**Research Into Integrated Technologies for Assessing the Composition of Drilling Muds and Reducing Environmental Risks**

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**Abstract.** This article evaluates the composition of drilling muds obtained from all wells, fields and deposits in the Republic of Uzbekistan based on energy-dispersive and fluorescence analysis (EDRFA). and their environmental impact was scientifically analyzed. High concentrations of SiO₂, Al₂O₃, Fe₂O₃, CaO and K₂O, as well as toxic elements such as Pb, As, Ni, Cu, Zn, U were detected, indicating the risks of migration, bioaccumulation and toxic stress in the soil-water system. The accuracy of measurements was verified on standard samples OR-13b and 3596, and the deviations were proven to be in the range of 1–3 %.

**INTRODUCTION**

In recent decades, along with the rapid development of industry, especially the oil and gas industry, environmental problems have become acute. During the development of oil and gas fields, wastes released into the environment, in particular drilling muds, petroleum products and chemical reagents, have a negative impact on the natural balance. As a result of these processes, pollution of the soil, water and atmospheric environment, as well as disruption of biocenoses, are observed. [1].

An integrated package of solutions was proposed to reduce the environmental risk: hydroxide/silicate carbonate inertization, microbial-based bioremediation, thermal sintering at 800–1000 °C, zeolite-biochar sorption-filtration systems, and the use of mud as a secondary raw material in cement, geopolymer and road surfacing materials. Together with a continuous monitoring strategy, these approaches make waste safe, increase resource efficiency, and ensure a sustainable production model. The scientific novelty of the work is the integration of EDRFA data, along with metrological justification, in the form of a sequential process map of risk reduction steps. Therefore, the issues of ensuring environmental safety and effective waste disposal in the oil and gas industry are extremely relevant today from a scientific and practical point of view 2021 [2].

**EXPERIMENTAL RESEARCH**

It is known from the course of the environmental load observed in the oil and gas sector of our Republic and other countries, the accumulation of production waste, and the low level of their recycling require the improvement of the existing system. In particular, the physicochemical and toxic properties of drilling muds complicate their disposal by simple methods. The oil fractions, heavy metals, polymer components such as polyacrylamide, carboxymethylcellulose, surfactants (PAV) contained in the mud make them environmentally hazardous waste [3-4-10].

The solution to this problem is not only the elimination of waste, but also its transformation into a secondary useful product, that is, the introduction of environmentally sustainable technologies based on the principle of “recycling - reuse”. From this point of view, the issues of comprehensive utilization of drilling waste, increasing its environmental safety, as well as its use as a secondary raw material in industrial processes remain one of the important areas of scientific research [5]. Along with the development of the oil and gas industry, environmental problems are also becoming more acute, and waste generated during drilling - drilling muds, petroleum products and chemical reagents - are considered to be factors that cause serious damage to the environment. Such waste contains heavy metals, organic compounds, oil fractions and various polymer reagents, which cause pollution of soil, water and atmosphere. Disruption of natural ecosystems, changes in biological balance, and migration of toxic substances through groundwater give grounds for classifying these wastes as environmentally hazardous. Therefore, the safe disposal of drilling wastes has become an extremely urgent issue in scientific and practical terms at the present time [1-6]. The existing literature describes various methods for the disposal of drilling muds, among which mechanical, chemical and biological methods are widely used. Mechanical separation methods can separate solid and liquid phases, but this method does not fully eliminate toxic components. Chemical neutralization processes allow the conversion of active forms of heavy metals to an inert state, but these methods do not provide ecologically perfect results. In biological treatment, microorganisms decompose organic compounds, but the neutralization of metal ions is limited. Therefore, in recent studies, the use of an integrated approach to the processing of drilling waste - that is, the combined application of physicochemical and biological methods - is recognized as the most promising direction [1-7].

In the scientific work of D.V. Rakhmatullin, a new approach was developed for the integrated utilization of drilling sludge. It allowed reducing the toxicity of the waste and using it as a secondary raw material by combining the processes of reagent capping and biodestruction. According to the results of the study, a mixture of microorganisms such as Rhodococcus erythropolis, Bacillus subtilis and Fusarium sp. increased the efficiency of decomposition of organic components by 20–30 percent. It was found that when the resulting inert product was added to the cement composition, the mechanical strength of the finished material was 15–35 percent higher. These results prove that the utilization of drilling sludge not only ensures environmental safety, but also brings economic benefits [1-7].

