Approach to environmental risk assessment in the design and operation of oil fields in the Arctic region

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Abstract. Environmental risk is the basis for environmental safety assessment for any object. Without a risk assessment, it is extremely difficult to control the permissibility of certain anthropogenic impacts on the environment. At the same time the active development of hydrocarbon production in the Arctic region, can lead to irreversible consequences for the environment because of the special vulnerability of this territory to man-made impacts. In this regard it became necessary to create a universal and practical methodology for the environmental risks assessment. This article proposes an approach to assessing environmental risks for the design and operation of oil fields in the Arctic region, which allows comprehensive reviewing of the environmental safety of hydrocarbon production, as well as prompt and optimal response to environmental pollution. The criteria for risk assessment, their significance, as well as the structure and methodology of the assessment itself are analyzed.

1. Introduction
Today, the development of the Arctic region is becoming more relevant and significant in connection with the discovery of new mineral deposits and the importance of the region from a commercial and military point of view. Hydrocarbon production is also among the priority areas of the region development. However, the extraction of petroleum products often has a negative impact on the environment. At the same time, for the Arctic region such an impact will be much more dangerous due to the slow flow of all natural processes due to low temperatures. Therefore, environmental protection and management in the Arctic region should be given a special attention.

Therefore environmental impact should be strictly assessed. Environmental Impact Assessment (EIA) is based on a detailed analysis of the expected and other potential impacts on individual components of the environment and the population [1]. These components are air, soil, water, climate, landscape, flora and fauna, cultural and historical monuments [2]. Numerous EIA methodological approaches have been designed as a tool for identifying, predicting and assessing the impact of a proposed project [3] and for preparing an Environmental Impact Statement [4]. The process of prioritizing investment projects [5] EIA, has become an important tool for promoting the principles of sustainable development and the best available technologies. Today EIA was improved by numerous effective methods and instrumetns. Topical issues in EIA research include public participation [6], efficiency [7] and new methodologies development [8].

To reduce negative impacts, it is important to detect and control them in time so that they do not cause irreversible changes in the Arctic’s fragile ecosystem.
In order to achieve this objective in the field of hydrocarbon production, it is important to assess the emerging environmental risks in a timely and correct manner.

In this regard, we set a goal to developed a methodology that allows us to universally assess environmental risks at Arctic oil fields, taking into account the production process, the characteristics of the region and the nature of the impact of oil production to the environment. The results of this goal achievement are presented in this article.

This assessment is based on the constant collection and updating of information about the natural environment conditions in the hydrocarbon production area, as well as on correct design solutions that reduce any impacts of subsoil use facilities to the ecosystems of the region.

To make such design decisions, it is necessary to assess the location of the oil production facility not only from the economic feasibility point of view, but also from the potential negative environmental consequences point of view that increase environmental risk. Such a risk can be assessed through a number of criteria accurately suited to the Arctic region.

However, even taking into account all environmental risks in the project is not a guarantee that it will be no contamination during the deposit operation. Therefore, after commissioning of the facility, the environmental risk assessment should not be completed, but during the operation of the deposits, the approach to this assessment should be changed. During operation, it is possible to monitor the situation in the field in real time and thereby collect valuable information for environmental risk assessment. The source of such information can be a production control, regularly carried out in all Arctic fields. The recurrence of the requirements violations of this control will determine the existing environmental risk.

2. Method description

As mentioned above, the environmental risk assessment for hydrocarbon production in the Arctic region should be carried out in two stages:
- risk assessment at the design stage;
- risk assessment at the operation stage.

The environmental risk assessment for each stage is described in detail below.

2.1. Risk assessment during the design stage

2.1.1. General risk assessment. Risk assessment and environmental impact assessment (EIA) processes have a mutual base. Both approaches are highly interdisciplinary. EIA and risk assessment are based on a very similar concept and generally have the same objectives [8].

The proposed methodology for environmental risk assessment at the design stage largely involves environmental impact assessment.

