency;
- using the “zero discharge” approach, in which all human and industrial waste is collected in special closed containers transported to the shore for disposal;
- vessels of the auxiliary fleet are equipped with the appropriate equipment enabling them to be directly eliminate emergency oil spills;
- annual oil spill response (OSR) exercises are held;
- since the terminal is located in a permafrost region, the oil storage tanks were built with double walls (the tank-in-tank principle), which virtually eliminates the risks of oil spills.

Gazprom Neft PJSC is actively exploring options for developing the Dolginskoye oil field, located in the central part of the Pechora Sea, 110 km north of the coastline of mainland Russia and 120 km south of the Yuzhny Island of the Novaya Zemlya archipelago. The Dolginskoye field is the best-studied one of the company's subsidiary assets. Four exploration wells were drilled in the field, with geophysical and hydrodynamic studies conducted for them.

The exploratory wells were drilled complying with modern environmental standards:

- environmentally safe water-based drilling fluids were used;
- a controlled rotary system for automated vertical drilling helps reduce the duration of drilling and the drill sludge volume;
- the “zero discharge” approach is used, with all sludge and drilling fluid transported to the shore for subsequent disposal.

3D seismic surveys, completed in 2018, were performed using modern Arc4 ice-class research ships (maximum ice class for ships of this type) carrying unique equipment adapted for use in the Arctic, allowing to obtain detailed high-quality seismic data. The ships comply with the modern international standards in the field of industrial and environmental safety. For example, the ships are equipped with lock-heating systems on life rafts, railings, steps and decks, which significantly increases the safety of the crew under icing of the ship.

In view of the exploratory drilling and seismic surveys carried out, Gazprom Neft PJSC is considering different options for development of the Dolginskoye field. Using the Prirazlomnaya OIFRP for extracting oil from this field is one of the projects that have been proposed after seismic survey. As the Dolginskoye field is not far from the Prirazlomnoye, the company is looking into the possibilities of simultaneous development of both field from a single platform.
The focus on environmental problems in the Arctic, especially in the Arctic sea waters is because the ecosystems of this region are particularly vulnerable, while severe climatic conditions dictate the specifics of industrial practices and disaster response.

The term Valued Ecosystem Component (VEC) is understood in ecology as a natural component of the ecosystem, distinguished from other components by its particular environmental, economic or socio-cultural significance. The VECs for the Pechora Sea are divided into four main groups: marine mammals, ichthyofauna, avifauna and benthic invertebrates [14].

Up to 19 species of marine mammals populate the Pechora Sea and its adjacent territories, inhabiting the region permanently, seasonally or periodically. Among these species, the beluga whale, the polar bear, the Atlantic walrus, the bearded seal and the ringed seal can be classified as VECs. Current and future projects for oil extraction and transportation [15] in the Pechora Sea can threaten marine mammals in two cases: from January to April, when ringed seal pups are born on shore ice in the Pechora and Khaypudyr Bays, and year-round for the walrus inhabiting the middle part of the Pechora Sea between the mainland and the Yuzhny island of the Novaya Zemlya archipelago, in areas rich in benthos where the walrus feeds during its fattening period.

The ichthyofauna of the Pechora Sea includes 63 taxa (species and subspecies) belonging to 21 fish families (the proportion of fish taxa from the total number,%): cottids (14.3%), eelpout (11.0%), whitefish (9.5 %), cod (9.5%), flounder (9.5%), salmon (6.3%), smelt (6.3%), smelt (4.8%), prickleback (4.8%), poacher (4.8%), herring (3.2%), northern lamprey (1.6%), lantern shark (1.6%), skate (1.6%), freshwater eel (1.6 %), burbot (1.6%), stickleback (1.6%), lump sucker (1.6%), gunnel (1.6%), wolffish (1.6%) and sand lance (1.6%). 20 of these fish species are mass-produced commercially important species, another 15 are minor small-population species, and 28 are non-commercial species. Development of hydrocarbon deposits in the Pechora Sea affects migratory fish (Atlantic salmon, Arctic cisco) by disrupting their migration routes and timing, and semi-migratory fish (common, broad and northern whitefish, European cisco, sheefish) by corrupting their feeding grounds.

The avifauna consists of 32 species, including those belonging to the following ecological groups: flying, surface-feeding (11 species, including Arctic fulmar, gull and skua), pursuit- and plunge-diving (18 species, including cormorant, seaduck and auk) and semiaquatic nearshore-feeding (3 species, including wader). Notable benthic invertebrates include the bivalve mollusk and the Icelandic scallop. The total biomass in the Pechora Sea ranges from 10 to 200 grams per square meter.

Exploration and development of hydrocarbon fields are often accompanied by oil spills occurring on the water surface and hydrocarbon waste deposits forming in the near surface section (up to 500-800 meters), primarily in aquifers; this leads to pollution of the marine ecosystem. However, while detecting accidental oil spills on the sea surface by aerospace or ground-based observations is not particularly difficult, detecting waste deposits of oil is much more difficult. Accumulation of waste deposits of oil is usually induced by fluid-dynamic processes occurring around wells for a number of reasons: poor sealing of the well with cement mortars, depressurization of coupling joints, corrosion of casing strings, as well as damage to wells during operation or due to natural seismic and tectonic processes. Waste deposits of oil are a reason for serious pollution of underground ecosystems and emergencies affecting the terrestrial ecosystem and the atmosphere.