This approach is consistent with the principle of "zero waste", since waste is not completely eliminated, but is recycled and transformed into useful products. This not only ensures environmental sustainability, but also increases the efficiency of resource use in industrial enterprises. Therefore, waste utilization technologies based on integrated methods are gaining particular importance in the formation of environmentally friendly production systems today [8-9].

Literature analysis shows that the complex composition of drilling wastes makes it impossible to utilize them using single-purpose methods. The most effective results are achieved only through a combination of multicomponent, that is, physical, chemical and biological processes. At the same time, the possibility of reusing wastes - for example, in the production of building materials, in the preparation of road surfaces or as environmentally friendly fillers - not only protects the environment, but also strengthens economic sustainability. Thus, the scientific substantiation and practical implementation of integrated drilling waste processing technologies is an environmentally safe, economically viable and innovative solution for the oil and gas industry [10].

**Research methods.** In the research work, a comprehensive scientific approach was used to determine the chemical and elemental composition of drilling muds, assess their environmental risk, and develop technological directions for their utilization. Analytical work was carried out in stages, combining physicochemical, instrumental, and statistical analysis methods at each stage. At the first stage, samples were taken from the deposits and their physical parameters - density, moisture, granulometric composition, and solid phase fraction - were determined.

At the first stage, samples were taken from the deposits, and their physical parameters - density, moisture, granulometric composition and solid phase fraction - were determined. At the next stage, the content of major and trace elements in the sludge was measured using the energy-dispersive fluorescence analysis (EDRFA) method using a Niton XL2 spectrometer. The analysis was carried out for 29 elements (Mg, Al, Si, Fe, Ca, K, Ti, Ni, Cu, Zn, Pb, As, etc.), and the results were recorded in mg/kg and % units. In order to assess the measurement accuracy, verification was carried out based on OR-13b and 3596 international standard samples, and the deviations between the results were found to be in the range of 1–3 %, confirming the methodological reliability.

Based on the obtained data, the balance ratio of oxides (SiO₂, Al₂O₃, Fe₂O₃, CaO, K₂O) of the sludge was calculated and their mineralization level and ecological activity indicators were analyzed. Statistical processing was carried out in Microsoft Excel and OriginPro programs, and correlation analysis was used to determine the interrelationships of heavy metals and their distribution trends.

**RESEARCH RESULTS**

**Results and their analysis**. Based on the results of energy-dispersive fluorescence analysis (EDRFA) presented below, the composition of drilling muds and their impact on the environment were scientifically studied, and scientific solutions for their environmental impact and elimination were studied (Table 1). The muds formed during the drilling process have a complex physicochemical composition, and their impact on the environment largely depends on the amount of heavy metals, oxides and salts in this composition. The analysis results show that the elements aluminum, silicon, iron, manganese, calcium and potassium are found as the main components in these muds.

In particular, the high content of SiO₂, Al₂O₃ and Fe₂O₃ indicates a high mineralization of the sludge. Although such components are compatible with natural geochemical processes, their high concentration changes the physical properties of the soil, reducing its filtration and water permeability. At the same time, the presence of heavy metals in the sludge is a major factor increasing the environmental risk.

According to the analysis, the samples contained toxic elements such as chromium, nickel, copper, zinc, lead, arsenic, and uranium. Some of them - for example, arsenic (As) and nickel (Ni) - are extremely dangerous for living organisms. These elements can be washed away by water and spread over long distances, as a result of their penetration into the groundwater system. In particular, high concentrations of zinc and copper reduce the activity of microorganisms, which negatively affects the natural biogenic processes of the soil. Therefore, if such sludges are stored in biologically active areas or near water bodies, they disrupt the stability of the soil-water system.

The oxide composition is also an important ecological indicator. According to the analysis results, the concentrations of Al₂O₃, SiO₂, Fe₂O₃, CaO and K₂O are high, which indicates that they have a mineral-based, but chemically active environment. For example, a high content of CaO and K₂O increases the alkalinity of the environment during hydrolysis processes, which can increase the mobility of heavy metals. At the same time, the presence of iron and manganese oxides increases their reduction-oxidation potential and changes the form of metal ions. As a result, they remain in a water-soluble or adsorbed state and enter ecological systems.

