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Evaluation of Drilling Cutting Components and Their Impact on the Environment Using Bioassay (Siberia, Russia)

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Abstract. To meet the demands for oil and gas production, the number of oil and gas wells is increasing every year, construction of drilling sites is growing and, as a consequence, the amount of drilling wastes continues to grow too. The article is concerned with consideration of hazards from produced chemicals for different environments as industrial anthropogenic sources based on drilling cuttings (DC) from Tomsk Oblast oil fields (Siberia, Tomsk) as an example. The rock-forming minerals in all samples are *quartz, albite,* and *muscovite*. Bioassay results of DC from research oil field showed the biological effect on the test culture.

1. Introduction

Russia is among the top ten countries in terms of oil and gas production and reserves whose economy is based on natural resources. However, oil and gas production is accompanied by emission of large amount of wastes.

Drilling cuts belong to the Hazard Category 4-5 waste according to the Russian classification (non-hazardous wastes) [4], [20-23]. The environmental impact of oil industry is explained by toxicity of hydrocarbons and accompanied compounds, variety of chemicals used in technological procedures as well as oil production, processing, transportation, and refining.

The purpose of the article is to study drilling cuttings from the oil field of Tomsk Oblast (Siberia, Russia), reveal their properties and, based on the data obtained, propose the measures of environmental safety when storing cuttings in sludge pits, their treatment and recycling.

2. Methods and materials

Samples were taken in the territory of Tomsk Oblast, Siberia, Russia. Oil fields are located within Parabel and Kargasok Regions.

Composition of drilling cuttings is rather various contain up to 7.5 % of oil and depends on the geological conditions, technical processes of mud cleaning as well as drilling intervals [2, 6]. Therefore, drilling cutting samples were initially treated, namely, they were dried and grinded. The advantage of X-ray analysis is identification of a substance or its constituents without changing sample state. Every crystal substance has its typical crystal lattice, chemical composition, and definite atom distribution in a lattice cell, the lattice geometry defining the lattice spacing [18].

The process is performed automatically, an operator needs to select a mineral appropriate for a definite spectrum registered on diffraction pattern. X-rays are directed to a sample and after their exposure the sample is dispersed, then the dispersed radiation is registered.

The rock-forming minerals in all samples are quartz, albite, and muscovite. In the cuttings from Pervomaiskoye field, illite, a micaceous mineral of argillaceous deposits is an essential rock-forming mineral which makes up a great share.

Katyl'ginskoye and Yuzhno-Chremshanskoye fields are characterized by microcline, which is a common rock-forming silicate feldspar mineral.

Besides, the samples of Luginetskoye oil field contain potassic feldspar mineral – anorthoclase.

To define chemical composition of studied DC samples from the oil fields of Tomsk Oblast the scanning electron microscope was used.

Analyses of mineral composition by means of scanning electron microscope and X-rays have revealed several minerals, in composition of which there are the following elements: As, Pb, Ba, Fe, Ti, Zr, Mn. It is supported by the results of atomic-emission analysis of drilling cutting samples.

It should be noted that scanning electron microscope together with X-ray analysis and X-ray diffraction analysis are complementary.

To analyze the DC samples from oil fields of Tomsk Oblast quantitatively, the atomic emission spectrometer was used. One could note that at present atomic emission spectrometry is the most common technique in identification and quantitative analysis of impurities in gases, liquids, and solids. Its advantage consists in its time-efficiency and high detection rate [15].

The research results showed the presence of large amount of heavy metals in DC samples (Fig. 1).