The main essence of the methodology is to identify and evaluate factors that are significant in terms of their impact on the environment. To do this, a universal matrix method is used. The main principle of its work is the calculation of the risk index derived from the score assessment. It can be quantified based on the individual risk calculation for each identified negative impact on the natural environment.

The specification of such influences is based on the proposal of the authors. For each of the selected factors, criteria for its assessment were selected in terms of negative impact and in terms of the likelihood of such event occurring.

This approach is most suitable for the construction of new oil production facilities, as it assesses the factors associated with the production process.

Factors related to chemical contamination, noise, vibration, and waste generation were selected for risk assessment.

The probability was assessed as the possibility of negative effects due to the influence of external components on the criterion. To assess the significance of probability, it was divided into 4 levels: from 0.25 to 1 [9].
The consequence occurs after a negative factor affects the environment. The consequence of negative effects should be investigated at different levels. For example, damage to human health is usually considered at the individual level, and environmental damage is usually considered at the level of populations, species or communities.

To determine the most negative impact and transfer it into a score assessment, its impact was also relatively divided into 4 levels (0.25–1).

Further, probability scores and impact scores are multiplied for risk assessment and score determination (Table 1). To assess the overall environmental risk, it is necessary to add all the risks of each individual factor. The total risk significance was estimated based on the sum of points and was also divided into 4 categories. Since 15 risk factors were selected for environmental risk assessment, 4 categories had the following ranges:

- 0.93-3.74 – very low
- 3.74-5.62 – low
- 5.63-8.43 – medium
- 8.44-15 – high

| Table 1. Matrix of qualitative risk analysis. |
|---------------------------------------------|
| Consequence | Marg. | Low | Med. | High |
|-------------|-------|-----|------|------|
| Highly unlikely | 0.25 | 0.0625 | 0.125 | 0.1875 | 0.25 |
| Unlikely | 0.125 | 0.0625 | 0.125 | 0.1875 | 0.25 |
| Probable | 0.1875 | 0.0625 | 0.125 | 0.1875 | 0.25 |
| Highly probably | 0.25 | 0.0625 | 0.125 | 0.1875 | 0.25 |

2.1.2. Risk factors. At the design stage in the Arctic region, the factors that have the greatest impact to the natural environment condition, most related to the oil production process and at the same time are key for the Arctic region, were selected. There are:

1. Snow cover total pollution indicator [10];
2. Soil total pollution indicator [10];
3. Air total pollution index [11];
4. Specific combinatorial index of surface water contamination [12];
5. Noise level at the site boundary;
6. Vibration at the site boundary;
7. The number of Red Book species of animals in the construction area;
8. Area of water-resistant layers in the area of oil production;
9. Availability of protected areas;
10. Availability of water protection zones;
11. Availability of cultural monuments of small peoples;
12. Quantity of generated hazardous waste (class I-IV);
13. Quantity of generated not hazardous waste (class V);
14. Quantity of wastewater;
15. Area of soil layer removal.

Taking into account the degree of violations for each of these factors in conjunction with the assessment of the probability of such violations for each designed oil production facility makes it
possible to quantify the environmental risk of each design solution and make a choice from the side of the most optimal option.

This will make it possible to implement new projects for the extraction of hydrocarbons in the Arctic region with minimal environmental costs, while maintaining the economic effect.

2.2. Risk assessment during the operation stage

2.2.1. General risk assessment. The environmental risk assessment during the operation stage of oil production facilities is based on materials of production environmental control carried out at these facilities.

As in the case of the design stage risk assessment, it is necessary to select the most significant factors, assess their impact and consequences for the natural environment, as well as the probability of such a negative impact.

The cardinal difference between the operational risk assessment and the design risk assessment is the assessment of the probability of negative consequences. In the case of operation stage, statistics for estimating this probability are collected daily in the order of supervision of the oil production facility. This allows us to assess the risk more accurately and reliably.

