Assessment of environmental damage from oil sludge to land resources in the Irkutsk region

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Abstract. The problem of oil sludge is considered to be serious in the regions of oil and gas production, since it migrates and transforms when in contact with the environment. In this article, we considered the amount of oil sludge produced in the fields of the Irkutsk region and methods of its disposal using the example of the three most promising fields in Eastern Siberia: Yarakta, Markovo and Dulisma fields. We considered the ways of oil sludge disposal and treatment in these fields, fees for the drilling waste produced and made a comparative assessment of the waste produced.

1. Introduction

The problems of the negative impact on the environment during oil and gas production begin from the period of field exploration. The negative impact on the entire environment occurs at all stages of oil and gas production and oil and gas processing. The withdrawal of large areas of land resources from forest funds, the extracted rock and the areas of fields themselves become a source of the negative impact. As a result, vast territories in oil and gas production regions are polluted with oil.

Sources of significant damage in the form of air, soil, and water pollution are sludge pits. Sludge pits are environmental facilities designed for the centralized collection, treatment and disposal of toxic industrial waste from drilling oil wells. During the construction of these facilities, vegetation in the form of trees and shrubs is eradicated, soil surface is degraded, and fertile lands are divested. Moreover, vast areas of land are withdrawn from use as a result of the need to place the sludge pits themselves containing hazardous drilling oil sludge. The capacity of sludge pits depends primarily on the system for performing drilling operations, the depth of raw materials and the period of the well construction, water supply and drainage systems as well as factors of the natural environment. Drilling waste has the following variation: barren rock, used drilling brines, drilling wastewater and its sediment, drilling sludge. [2]. Let us analyze the main environmental impact of the drilling oil sludge.

The main environmental pollution occurs as a result of exposure to mineral salts, chemical agents used and petroleum products themselves, which are contained in drilling oil sludge in the following proportions: barren rock (60–80%), natural matter (8–10%), salts mainly soluble in water (6%), oil, and various chemical inclusions.

Oil production, including gas condensate, in Russia from January to December 2017 decreased by 0.3% to 546 million tons, gas production increased by 8.7% to 604 billion cubic meters compared to the same period of 2016. The following volumes are extracted in the Irkutsk region: 17.8 million tons of oil, 7.5 trillion cubic meters of natural gas. Large fields - Yarakta, Dulisma and Markovo - have been discovered. There are about 80 oil and gas production sites owned by various enterprises. The
development of the region’s rich hydrocarbon potential causes significant damage to the environment, including that of the lake Baikal.

Let us consider the amount of oil sludge produced in the fields of the Irkutsk region and methods of its disposal using the example of the three most promising fields in Eastern Siberia: Yarakta, Markovo and Dulisma fields. These fields have a similar depth of oil horizons, which allows giving an adequate assessment of the oil sludge formation. Let us consider them in more detail.

The Yarakta oil and gas condensate field is located 140 km north-east of the city of Ust-Kut, in the northern part of the Ust-Kut municipality and the southern part of the Katangsky municipality of the Irkutsk region of the Russian Federation. The field was discovered in 1969, its exploration was completed in 1978. Until 1992, the field was temporary abandoned and waited to be developed. Its operator is Irkutsk Oil Company (INK), for which the Yarakta field is the main field. Approximately 80% of the company's raw hydrocarbon deposits is developed here. The drilling waste at the 16 cluster sites of the Yarakta field include the following types of waste: drilling sludge, waste drilling mud. The amount of waste includes oil-containing products of well development and liquid domestic waste from temporary housing for drillers.

The Markovo oil and gas condensate field is located near the village of Markovo, 100 km north-east of the city of Ust-Kut and 60 km south-west of the city of Kirensk in the Irkutsk region of the Russian Federation. Oil reserves amount to 20 million tons. Its operator is Irkutsk Oil Company (INK). The drilling sludge at each of the 8 cluster sites of the Markovo field is dumped into specially equipped hydro-insulated platforms with subsequent inertization and disposal in hydro-insulated sectional sludge pits.

The Dulisma oil and gas condensate field is located in the Katangsky municipality, 90 km north-west of the city of Kirensk. The design capacity of the Dulisma field amounts to 400–450 thousand tons of oil per year. The license for the development of the field belongs to NK Dulisma CJSC. The solid phase separated during the drilling mud cleaning is dumped into the sludge pit. The following amount of drilling waste will be generated in the process of drilling and developing an oil producing deviated horizontal sidetrack well in the productive sediments of the Yarakta horizon in the Dulisma field according to the traditional technology using design formulations of drilling mud and the 4-step system for its cleaning.

