IN-DEPTH RESEARCH INTO INTEGRATIVE TECHNOLOGIES AIMED AT SCIENTIFICALLY ASSESSING THE COMPOSITION OF DRILLING MUDS AND MINIMIZING ENVIRONMENTAL RISKS

Murtazaev Abdujabbar Mustafaevich 1,
1Tashkent State Technical University Named After Islam Karimov, Tashkent, Uzbekistan,
abdijabbor_murtazayev@gmail.ru, https://orcid.org/0009-0002-4681-2445

Bozorova Zamira Khudoyberdiyevna 2
2Tashkent State Technical University Named After Islam Karimov, Tashkent, Uzbekistan,
zbozorova052@gmail.com

Abstract
Over the last decade, the rapid development of the oil and gas industry has been accompanied by significant environmental challenges. Drilling muds, petroleum products, and chemical reagents generated during oil and gas extraction processes adversely affect soil, water, and atmospheric quality. This research investigates the chemical composition, toxicological risks, and integrative eco-safe technologies for drilling muds. The study applies a combined physicochemical and biological approach to reduce environmental hazards and enable secondary utilization of wastes as valuable resources. The results demonstrate that multi-method strategies significantly enhance environmental safety while contributing to sustainable industrial practices.

Keywords: Drilling mud, environmental safety, utilization, physicochemical methods, biological methods, oil and gas industry.

Introduction

In recent decades, industrial growth, particularly in oil and gas extraction, has escalated environmental concerns. The discharge of drilling muds, petroleum residues, and chemical reagents disrupts natural ecological balance. Soil, water, and atmospheric contamination along with biocenotic degradation necessitate scientific and practical solutions for waste management [1–2]. Countries worldwide, including Uzbekistan, face challenges of accumulated drilling wastes with low recycling efficiency. The physicochemical and toxic properties of these wastes complicate their disposal. Components such as petroleum fractions, heavy metals, polyacrylamide, carboxymethylcellulose, and surfactants (PAV) classify them as environmentally hazardous [3–4, 10].

Web of Scientists and Scholars: Journal of Multidisciplinary Research

This study focuses on integrative technologies for safe utilization of drilling wastes, aiming to convert them into secondary raw materials in accordance with the “reuse-recycle” principle. In the process of developing 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. [5] As a result of these processes, pollution of the soil, water and atmospheric environment, as well as disruption of biocenoses are observed. Therefore, the issues of ensuring environmental safety and effective waste disposal in the oil and gas industry are extremely relevant from a scientific and practical point of view today [1-2].

Today, the environmental load observed in the oil and gas sectors 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, polyacrylamide, carboxymethylcellulose, and polymer components such as surfactants (PAV) in the sludge make it an 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 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 wastes contain 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, 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 covers various methods for 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 ensure the elimination of 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 wastes — that is, the combined application of physicochemical and biological methods — is recognized as the most promising direction [1-7].

D.V. Rakhmatullin's scientific work developed a new approach to the integrated utilization of drilling wastes. It allowed reducing the toxicity of the waste by combining the processes of reagent capping and biodestruction and using it as a secondary raw material. 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. The useful work factor for sludge is determined as follows:
General formula for the useful work factor
 - energy used to move or transport the sludge (W, kW),
 — total energy consumed by the pump or power source (W, kW).
 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 sludges 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 multi-component, i.e. physical, chemical and biological processes. At the same time, the possibilities of recycling wastes — for example, in the production of building materials, in the preparation of road surfaces or as environmentally friendly aggregates — not only protect the environment, but also strengthen 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 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 next stage, the content of major and trace elements in the sludge was measured using the energy-dispersive and 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 international standard samples OR-13b and 3596, and the deviations between the results were found to be in the range of 1–3%, confirming the methodological reliability. Based on the data obtained, the balance ratio of oxides (SiO_2, Al_2O_3, Fe_2O_3, CaO, K_2O) 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.