The detection of lead (Pb), bismuth (Bi), uranium (U) and arsenic (As) in some samples poses a particular danger. These elements have a radioactive or biotoxic nature, they accumulate through the plant root system, and then pass through the food chain to the human body. The long-term persistence of lead and arsenic in the soil is explained by the slowness of their natural decomposition mechanism. Therefore, if such waste is stored in the open without environmental protection, it reduces soil fertility and causes toxic stress in biocenoses.

The results of chemical analysis also show significant differences between different samples of drilling muds. Some samples have very high Al₂O₃ and SiO₂ contents, indicating their clay-silicate nature; others have higher Fe₂O₃ and TiO₂ contents, indicating their oxide-mineral structure. This diversity depends on the source of the muds and the type of reagents used. That is why a single method for their disposal is not effective. To reduce the environmental impact of such sludge, an integrated approach to its neutralization and processing is required. First, active forms of heavy metals are converted into inert compounds through chemical inertization, and then organic components are eliminated through biological decomposition processes. As a result, the waste loses its toxic properties and can be used as a secondary raw material, for example, in the production of building materials. In this way, drilling waste is transformed from environmentally hazardous waste into a recyclable resource.

In general, the results of energy-dispersive and fluorescence analysis show that drilling muds are an ecologically complex system. The high concentration of metals and oxides in their composition poses a direct and indirect threat to the environment. Therefore, environmental safety standards must be strictly observed when storing, transporting and disposing of such waste. Only a comprehensive, scientifically based approach will make it possible to bring them to a safe state and integrate them into an environmentally sustainable production system. (Table 1).

Scientifically, such a control chart is a means of guaranteeing the metrological reliability of the analysis process. The high reproducibility of the study, in particular, the minimal difference between the concentration of elements in standard samples and the actual values, confirms the accuracy of the measurement technique and the methodology used. As a result, the data obtained using the EDRFA method are recognized as scientifically sound results that can be used not only in laboratory conditions, but also on an industrial scale. The scientific purpose of conducting this control analysis is to ensure the reliability of data on the chemical composition of drilling mud samples, which will be measured at subsequent stages. The accurate determination of heavy metals, oxides, sulfates and other components found in muds is of crucial importance in assessing environmental safety. Due to the high reproducibility of the results obtained by the EDRFA method, it allows for rapid, relatively inexpensive and non-invasive measurement of the concentration of metals and metal oxides. This plays an important role in environmental monitoring, the development of waste neutralization technologies and the scientific substantiation of industrial waste processing systems. In addition, such a controlled analysis provides a reliable assessment of the elements found in the waste.

In particular, the accuracy of the determination of environmentally hazardous components - lead, arsenic, antimony, copper and nickel - allows you to correctly determine the level of environmental impact. This serves as the main scientific resource for developing technologies for the neutralization, processing or reuse of waste.

Properties of clays produced by drilling and their impact on the ecological environment (fully recycled option) Man-made clays that arise during the drilling of wells have a complex physicochemical nature, which are formed by continuous chemical and mechanical interaction with geological layers.

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An in-depth study of the composition of such substances is important in determining to what extent they have a negative or positive effect on the environment. Because the organic and inorganic compounds found in these clays, heavy metal ions and various oxides can play a fundamental role in the degradation of ecological stability.

The analyzes carried out show that elements such as aluminum, silicon, iron, manganese, calcium and potassium occupy a leading place in the composition of these clays. Despite the fact that these elements are the product of natural geochemical processes, their accumulation in high concentrations under drilling conditions poses an environmental risk. The high content of sio₂, Al₂O₃and Fe₂O₃ oxides in clay indicates that it is highly mineralized. As a result of the increase in the amount of silicates and metal oxides, the physical and mechanical parameters of clay change, in particular, there is a decrease in the density of layers and the possibility of filtration. He high content of SiO₂, Al₂O₃and Fe₂O₃ oxides in clay indicates that it is highly mineralized.