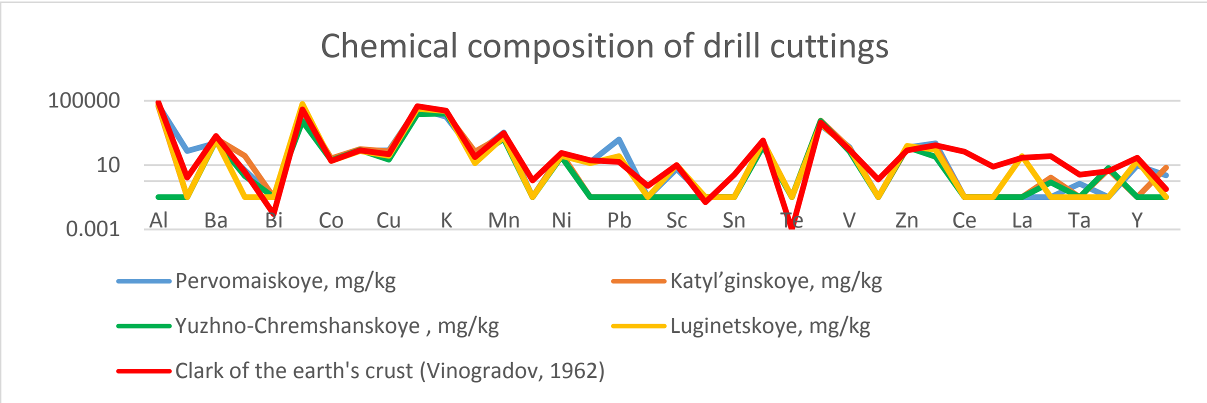

Figure 1. Chemical composition of drilling cuttings of oil fields in Tomsk region.

The research has shown the presence of high concentration of I and II hazard category elements of cuttings, such as As, Pb, Zn, Cu, whose concentrations exceed MAC and Clarke number in soil many times.

The term "heavy metals" is referred to a wide group of pollutants. The researchers interpret this term in different ways.

The following features are used as basic criteria for definition: atomic mass, density, toxicity, natural occurrence, involvement in natural and technogenic cycles.

The current studies dealing with environmental contamination and monitoring consider more than 40 metals of Mendeleev's Periodical Table as heavy ones with atomic mass of more than 50 atomic units: V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Mo, Cd, Sn, Hg, Pb, Bi, As, Mo etc.

In this case the following conditions play an important role in grouping heavy metals: their high toxicity for living organisms in relatively low concentrations as well as capacity for bioaccumulation and biomagnification.

3. Results and discussion

The hazard rate of DC for the environment is estimated by drilling mud composition used in drilling. It was proved that DC saturated with drilling water-based muds are less dangerous than that saturated with hydrocarbon-based muds [1].

To choose the technique of DC utilization it is, first of all, necessary to consider its composition and physical-chemical properties [9].

The ecotoxic tests of DC impact were performed by numerous researchers [4, 10-14]. For example, Gagarina [14] has shown an actual decrease in photosynthesis intensity and phytoplankton survival rate. Using chironomids, Kryuchkov [4] and Kurapov have made a conclusion on single-point effect in vicinity of drilling waste discharge.

DC toxicity was identified by bioassay. It is used to establish toxic (mutagenic) effect. When evaluating pollutants' mutagenic activity (toxicity), different test-systems can be used – from bacteria to mammals [19].

It is worth noting that in Russia water bioassay using daphnids and infusoria is included in the list of GOST indicators for fishery water bodies. However, these techniques are used not only in Russia, which confirms their expediency, but also in the USA, Germany and other countries [8,18].

We estimated the toxic effect of cuttings from the oil fields of Tomsk Oblast, Kargasok Region: Pervomaiskoye, Katyl'ginskoye, Yuzhno-Chremshanskoye Luginetskoye oil fields.

Using the calculation technique "Criteria of Hazardous Wastes Classification", the fifth criterion of the research DC was identified.

3.1. Technique of identifying acute toxicity based on changes in optical density of testing culture of protococcale algae Chlorella vulgaris Beijer

The technique is based on fixing the differences in optical density of testing culture of chlorella algae. Changes in optical density of algae suspension allow monitoring the changes in cell abundance. We estimated the quality of DC water extract using Chlorella vulgaris Beijer according to the methodic in Russia

Bioassay results of DC from research oil field showed the biological effect on the test culture (Table 1).

Table 1. Results of the study of the quality of drill cuttings water extract.

Oil Field	Hazard category	The result of toxicological analysis
Pervomaiskoye	4	Low toxicity
Katyl'ginskoye	5	Acute toxicity
Yuzhno-Chremshanskoye	5	Acute toxicity
Luginetskoye	5	Toxicity

DC test evidences the adverse effect, which is eliminated by two-fold dilution (in case of Pervomaiskoye oil field) and 30-fold dilution (in case of Katyl'ginskoye oil field). As for Yuzhno-Chremshanskoye oil field, the adverse effect can be eliminated at 40-fold dilution.

3.2. Technique of identifying toxicity using fruit flies Drosophila melanogaster

As compared with other test organisms, fruit fly bioassay has a number of advantages, since drosophila is exposed to all types of mutation. It has small number of chromosomes, short life-cycle, high fertility; metabolic activation of elements entering an organism. The data obtained using fruit flies make possible to continue research in higher life forms, including mammals, and can be used to forecast environmental risk for population.