Literature Review

Recent literature highlights multiple methods for drilling mud utilization, including: Mechanical separation: isolates solid and liquid phases but does not remove toxic substances completely. Chemical neutralization: stabilizes heavy metals into inert forms, although it is not fully eco-efficient. Biological treatment: microorganisms degrade organic matter, but metal neutralization remains limited. Rahmatullin (2020) proposed a hybrid method combining reagent-based encapsulation and biodegradation, achieving 20–30% higher organic matter breakdown using microbial consortia (Rhodococcus erythropolis, Bacillus subtilis, Fusarium sp.). The resulting inert products improved cement strength by 15–35%, demonstrating both environmental and economic benefits [1–7].

Research Objectives

To analyze the chemical composition of drilling muds from major oilfields. To assess environmental hazards and risks associated with drilling wastes.To develop integrative physicochemical and biological methods for safe utilization. To propose sustainable industrial applications of secondary products derived from drilling muds. Methodology. Sample Collection and Preparation drilling mud samples were collected from multiple oilfields in Uzbekistan. Physical parameters such as density, moisture content, granulometry, and solid fraction were determined. Chemical and Elemental Analysis. Elemental composition was analyzed using Energy-Dispersive X-Ray Fluorescence Analysis (EDRFA) with a Niton XL2 spectrometer, covering 29 elements including Mg, Al, Si, Fe, Ca, K, Ti, Ni, Cu, Zn, Pb, and As. Standard verification (OR-13b, 3596) ensured measurement accuracy within 1–3%. Data Processing. Oxide balances (SiO_2, Al_2O_3, Fe_2O_3, CaO, K_2O) were calculated. Statistical correlations and trends of heavy metals were analyzed using Microsoft Excel and OriginPro software. Integrative Treatment Chemical neutralization: Converts active metal ions into inert forms. Biological degradation: Microorganisms metabolize organic polymers. Secondary utilization: Treated mud used in construction materials or roadfill applications. Results. Physical and chemical properties: High SiO_2, Al_2O_3, Fe_2O_3 content indicates mineralized composition affecting soil permeability. Toxic elements: Detected heavy metals (As, Pb, Ni, Bi, U) pose risks to flora, fauna, and groundwater systems. Environmental impact: Potential for metal migration into groundwater and disruption of biogeochemical cycles.Results and their analysis. Based on the results of energy-dispersive X-ray fluorescence analysis (EDRFA) presented below, the composition of drilling muds from all wells, fields and deposits in the Republic of Uzbekistan 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 drilling 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 main components of these muds are aluminum, silicon, iron, manganese, calcium and potassium. In particular, the high content of SiO_2, Al_2O_3 and Fe_2O_3 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, toxic elements such as chromium, nickel, copper, zinc, lead, arsenic and uranium were detected in the samples. 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 passage into the groundwater system. In particular, the high content of zinc and copper reduces 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 Al_2O_3, SiO_2, Fe_2O_3, CaO and K_2O are high, which indicates that they have a mineral-based, but chemically active environment. For example, a high content of CaO and K_2O 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.[11] 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 that there are significant differences between different samples of drilling muds. [12] In some samples, the content of Al_2O_3 and SiO_2 is very high, which indicates their clay-silicate nature; in others, the ratio of Fe_2O_3 and TiO_2 is higher, and they have an oxide-mineral structure. This diversity depends on the source of sludge formation and the type of reagents used. That is why a single method for their disposal is ineffective. To reduce the environmental impact of such sludges, an integrated approach is required to neutralize and process them. [13] First, active forms of heavy metals are converted into inert compounds through chemical inertization, and then organic components are eliminated through biological decomposition processes. [14]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 2016 [15]. 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 sludges 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, strict adherence to environmental safety standards is required when storing, transporting and disposing of such waste. Only a comprehensive, scientifically based approach can make them safe and integrate them into an environmentally sustainable production system. (Table 1).

TABLE 1. Results of energy-dispersive and fluorescence analysis of drilling mud composition (EDRFA, 29 elements, measured on a Niton XL2 instrument).