Since it is proposed to take data for risk assessment from the results of industrial environmental control, the assessment of the negative impact of the selected factors should be carried out through the analysis of the identified violations during inspections. Thus, for the convenience of processing the results, the impact of the negative impact in this case is proposed to be divided into 2 levels: compliance with the standard, non-compliance with the standard. A score of 0.25 or 1 is also assigned to each level to preserve the risk calculation logic.

In the case of probability calculation, its transfer to the score is similar to the risk assessment during the design stage. The probability is divided into 4 levels from 0.25 to 1.

During daily inspections within the framework of environmental production control at oil production facilities, the presence or absence of violations for each of the evaluation criteria is recorded, as a result of which information is accumulated on the frequency and type of violations detected. Based on the results of the year, this database allows us to form a reliable sample to assess the probability of a violation, as a result of which it is possible to assess the environmental risk itself.

Further, to estimate the overall risk, it is made the multiplication of probability and impact of negative factor (Table 2).

Table 2. Matrix of qualitative risk analysis.

| Probability       | Consequence | Marg. 0.25 | High 1 |
|-------------------|-------------|------------|--------|
| Highly unlikely   | 0.0625      | 0.25       |
| 0.25              |             |            |
| Unlikely          | 0.125       | 0.5        |
| 0.5               |             |            |
| Probable          | 0.1875      | 0.75       |
| 0.75              |             |            |
| Highly probably   | 0.25        | 1          |
| 1                 |             |            |

To assess the overall environmental risk, it is necessary to add all the risks of each individual factor. The total significance of risk during the operation stage was estimated based on the sum of points and was also divided into 4 categories. Since 33 risk factors were chosen for environmental risk assessment, 4 categories had the following ranges:
- 2.06-8.25 – very low
- 8.26-12.37 – low
- 12.38-18.56 – medium
- 18.57-33 – high

The total score is an assessment of the annual operation and the accumulated environmental risk during this time. Based on this information, it is possible to assess the priority of management decisions in the field of improving the environmental situation in existing areas.

2.2.2. Risk factors. Environmental risk factors during the operation stage can be conditionally divided into 6 categories:

1. Waste management;
2. Spill Prevention, Oil Storage
3. Atmospheric air protection
4. Use and protection of water
5. Protection of the plant and animal world
6. Radiation protection

In each category, a number of factors were selected, which are estimated during daily production control in the oil fields of the Arctic region. The influence of the factor is assessed as the presence or absence of violations for each of them.

Environmental Risk Assessment Factors for Arctic Oil Production Facilities are:

1. Waste management
   1.1. Class I wastes are contained in a specially equipped place
   1.2. Class II wastes are contained in a specially equipped place
   1.3. Class III wastes are contained in a specially equipped place
   1.4. Class IV wastes are contained in a specially equipped place
   1.5. Class V wastes are contained in a specially equipped place
2. Spill Prevention, Oil Storage
   2.1. All petroleum products are stored in sealed containers with metal pallets.
   2.2. There is no leaking of tanks with oil products.
   2.3. Availability of means to eliminate emergency oil spills
   2.4. Tightness of fuel, lubricating and hydraulic systems connections is not compromised
   2.5. There are no traces of oil products on the ground
   2.6. Repair of equipment, filling of equipment is carried out on a sealed surface with protection against leaks or using pallets. Collection of oil products and contaminated waste water during repair works is carried out in sealed tanks with subsequent disposal
   2.7. Monitoring of integrity of boarding and waterproofing of hazardous areas of the sites (site of drilling, tank with fuel, site of chemical reactants storage in all areas related to operations of oil discharge/filling)
   2.8. Layout of process sites, barns, their waterproofing, installation of trays for waste drilling and rain (melt) waters
   2.9. Casing tightness control: use of appropriate lubricants to seal threaded connections
   2.10. Construction of hydro insulated horizontal flare barn for well testing
   2.11. Collection of drilling mud and spent drilling mud into temporary sludge accumulator with further processing of drilling waste into mineral soil; Temporary sludge accumulator for drilling waste (buried, waterproof coating, canopy).
3. Atmospheric air protection
   3.1. No unauthorized incineration of waste.
   3.2. No vehicles with running engine during long-term outage
   3.3. Before opening of productive formation:
      3.3.1. additional check of BOP readiness,
      3.3.2. monitoring of serviceability of cleaning and degassing facilities,
3.3.3. controlling of drilling fluid reserve in amount of at least two well volumes with parameters corresponding to geological and technical combination.