To establish the degree of damage to the environment from the disposal of sludge waste, we carried out an appropriate assessment and expressed this damage in monetary terms.

2. Materials and methods

Values for waste disposal from draft waste generation standards and limits on its disposal and quarterly reports on the disposal of production and consumption waste, as well as statistical data on monitoring the activities of enterprises, were used as initial assessment materials.

To assess the damage to the environment from oil sludge, we used the legislatively developed and approved procedure described in the document *Methodology for Calculating the Amount of Damage Caused to the Soil as an Object of Environmental Protection*. This methodology was approved by Order No. 238 of the Ministry of Natural Resources and Environment of the Russian Federation dated July 8, 2010 (as amended on July 11, 2018) [1].

The damage to the soil as a protected element of the environment, expressed in monetary form, is calculated according to the following formula:

\[ DA = DA_{cont} + DA_{was} + DA_{cov} + DA_{rem} + DA_{dest}, \]

where \( DA \) is the total amount of damage caused to land resources (in rubles);

\( DA_{cont} \) is the amount of damage as a result of soil contamination, the impact of which occurred when contaminants entered the soil, leading to non-compliance with environmental quality standards for the soil, including standards for the maximum (approximately) allowable concentrations of contaminants in the soil (in rubles);

\( DA_{was} \) is the amount of damage as a result of soil deterioration when used to place household and industrial waste on its surface (in rubles);
DA_{cov} is the amount of damage as a result of land divestment for construction objects in the form of buildings and structures for various purposes (in rubles);

DA_{rem} is the amount of damage as a result of soil deterioration during the removal of the fertile surface layer (in rubles);

DA_{dest} is the amount of damage as a result of destruction of the fertile soil layer (in rubles).

The damage as a result of soil contamination, the impact of which occurs when contaminants enter the soil, leading to non-compliance with environmental quality standards for the soil, including standards for the maximum (approximately) allowable concentrations of contaminants in the soil, expressed in monetary terms, is calculated according to the following formula:

$$DA_{cont} = CD \cdot S \cdot C_d \cdot C_{us} \cdot T_x,$$

where $DA_{cont}$ is the amount of damage (in rubles);

$CD$ is the contamination degree depending on the ratio of the actual content of the $i$-contaminant in the soil to the maximum permissible value for the soil;

$S$ is the area of the contaminated territory ($m^2$);

$C_d$ is the coefficient taking into account the depth of contamination, soil deterioration when its surface is covered with artificial surfaces and (or) objects (including linear ones);

$C_{us}$ is the coefficient taking into account the land category and the type of permitted use of the land;

$T_x$ is the value of the tariff for damaging the soil as a protected element of the environment in the form of its contamination (rub/m$^2$).

The damage to the soil as a result of using it to place household and industrial waste on its surface, expressed in monetary form, is calculated according to the following formula:

$$DA_{was} = \sum (M_i \cdot T_{was}) \cdot C_{us},$$

where $DA_{was}$ is the amount of damage (in rubles);

$M_i$ is the mass of waste with the same hazard class ($t$);

$n$ is the sum of the waste types grouped according to hazard classes within the same zone where unauthorized disposal of production and consumption waste have been registered;

$C_{us}$ is the coefficient taking into account the land category and the type of permitted use of the land;

$T_{was}$ is the value of the tariff for damaging the soil as a protected element of the environment as a result of soil deterioration when littered (rub/ton).

The damage to the soil as a result of land divestment for construction objects in the form of buildings and structures for various purposes, expressed in monetary terms, is calculated according to the following formula:

$$DA_{cov} = S \cdot C_d \cdot C_{us} \cdot T_x,$$

where $DA_{cov}$ is the amount of damage (in rubles);

$S$ is the area of the land degradation zone ($m^2$);

$C_d$ is the coefficient taking into account the depth of contamination, soil deterioration when its surface is covered with artificial surfaces and (or) objects (including linear ones);

$C_{us}$ is the coefficient taking into account the land category and the type of permitted use of the land;

$T_x$ is the value of the tariff for damaging the soil as a protected element of the environment as a result of land divestment for construction objects in the form of buildings and structures for various purposes (rub/m$^2$).

The damage to the soil as a result of soil deterioration during the removal of the fertile surface layer, expressed in monetary terms, is calculated according to the following formula:

$$DA_{rem} = S \cdot C_{us} \cdot T_x,$$

where $DA_{rem}$ is the amount of damage (in rubles);

$S$ is the area of the removal of the fertile surface layer ($m^2$);

$C_{us}$ is the coefficient taking into account the land category and the type of permitted use of the land;
Тₙ is the value of the tariff for damaging the soil as a protected element of the environment in case of soil deterioration (rub/m²).