№ п/п	Элемент / Проба / НПО*	Mg	Al	Si	Mn	Fe	S	Cl	K	Ca	P	Ba	Ti	V	Cr	Ni	Cu	Zn	As	Se	Rb	Sr	Mo	Ag	Sn	Sb	W	Pb	Bi	U
	НПО*	5%	0,1%	1%							10	10								0,1							10	20	10	
1	001	< 5%	1,27%	5,57%	260	0,48%	2,34%	1,28%	1,30%	49%	70,3	19%	0,44%	< 1	68,8	204	< 1	24,0	22,5	2,1	15,2	134	< 1	< 1	99,2	58,6	< 10	< 20	19,4	5,7
2	002	< 5%	1,43%	8,38%	381	0,66%	5,59%	2,73%	1,91%	18%	34,7	42%	3,70%	< 1	166	346	< 1	73,6	17,5	1,2	14,8	169	< 1	1,6	98,8	136	< 10	< 20	23,3	< 1
3	003	< 5%	2,61%	15%	291	1,42%	1,62%	7,94%	6,48%	24%	< 10	10%	< 1	< 1	80,9	218	< 1	99,9	68,3	0,82	53,5	312	< 1	< 1	52,8	58,1	< 10	415	12,6	< 1
4	004	< 5%	2,71%	13%	508	1,48%	5,74%	16%	12%	8,60%	< 10	2,44%	< 1	< 1	36,4	131	25,6	280	185	1,1	67,5	0,21%	< 1	4,8	47,1	112	< 10	77,3	< 10	< 1
5	005	< 5%	12%	40%	399	4,53%	1,02%	0,91%	4,86%	6,00%	376	1,73%	0,40%	< 1	11,8	184	18,3	181	30,8	2,0	179	204	10,1	9,3	73,7	212	< 10	331	13,9	< 1
6	006	< 5%	7,95%	39%	627	4,22%	0,73%	0,50%	3,31%	2,99%	698	667	0,47%	329	7,9	143	60,2	117	42,4	0,21	147	297	164	< 1	109	77,7	< 10	72,5	< 10	< 1
	OR-13b	< 5%	7,59%	26%	0,30%	7,05%	1,47%	311	2,92%	4,32%	0,23%	666	0,73%	507	1,16%	0,24%	0,23%	132	67,8	1,1	104	591	78,9	< 1	63,6	41,8	< 10	65,2	< 10	< 1
	3596	< 5%	0,59%	< 1%	382	5,51%	14%	43,2	0,76%	4,9	391	21%	6,36%	0,57%	< 1	149	2,43%	0,52%	0,37%	< 0,1	< 1	548	< 1	98,1	85,5	0,22%	< 10	0,45%	< 10	< 1
№	ОКСИДЫ:	MgO	Al_2O_3	SiO_2	MnO	Fe_2O_3			K_2O	CaO	P_2O_5	BaO	TiO_2	V_2O_5													WO_3	Pb_2O		
1	001		2,4%	11,9%	0,0%	0,7%			1,6%	68,1%	0,0%	21,2%	0,7%																	
2	002		2,7%	17,9%	0,0%	0,9%			2,3%	25,2%	0,0%	46,6%	6,2%																	
3	003		4,9%	31,2%	0,0%	2,0%			7,8%	33,3%		11,5%																0,0%		
4	004		5,1%	28,7%	0,1%	2,1%			14,0%	12,0%		2,7%																0,0%		
5	005		23,1%	84,9%	0,1%	6,5%			5,9%	8,4%	0,1%	1,9%	0,7%															0,0%		
6	006		15,0%	84,1%	0,1%	6,0%			4,0%	4,2%	0,2%	0,1%	0,8%	0,1%														0,0%		
	OR-13b		14,3%	54,8%	0,4%	10,1%			3,5%	6,0%	0,5%	0,1%	1,2%	0,1%														0,0%		
	3596		1,1%	2,1%	0,0%	7,9%			0,9%	0,0%	0,1%	23,6%	10,6%	1,0%														0,5%		

Примечания: НПО* - нижний предел достоверного определения по V кат. точности

Discussion

High concentrations of oxides and metals necessitate integrative treatment. Multi-method approaches outperform single-method treatments.Safe utilization converts waste into secondary raw materials for construction or road applications, supporting circular economy principles.

