Development of a Method for Minimizing the Negative Environmental Impact of Drill Cuttings by Using It as a Mineral Powder in Asphalt Concrete

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Abstract. The article describes the problem of environmental pollution from the placement of drill cuttings in it. The main sources of contamination are oil products included in the drill cuttings, chemicals added to the drilling fluid, and heavy metals. In order to reduce the negative impact, it was proposed to use the resource potential of drill cuttings as a mineral powder in the technology for producing asphalt concrete. Samples of drill cuttings were taken in the fields of Western Siberia. It has been established that there are no excesses in the standards for the content of heavy metals in mobile form in samples of drill cuttings. The analysis of physical and chemical characteristics showed that there are high values of COD, oil content, dry residue, rigidity, magnesium and calcium ions, chlorides. Laboratory studies have shown the possibility of using drill cuttings as a mineral powder in asphalt concrete. The optimum composition of the asphalt mixture was obtained. The obtained physical and mechanical properties of asphalt concrete samples comply with the requirements of regulatory documents. It is established that the strength characteristics depend on the percentage of drill cuttings in asphalt concrete: with an increase in the share of drill cuttings, the value of the tensile strength decreases, and at the same time there is a discrepancy with regulatory requirements.

1. Introduction
The activities of oil companies are accompanied by the formation of a significant amount of industrial waste - drill cuttings (hereinafter DC), which, having in its composition polluting agents, has a negative impact on the environment. An important issue remains the neutralization of the negative environmental impact from DC [1-3]. DC is crushed drill cuttings contaminated with mud residues.
The volume of DC formations is estimated at millions of tons per year [3-5]. For example, 5 million m³ of DC are formed every year in the Khanty-Mansi Autonomous Okrug-Yugra, where 70% of all oil wells in Russia are located.

Oil products included in the DC, drilling fluid reagents, heavy metals, chlorides (calcium, magnesium, sodium, ammonium chlorides) form a negative impact of DC on the environment due to their interaction with the environment from [5-8]. The composition of DC can include the following components: water - 15-35%; cuttings - 50-70%; chlorides - 0.1-0.5%; heavy metals - 4-6%; drilling fluid reagents - 5-7%; oil and oil products - 0.1-2%; other compounds - 0.1-1%. DC, having in its composition useful elements, is one of the examples of technogenic waste having a resource potential [9-12].

Known technologies for utilizing DC in a marketable product that is in demand on the market, for example, it is proposed to use DC in concrete as a partial replacement of cement, which allows to increase the compressive strength of concrete by 13% [13].

In [14], a technology was presented that, using melting and mixing with sodium and calcium oxides to minimize the melting temperature, uses DC in glass ceramics. The physical, chemical and mechanical properties presented indicate that glass ceramics has the necessary properties, strength, wear resistance, heat resistance, crack resistance, which makes the materials suitable for producing tiles, building materials (tiles).

The known technology [15] of using DC, sewage sludge and sawdust for the production of soil-like mixtures. In accordance with applicable law, the concentration of metals in soil-like materials allows their use on class II soils (arable land).

The research results of many authors [16-19] showed the possibility of wide use of the resource potential of DC: obtaining building products and materials, soil-agricultural mixtures for agricultural purposes, etc.

The purpose of this work is to develop a method of minimizing the negative environmental impact from DC by using its resource potential as a replacement for mineral powder in asphalt concrete.

2. Objects and research methods
DC samples were selected as objects of study:
- Sample DC No. 1 on a hydrocarbon basis: Khanty-Mansiysk Autonomous Okrug field.
- Sample DC No. 2 on a clay basis: deposit of the Orenburg region.

Research methods are presented in table 1:

| Defined indicators                                           | Research method normative document                                      |
|--------------------------------------------------------------|------------------------------------------------------------------------|
| The content of heavy metals in mobile form in DC              | PND F 16.1: 2.3: 3.50-08                                               |
| Physical and chemical characteristics of DC:                 |                                                                        |
| COD water extract                                            | PND F 14.1: 2: 4.190-03 (ed. 2012)                                     |
| Dry residue                                                  | PND F 16.2.2: 2.3: 3.32-02 (ed. 2005)                                  |
| Chloride ion                                                 | PND F 16.2.2: 2.3: 3.28-02 (ed. 2005)                                  |
| Rigidity                                                     | PND F 14.1 2 3.98-97                                                  |
| Petroleum products (water soluble)                           | RD 39-0147098-015-90                                                 |
| Physical and mechanical properties:                         | GOST 9128-2013. Asphaltic concrete and polimer                          |
| Average density, water saturation, compressive strength,    | asphaltic concrete mixtures, asphaltic concrete and                     |
| shear resistance, crack resistance, water resistance         | polimer asphaltic concrete for roads and aerodromes.                   |
| Specifications                                              |                                                                        |
3. Results and discussion