Modern technologies are not 100% effective for protection against the risks inherent in exploration, extraction and transportation of hydrocarbons, including oil, particularly, against the human factor. For instance, according to international statistics of oil tanker accidents causing oil spills, the accidents due to human error make up 84–88% of their total number [16]. In addition to numerous systems for physical protection against accidents and disasters, minimizing human participation in routine operations through increased automation is the main factor in achieving environmental safety. The Ministry of Natural Resources and Environment of the Russian Federation, Rosprirodnadzor and the regions of the Russian Federation (including the northern ones) have signed agreements on implementing integrated plans of National Project Ecology. The activities planned as part of the national project were developed taking into account the needs and characteristics of the
regions and in view of obtaining a real environmental effect, which should help reduce environmental risks.

5. Conclusions
To summarize, the following steps should be taken to maintain sustainable environmental status of the continental shelf of the Pechora Sea:
- continuing to develop innovative methods of exploration, drilling, production, processing, shipment and transportation of oil, adapting all of these stages to the natural and climatic conditions of the Arctic;
- protection against emergencies during design, installation and operation of equipment and systems should consist of two, three or more levels (for example, duplicate safeguards, double hulls of ships, and double walls of oil storage tanks (tank-in-tank, etc.);
- automation of operation and safety systems of objects should exclude the human error not only in case of emergencies but also for the entire chain of oil field development processes with minimal human participation;
- extending the principle of “zero discharge” for any objects in operation in the Arctic sea waters to federal or supranational legislation;
- strict control should be exercised by the responsible and supervisory authorities over compliance with OSR legislation;
- environmental organizations and the appropriate authorities should constantly monitor the environmental impact of resource extraction projects.

The article was prepared in the framework of R & D №13-19Г3 "Improving the methods of operational and long-term diagnostics of the habitat of marine hydrobionts in the conditions of active industrial development of hydrocarbons of the Arctic shelf", conducted by the state task of the Ministry of Science and Higher Education

References
[1] Marshall C Thomas A Maximising economic recovery - A review of well test procedures in the North Sea 2015 Society of Petroleum Engineers - SPE Offshore Europe Conference and Exhibition, OE 2015
[2] Alcorn S Minerals management and conflict resolution 1993 Coastal Zone: Proceedings of the Symposium on Coastal and Ocean Management 3 p 3235
[3] Amiragian A 2016 Oil and gas in the Russian Arctic FEC of Russia 9 34
[4] Ivanova V et al Assessment of ecological risks during the mastering of hydrocarbon deposits of arctic shelf 2013 Gornyi Zhurnal Issue В 11 p 30
[5] Didenko N and Kulik S 2018 Environmental Shocks: Modelling the Dynamics IOP Conference Series: Earth and Environmental Science B 180 (1) 1 10 August 2018, No 012013 Available from: http://iopscience.iop.org/article/10.1088/1755-1315/180/1/012013/pdf [Accessed 15th February 2019]
[6] Epifanov A et al Legal aspects of economic regulation in the field of waste management 2018 International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management SGEMB 18 (5.3) p 553
[7] Kozmenko S et al Maritime economics of the Arctic: Legal regulation of environmental monitoring 2018 IOP Conference Series: Earth and Environmental Science 180(1) 012009
[8] Kozlov A et al Strategic map as a tool for increasing the investment attractiveness of the regional construction sector: Case of the Murmansk region 2018 MATEC Web of Conferences 170 02005
[9] Zaychenko I et al Digital transformation: The case of the application of drones in construction 2018 MATEC Web of Conferences 193 Number 050662018
[10] Zakharov E and Tolstikov A Once again on the feasibility of searching for oil fields in the Barents and Pechora seas. Geology, geophysics and development of oil and gas fields 2014 Б 9 p 13 (in Russian)
[11] Voronina E Influence of the development and transportation of hydrocarbon resources of the Arctic shelf on the development of the Northern Sea Route. North and the market: the formation of an economic order 2014 B 6 (43) p 3 (in Russian)

[12] Halizeva M The Arctic project "Sevmash" Science in Russia 2013 B 2 (194) p 21 (in Russian)

[13] Egorova A The case of the ship "The Arctic Sunrise": analysis of the international legal position of the Russian Federation Electronic collection of articles based on materials from the LVI student international scientific-practical conference "Scientific community of students of the XXI century. Social Sciences" 2017 Novosibirsk: Association of Researchers Siberian Academic Book p 70 (in Russian)

[14] Boltunov A Dubinin Metc Areas of restriction of anthropogenic activity: the Pechora Sea. 2014 Oil and gas complex Murmansk: World Wide Fund for Nature (WWF) 76 p (in Russian)

[15] Kozmenko S Savelyev A Shchegolkova A Economic development of Arctic communications under the influence of defense and economic activities in the Arctic 2014 Modern Problems of Education and Science. B 1 p 272 (in Russian)

[16] Bogoyavlenskiy V and Bogoyavlenskiy I The Arctic Oil and Gas Resource Development Strategy - Ensuring Russia's Energy, Environmental, and Economic Security 2017 Geopolitics and Security. B 3 (39) p 72 (in Russian)