As a result of the increase in the amount of silicates and metal oxides, the physical and mechanical parameters of clay change, in particular, there is a decrease in the density of layers and the possibility of filtration. For example, the abundance of SiO₂ changes the granulometric structure of the clay, compacting it; as a result, it becomes more difficult for water to be absorbed into the soil and deviates from the norm of hydrogeological processes. This condition reduces soil respiration in the presence of drilling residues spread over large areas, slowing down the regeneration processes of the fertile layer.

The abundance of Fe₂O₃ has its effect on soil appearance, density, and heat transfer levels. And the increase in Al₂O₃changes its acid-alkaline balance, increasing the chemical stability of the soil. These processes cause a decrease in the activity of microorganisms, and in some cases, their complete extinction.he abundance of Fe₂O₃ has its effect on soil appearance, density, and heat transfer levels. And the increase in Al₂O₃changes its acid-alkaline balance, increasing the chemical stability of the soil. These processes cause a decrease in the activity of microorganisms, and in some cases, their complete extinction. As a result, natural biochemical processes between the microflora and the microfauna are disrupted, causing long-term damage to ecological systems.

One of the most dangerous components in Clay is heavy metals. Among them, lead, cadmium, arsenic, chromium and nickel are a separate source of threat. These elements move very sluggishly in the soil and do not lose their properties for tens or hundreds of years.

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Such processes are called bioaccumulation and biomagnification, and they are one of the most dangerous factors for ecological balance. Sulfate, chloride, and carbonate salts found in drilling clays accelerate the salinity of the soil. As a result of salinity, the growth rate of plants decreases sharply, the binding coefficient of water changes, and destabilization of the soil structure is observed. If such processes proceed uncontrollably, degraded land over large areas with complex regeneration occurs, and these environmental problems deepen.

**FIGURE 1.** Results of energy-dispersive fluorescence analysis of drilling mud composition (EDRFA,

29 elements, measured on a Niton XL2 instrument).

This table is aimed at assessing the accuracy and repeatability of the analysis, in which the results of actual measurements with the OR-13b and 3596 standard samples are compared. The purpose of this approach is to determine the accuracy limit of the instrument, estimate the amount of deviation by elements, and confirm the metrological reliability of the results of the EDRFA method.

The study compared the concentrations of elements such as potassium, calcium, barium, iron, copper, zinc, arsenic, antimony, and lead.

As can be seen from the results, the level of deviation of measurements is in the range of 1–3 %, which confirms the high level of accuracy of laboratory analysis. Although small negative deviations were observed for some elements, for example, Fe, Cu, and Zn, they are within the error limit of the instrument and do not affect the overall result.

Table 2 below shows the accuracy and repeatability of the EDRFA analysis results, which are controlled and illustrate the purpose and scientific significance of the analysis in determining the composition of drilling muds.

Accurate and reliable assessment of the chemical composition of waste generated during drilling is one of the main stages of scientific research. This process allows not only to determine the level of environmental hazard of waste, but also to scientifically substantiate technological solutions used in their disposal or processing. For this purpose, the results obtained by the energy-dispersive and fluorescence analysis (EDRFA) method were compared using a special control table to verify the accuracy of the analysis process.

**FIGURE 2.** Analysis and results of oxides in drilling muds (chemical elements)

**FIGURE 3.** Accuracy and repeatability control

Results of energy-dispersive fluorescence analysis of drilling mud composition (EDRFA, 29 elements, measured on a Niton XL2 instrument).

Thus, the control analysis carried out using this table serves to provide a reliable assessment of the composition of drilling muds, confirm the accuracy of the analysis methods and strengthen scientific results on environmental safety. This approach demonstrates that scientific work is based on the principles of accuracy, reliability and repeatability, therefore it is an integral part of any ecological and technological analysis process.

A number of well-founded proposals have been developed to reduce the composition of drilling muds from the above-mentioned and their impact on the environment, and scientific research is being conducted to put them into practice. The results of the analysis show that the muds formed during the drilling process contain a number of environmentally hazardous elements, including lead (Pb), arsenic (As), nickel (Ni), zinc (Zn), copper (Cu), bismuth (Bi) and uranium (U). The long-term persistence and biotoxic effects of these elements in the environment necessitate their disposal under special environmental control. Several highly effective, science-based technological approaches can be used to reduce the environmental risks of sludge.