To determine the degree of negative impact of DC on the environment, its physical and chemical parameters and the content of heavy metals were determined. The content of heavy metals in DC samples is shown in table 2:

**Table 2. Heavy metal content in DC samples.**

| Name                  | Cadmium               | Chrome         | Nickel         | Cobalt       | Plumbum       | Cuprum        | Manganese     |
|-----------------------|-----------------------|----------------|----------------|--------------|---------------|---------------|---------------|
| DC sample No. 1       | less than 0,2         | 0,89±0,27      | 3,6±0,9        | 1,8±0,4      | 2,8±0,7       | 2,3±0,6       | more than 100 |
| DC sample No. 2       | less than 0,2         | 1,8±0,4        | 0,60±0,18      | less than 4  | less than 5   | 2,0±0,5       | 23±4          |
| Permissible value     | 1,0                   | 6,0            | 4,0            | 5,0          | 6,0           | 3,0           | 600,0         |

The results of laboratory studies of DC samples show that there are no excesses of standards for the content of heavy metals in mobile form.

Aqueous extracts were prepared from DC samples preliminarily dried at 105°C to constant weight to determine the physical and chemical parameters. The research results are presented in table 3:

**Table 3. Results of quantitative chemical analysis.**

| Defined characteristics | Units               | Analysis results | Limit of permissible concentrations |
|-------------------------|---------------------|------------------|-------------------------------------|
|                         | DC sample No. 1     | DC sample No. 2  |                                     |
| pH                      | un.pH               | 7,0 ± 0,05       | 6,9 ± 0,05                          | 6,5-9,0 |
| Chemical oxygen consumption | mgO₂/dm³           | 580 ± 23,0       | 1300 ± 65,0                         | 30      |
| Oil product             | mg/dm³              | 1,5 ± 0,30       | 4,4 ± 0,88                          | 0,05    |
| Dry residue             | mg/dm³              | 620 ± 62,0       | 1590,0 ± 159,0                      | 1000    |
| Rigidity                | Mmol-eq/dm³         | 11,5 ± 0,56      | 60 ± 3,0                            | 10,0    |
| Calcium ion             | mg/dm³              | 154 ± 7,7        | 800 ± 40,0                          | 180,0   |
| Magnesium ion           | mg/dm³              | 46 ± 2,3         | 240 ± 12,0                          | 40,0    |
| Chlorides               | mg/dm³              | 452,6 ± 25       | 1411,1 ± 70,6                       | 300     |

Analysis of the research results indicates a possible negative impact of DC on environmental objects when they are placed in sludge collectors. It was shown that all the studied samples have high values of COD, dry residue, chlorides, and rigidity.

It has been established that the physical and chemical properties of DC are significantly dependent on the composition of the drilling fluid used in drilling. In the sludge formed at technological sites where drilling using hydrocarbon-based solutions is carried out, the values of COD, oil products, dry residue, rigidity, chlorides are 2-5 times higher than the values of sludge generated during drilling using clay solutions.

An analysis of previously developed DC disposal technologies allowed us to determine the promising direction of using the DC resource potential, which allows us to involve DC in the resource cycle of road construction. It was proposed to use the resource potential of DC in asphalt concrete as a mineral powder. It will also reduce the negative impact on environmental objects due to the placement of DC in a dense and hydrophobic environment.
The grain composition and the content of dusty clay particles were determined in accordance with GOST R 52129-2003 “Mineral powder for asphalt concrete and organomineral mixtures” to determine the belonging of drill cuttings to known mineral powders [20, 21]. As a result of the analysis of particle size distribution, it was found that according to the requirements of GOST R 52129-2003, DC sample No. 2 according to the MP-2 classification is suitable as mineral powder — powders from non-carbonate rocks, solid and powder industrial wastes.