The damage to the soil as a result of destruction of the fertile soil layer, expressed in monetary terms, is calculated according to the following formula:

\[ DA_{dest} = 25 \cdot S \cdot C_{us} \cdot T_n , \]

where \( DA_{dest} \) is the amount of damage (in rubles);
\( S \) is the area of the plot where destruction of the fertile soil layer (m²) was detected;
\( C_{us} \) is the coefficient taking into account the land category and the type of permitted use of the land;
\( T_n \) is the value of the tariff for damaging the soil as a protected element of the environment in case of destruction of the fertile soil layer (rub/m²) [1].

The cost of waste disposal was calculated in accordance with the Decree of the Government of the Russian Federation dated September 13, 2016 No. 913 “On the rates of payment for the negative impact on the environment and additional factors”. Accordingly, after carrying out an assessment using these methodologies, we determined the monetary estimate of damage from oil sludge disposal.

3. The results of the study and their analysis

In Table 1, we will compare the fields by the main factors of drill cuttings formation and drilling mud waste.

| Factor                          | Yarakta field | Markovo field | Dulisma field |
|---------------------------------|---------------|---------------|---------------|
| Number of cluster wells         | 16            | 8             | 20            |
| Waste composition               | Solid. Composition: clay, rock, barite, petroleum products | Solid. Composition: clay, rock, barite, petroleum products | Solid. Composition: clay, rock, barite, petroleum products |
| Waste disposal method           | Disposal in a drilling mud pit at cluster sites | Disposal in a drilling mud pit at cluster sites | Disposal in a drilling mud pit at cluster sites |
| Hazard class                    | 4             | 4             | 4             |
| Quantity of waste generated, tons/year | 32,767.77   | 16,146.9      | 43,953.28     |
| Fees, rubles                    | 21,731,585.064 | 10,708,624.08 | 29,149,815.296 |
| Waste composition               | Sludge. Composition: water, petroleum products, carbon, barite, betonite, carbonates, sulfates, chlorides, Ca, Na, Mg, K | Sludge. Composition: water, petroleum products, carbon, barite, betonite, carbonates, sulfates, chlorides, Ca, Na, Mg, K | Sludge. Composition: water, petroleum products, carbon, barite, betonite, carbonates, sulfates, chlorides, Ca, Na, Mg, K |
| Waste disposal method           | Disposal in a sludge pit at cluster sites | Disposal in a sludge pit at cluster sites | Disposal in a sludge pit at cluster sites |
| Hazard class                    | 3             | 4             | 3             |
| Quantity of waste generated, tons/year | 2,098.58     | 549.3         | 2,100.13      |
| Fees, rubles                    | 2,784,815.66 | 364,295.76    | 1,392,806.216 |
| **Total final fee, rubles**     | **24,516,400.724** | **11,072,919.84** | **30,542,621.512** |
As we can see from Table 1, almost all companies use combined methods to minimize the impact. Due to the repeated use of drilling mud at the Markovo field, the fees are significantly reduced. Let us remember that the fees are also due to the different number of drilled cluster wells. To better estimate the fees for disposal of drill cuttings, we calculated the fee for 1 cluster well (Table 2).

| Table 2. Fees for disposal of drill cuttings of one cluster well. |
|---------------------------------------------------------------|
| Factor | Yarakta field | Markovo field | Dulisma field |
| Fees for disposal of drill cuttings of 1 cluster well, rubles | 1,532,275.04 | 1,384,114.98 | 1,527,131.07 |

4. Discussion
As we can see from Table 2, the Markovo field has the lowest fees for waste disposal. Due to a more ecological drilling mud, its hazard class is lower, which significantly reduces the fees for waste disposal.

Oil sludge contains oil, water, and solid particles of different diameter, often forming a resistant non-separating emulsion, which complicates the process of complete processing. As we can see, the standard methods of oil sludge disposal do not allow for complete oil sludge processing. At the moment there are several most effective methods of oil sludge processing: thermal; biological; chemical; physical; and physical-chemical method [4]. As a rule, companies use a combination of several of these methods. An integrated approach to oil sludge processing is achieved with the help of a specially designed three-phase decanter, i.e. tricanter. Tricanter is designed for continuous separation of the three-phase mixture stream and separates oil sludge into main components: oil, water and mechanical impurities in just one step.

5. Conclusion
The article addressed the problems of oil sludge formation and disposal. We analyzed the composition of the rock extracted while drilling oil and gas wells in the Irkutsk region. We also estimated environmental and economic damage done when drilling the Yarakta field, the Markovo field and the Dulisma field.

References
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