DC bioassay using Drosophila melanogaster as a test-object has revealed biological effect. Within the bioassay experiment such morphoses as deformed wings and deformed bristles were identified in Drosophila melanogaster (Fig. 2, Fig. 3).

Based on calculation, actual and expected results differ greatly from each other that can indicate the effect of cutting samples added to nutrient solution.

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Figure 2. Deformation of wings.

Figure 3. Deformation of bristles.

3.3. Proposed recycling measures based waste bioassay

There are four measures of environmental safety of DC disposal.

1. Technical measures. They include water isolation of sludge pit (SP) bottom and walls, bunding along SP perimeter; calculation of SP volume taking into account volumes of produced cuttings, drilling waste water, waste drilling mud and intake of atmospheric precipitation; selection of pit design – above the level of ground or burial surface.

2. Management activities: control over DC and drilling waste water (DWW) production, waste drilling mud (WDM) discharge and atmospheric precipitation intake in SP (its filling); monitoring the absence of oil in pit (oil patch to remove sticking of drill pipe, production horizon stripping); monitoring treatment quality (if treatment system is available).

3. Monitoring of DC production in drilling process (integrity of bunds, walls), monitoring SP conditions before its remediation, control over pollutant intake into the neighboring areas.

4. Remediation of sludge pits. This activity is included in monitoring of deadlines and compliance with applied technology.

3.4. Secondary Oil Sludge Production

Recycled products can be used in hot asphalt concrete production. Oil sludge recycling technique used to produce asphalt concrete consists of mixing a definite volume of oil sludge with sand and debris heated up to 220 ºC. Then, mineral powder is fed, which is followed by addition of viscous bitumen after uniform distribution at 140 – 160 ºC and finally mixed. According to Tursumuratov M. T. and Bekbulatov Sh. Kh., an optimal oil sludge content of debris and sand is 13 %, which results in good coating of mineral and saving up to 2 % of viscous road bitumen, as sufficient amount of fine-dispersed particles with fractions of less than 0.31 mm is present in oil sludge. [16]. there is no universal way of DC recycling, which meets all environmental requirements. Such methods as thermal, physical chemical, physical-chemical, biological, and their combinations are widely used [7].

At thermal recycling method of oil sludge secondary wastes are formed that can be referred to the fourth and fifth hazard category, they can be used in filling roads and construction sites.

Oil sludge is also used in production of primary petroleum products of benzene and kerosene fractions. To recycle oil and water-based fractions of oil sludge it is necessary to rectify oil collected from oil sludge surface simultaneously with burning residues of oil sludge using heat energy of burning oil sludge remains to produce gasoline, kerosene and other diesel fuels. 263 hydrocarbons from C6 to C30 were identified in hydrocarbons isolated from suspended oil sludge. On the whole, the properties of organic fraction isolated from oil sludge meet the requirements specified for the raw materials in production of kerosene–diesel fractions which is efficient to be used in diesel fuel production [17].

4. Conclusion
Based on the literature review and experimental results one can suggest the negative impact of DC due to moving wastes to atypical media, and, in this way, a number of elements can be introduced to the environment (e.g., As, Zn, Pb, Co), concentration of which is to increase with respect to the initial content in the environment. Therefore, continuous monitoring of element concentration is necessary to prevent cutting accumulation exceeding maximum permissible concentration in water, soil, and air.

Bioassay results of testing the immotile benthic forms of chlorella algae Chlorella vulgaris Beijer and fruit flies Drosophila melanogaster revealed toxic effect of all samples.

The results of bioassay have proved the fact that, despite low-hazard or non-hazard categories of wastes, they may have a negative effect on living organisms. Presumably, it may be explained by element transformation, e.g. transition to motile chemical forms posing a greater threat than total forms.

There is no universal way of DC recycling, which meets all environmental requirements. The most common are DC disposal in sludge pits; DC re-injection and manufacture of by-products (soil-sludge mixtures, dumping sand, porous filling) as a result of drilling waste and cutting conversion. However, one should take into account the increasing significance of land resources and growing necessity for sustainable use of natural resources because of reduction in biodiversity, increase in soil erosion and soil fertility degradation. Of particular interest are agricultural lands which are a strategic resource potential.

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