Next, a study was conducted according to GOST 9128-2013 “Asphaltic concrete and polimer asphaltic concrete mixtures, asphaltic concrete and polimer asphaltic concrete for roads and aerodromes. Specifications”. Asphalt mixtures of various compositions were prepared:

1. Asphalt mixture No. 1, %:
   - Natural sand - 12
   - Crushed stone - 46
   - Screening crushing - 38
   - Drill cuttings - 4
   - Bitumen 90/130 - 5.3 (in excess of 100% of the mixture)

2. Asphalt mixture No. 2, %:
   - Natural sand - 12
   - Crushed stone - 46
   - Screening crushing - 34
   - Drill cuttings - 8
   - Bitumen 90/130 - 5.3 (in excess of 100% of the mixture)

3. Asphalt mixture No. 3, %:
   - Natural sand - 12
   - Crushed stone - 46
   - Screening crushing - 30
   - Drill cuttings - 8
   - Bitumen 90/130 - 5.3 (in excess of 100% of the mixture)

The resulting asphalt mixtures are classified: type B, mark II, dense. Tests were conducted to determine the physical and mechanical properties of asphalt concrete samples molded from mixtures. The research results are shown in table 4:

According to the results of the study, the asphalt sample No. 1 meets the requirements of GOST 9128-2013.

Based on the data obtained, graphs were constructed of the dependences of the compressive strength of asphalt concrete samples on the percentage of DC in them. The schedules are presented in Figure 1:

![Figure 1. The schedules of compressive strength versus DC content.](image-url)
Table 4. Indicators of physical and mechanical properties of asphalt samples.

| Name                                      | Units   | Requirements GOST 9128-2013 | Asphalt sample No. 1 | Asphalt sample No. 2 | Asphalt sample No. 3 |
|-------------------------------------------|---------|----------------------------|----------------------|----------------------|----------------------|
| Average density                           | g/cm³   | -                          | 2,42                 | 2,43                 | 2,45                 |
| Compressive strength at a temperature of 50°C, not less | MPa     | 1,0                        | 1,31                 | 1,15                 | 1,14                 |
| Compressive strength at a temperature of 20°C, not less | MPa     | 2,2                        | 4,38                 | 3,76                 | 3,56                 |
| Compressive strength at a temperature of 20°C, no more | MPa     | 12,0                       | 9,8                  | 7,93                 | 9,26                 |
| Shear resistance by internal friction coefficient, not less | index   | 0,81                       | 0,91                 | 0,93                 | 0,92                 |
| Shear resistance: shear grip, not less    | index   | 0,35                       | 0,38                 | 0,30                 | 0,30                 |
| Crack resistance to compressive strength at split | MPa     | 3,0-6,5                    | 4,51                 | 5,15                 | 4,18                 |
| Water resistant, not less:                | index   | 0,85                       | 0,96                 | 0,83                 | 0,93                 |
| Water saturation                          | %       | 1,5-4,0                    | 1,5                  | 0,55                 | 0,36                 |

From this figure it follows that with an increase in the percentage of DC as a mineral powder in asphalt concrete, the compressive strength decreases. Based on the obtained physical and mechanical indicators, it follows that the optimal composition of the mixture that meets the requirements of GOST 9128-2013, has the following component composition, %:
- Natural sand – 12
- Crushed stone – 46
- Screening crushing – 30-31
- Drill cuttings – 0-7
- Bitumen 90/130 – 5.3 (in excess of 100% of the mixture)

4. Conclusion
During laboratory studies of the negative impact of DC on the environment, it was found that there are no excesses in the content of heavy metals in mobile form in DC samples. The analysis of the physicochemical characteristics of DC samples showed that there are high values of COD, chlorides, dry residue, oil products, calcium and magnesium ions, and rigidity, which indicates a negative impact on the environment.

It was proposed to use the resource potential of DC as a mineral powder in the technology for producing asphalt concrete, which will reduce the technogenic load on the environment from DC, as well as expand the range of road-building materials.

Laboratory studies have shown the possibility of using DC as a mineral powder in asphalt concrete. The optimum composition of the asphalt mixture was obtained. The obtained physical and mechanical
properties of asphalt concrete samples comply with the requirements of GOST 9128-2013. It was found that with an increase in the percentage of DC in asphalt concrete, strength characteristics decrease, and there is also a discrepancy with regulatory requirements.

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