3.3.4. provision of round-trip duty of the cementing unit.

4. Use and protection of water

4.1. Cleaning of domestic effluents at local cleaning constructions with subsequent use of treated effluents for technological needs. Serviceability check of local cleaning constructions. There is no discharge to the pond or to the terrain.

4.2. Arrangement of surface runoff collection system and drainage system. Surface wastewater formed on the site by vertical layout is withdrawn to reduced places and accumulated in pits for collecting surface wastewater with a volume of. Installation of drillwater and rainwater (meltwater) discharge trays. Use in construction and maintenance operations or for use in the process. There is no discharge to the open water or to the terrain.

4.3. Availability of technological device (pallets) in places of probable formation of drainage waters and spills of process liquids. The drainage water thus collected is directed to the drilling fluid preparation unit for further use. There is no discharge to the pond or to the terrain.

4.4. Compliance with the regime of water protection zones. Availability of special information signs of waterdefense area boundaries and usage mode.

4.5. Lack of water protection zones on land:

4.5.1. drilling site;

4.5.2. arrangement of drilling fluids and process fluids preparation points;

4.5.3. location of petrol, lubricants and chemicals warehouses;

4.5.4. arrangement of storage places of industrial and domestic waste, accumulators

4.6. wastewater;

4.6.1. garbage storage;

4.6.2. location of filling stations, washing and repair points of cars and other mechanisms;

4.6.3. parking of vehicles;

4.6.4. unauthorized cutting of wood-shrub vegetation.

4.7. Check of presence and integrity of geomembrane web, presence of collapse

5. Protection of the plant and animal world

5.1. Installation of opaque darkening screens to prevent unwanted light propagation; preventing the use of lighting equipment that is not equipped with factory-made light protection devices and propagates undesirably bright light in the horizontal direction. Disconnection of unused lighting equipment, reduction to the minimum amount of lighting at night.

5.2. Absence of man-made damming (installation of artificial dams) of streams, runoff lodges, "flooding" of slopes with construction waste

5.3. Compliance with the ban on the raising of bonfires and work with open fire outside the designated places, the absence of traces of the fire

5.4. Strict adherence to land removal boundaries. No movement of heavy equipment outside roads and areas of agreed land diversion

5.5. Personnel compliance with the ban on hunting, fishing, harvesting wild plants, collecting eggs of nesting birds, ruining nests

5.6. Compliance by personnel with the ban on feeding wild animals, preventing animals from accessing food waste storage places, banning the import of pets (cats, dogs) into the area of work

5.7. Water intake facility is equipped with fish protection device

6. Radiation protection

6.1. Storage of radiation sources for the duration of work is carried out in a marked special protective transport container, in a specially designated place, where its safety is ensured and access of unauthorized persons is excluded

6.2. Storage areas of sources shall have radiation hazard signs in accordance with GOST 17925-72. During inspection and other works with sources of ionizing radiation, radiation-hazardous zone is installed and marked
The above factors make it possible to universally assess the environmental risk during the operation stage of any oil production facilities in the Arctic region.

3. Conclusion
The developed methodology for environmental risk assessment in the design and the operation stages of oil production facilities in the Arctic region allows us to make a comprehensive and universal monitoring of the impact of such facilities to the natural environment and making timely decisions to minimize negative impacts.

This approach will allow the Arctic region to develop while maintaining its fragile ecosystem. Indeed, in the event of destruction, the period of its restoration can last centuries, which can lead to irreparable consequences, both for the local fauna and for the inhabitants of the Arctic region.

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