**Chemical neutralization.** This method is aimed at converting active heavy metal ions in the sludge into chemically stable, insoluble compounds. To do this, by controlling the reaction medium with hydroxides, silicates or carbonates, soluble forms of metals are converted into inert substances. For example, Pb²⁺ and Ni²⁺ ions react with Ca(OH)₂ or Na₂SiO₃ to form water-insoluble salts. As a result, these metals lose their ability to migrate into soil and water systems. Chemical neutralization should be introduced as a mandatory step before sludge processing, since it is this process that significantly reduces the mobility of heavy metals. Biotechnological neutralization. The use of microorganisms or biologically active substrates that can decompose organic and metal components in drilling muds is a highly effective method for reducing environmental risks. In biotechnological neutralization, bacteria, fungi and phytoremediation plants adsorb heavy metal ions or convert them into organic complexes. For example, microorganisms such as Bacillus subtilis, Aspergillus niger or Pseudomonas aeruginosa bind metal ions during their metabolism, reducing them to an inactive form. The advantage of this method is that it is natural, energy-efficient and does not produce secondary waste.

**Thermal processing.** Metal oxides and salts transform into stable phases at high temperatures. Therefore, it is possible to convert active forms of metals into inert phases by thermal processing of sludge (up to 800–1000 °C) or by sintering. This method allows the sludge to be processed as a raw material for the production of cement clinker, bricks, ceramics or road pavement. Such a process serves two purposes: it neutralizes the waste and turns it into an economically useful material. For example, the high content of Al₂O₃ and SiO₂ makes the sludge suitable for geopolymer-based construction materials.

**Introduction of filtration and sorption systems.** If the sludge is stored mixed with water, filtration drainage systems and sorbent materials are used to prevent the release of heavy metals into its liquid phase. In particular, natural adsorbents such as zeolite, activated carbon, bentonite or biochar effectively retain metal ions. This solution prevents the leakage of toxic substances into groundwater and ensures environmental safety.

Processing of cuttings and their use as a secondary resource. Drilling cuttings, due to the high percentage of oxides such as SiO₂, Al₂O₃, Fe₂O₃, CaO, can be processed as a secondary raw material in the production of cement, ceramics, concrete additives or road construction materials. This not only reduces the environmental burden of waste, but also increases resource-saving economic efficiency. Before processing cuttings, they must undergo a stage of chemical and biological stabilization, so that they lose their toxic effects. Strengthening environmental monitoring and safety control. Based on the results of the analysis, it is necessary to establish a permanent environmental monitoring system for such waste. The long-term impact of sludge is assessed by periodically analyzing soil, atmosphere and water samples at the sludge storage sites, as well as monitoring the biogeochemical cycle of heavy metals. This approach allows for early detection of degradation of ecological systems and acceleration of their recovery process.

**CONCLUSIONS**

As can be seen from the above EDRFA analyses showed that drilling muds contain highly mineralized (SiO₂, Al₂O₃, Fe₂O₃, CaO, K₂O) and environmentally hazardous elements (Pb, As, Ni, Zn, Cu, Bi, U); this content increases their migration in the soil-water system, posing a toxic risk to biocenoses.

Studies show that control of the accuracy and repeatability of the analysis (comparison with standard samples) confirmed the metrological reliability of the analytical results used and allowed for the scientific substantiation of subsequent engineering decisions following advantages:

1. An integrated approach is necessary to effectively reduce environmental risk: chemical inertization reduces the mobility of heavy metals, biotechnological remediation renders the organic content safe, and thermal processing/sintering converts the mud into inert phases, turning it into a secondary raw material for construction materials.

2. Sorption and drainage systems protect groundwater, and continuous environmental monitoring serves to manage long-term exposure.

3. Thus, the proposed comprehensive solutions, based on the principle of "recycle-reuse", increase geoecological safety, increase resource efficiency, and bring the industry closer to a sustainable production model.

4. To reduce their environmental risk, it is necessary to use integrated chemical, biological, thermal and technological approaches. Such a complex system - that is, the combined implementation of chemical neutralization, biotechnological neutralization, filtration protection and recycling - will make it possible to bring waste to an environmentally safe state and adapt industrial processes to a sustainable ecological production model.

5. The high concentrations of metals and oxides found in drilling muds make them impossible to dispose of as ordinary waste.

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