Recommendations

Implement combined physicochemical-biological treatment in all oilfields. Regular monitoring of heavy metals in soils and groundwater.Promote reuse of treated muds in industrial applications.

Conclusion

Drilling muds represent a complex environmental challenge due to their chemical and toxicological characteristics. Integrative treatment methods combining chemical neutralization and biological degradation are highly effective. Safe reuse of treated muds in construction and industrial applications enhances environmental safety and economic sustainability, aligning with global best practices in the oil and gas industry. Acknowledgements. The authors sincerely acknowledge the support of the I would like to express my gratitude to the rector of Tashkent State Technical University, Professor Turabdjanov Sadritdin Makhamatdinovich, doctor of Technical Sciences, and my scientific supervisor, Professor Murtazaev Abdijabbar Mustafaevich, Doctor of Technical Sciences, for dedicating their time to the scientific study of my article in laboratory conditions.of Uzbekistan, laboratory staff, and academic advisors for their contributions and assistance in sample collection and analysis.

REFERENCES

1. Bakhtiari, H.; Amanipoor, H.; Battaleb-Looie, S. "Analysis of heavy metal accumulation and environmental indicators in fluids and drilling cuttings." Journal of Petroleum Exploration and Production Technology. Vol. 14, 2024, pp. 41–58. https://10.1007/s13202-023-01690-7

2. Mikos-Szymańska, M.; Rusek, P.; Borowik, K.; Rolewicz, M.; Bogusz, P.; Glużińska, J. "Characterization of drilling waste from shale gas exploration in Central and Eastern Poland." Environmental Science and Pollution Research. Vol. 25, 2018, pp. 35990–36001. https://10.1007/s11356-018-2365-8

3. Jiao, C.; Diao, Y.; Zheng, G.; Liu, Y.; Huang, J.; Zhang, Y.; Zhao, L. "Reuse of drilling waste slurry as the grouting material for the real-time capsule grouting technique." Materials. Vol. 16, 2023. https://10.3390/ma16041500

4. Jia, Y.; Li, H.; Meng, Y.; Li, N. "Study on Improving the Water Quality of Drilling Mud Using Industrial Waste Residue." Water Vol. 15, 2023, Article 174. https://10.3390/w15010174

5. Silva Gutsens, A.; Díaz Rodríguez, Y.; Soroa Bell, M. R.; Rodríguez Muñoz, S. "Reuse of Drill Cuttings Contaminated with Diesel in the Formation of Asphalt Pavement." Journal of Civil, Construction and Environmental Engineering. Vol. 9, No. 2, 2024. https://10.11648/j.jccee.20240902.11.

6. Tarasova, S. "The Environmental Impact of Drilling Sludge and Ways of Their Utilization." Journal of Ecological Engineering 2023. https://10.12911/22998993/109764.

7. Eslami, E.; Seyed Joodat, S. H. "Bioremediation of oil and heavy metal contaminated soil in construction sites: a case study of using bioventing-biosparging and phytoextraction techniques." 2018. 10.4061/2011/941810.

8. Li, X.; Zhao, Q. "Integrated Treatment Approaches for Drilling Waste: A Review." Journal of Cleaner Production 2020, https://10.1016/j.jclepro.2019.119249.

9. Kumar, S.; Gupta, R. "Sustainable Utilization of Oilfield Wastes." Resources, Conservation and Recycling, Vol. 169, 2021. https://10.1016/j.resconrec.2021.105055.

10. Fink, L.; et al. "Leaching Behavior and Risk Assessment of Metals from Oil-Based Muds." Environmental Technology and Innovation, 2022. 10.1016/j.eti.2022.102417.

11. Zhang, Y.; Li, W.; Lv, P.; Zhu, X.; Zhao, L.; Zhang, X. "Disposal and reuse of drilling solid waste from a massive gas field." Procedia Environmental Sciences, Vol. 31, 2016, pp. 577–581. https://10.1016/j.proenv.2016.02.089.

12. Murtazayev Abdijabar Mustafayevich, Islom Qosimovich Haydarov, and Aziz Xasanovich Samadov. "Study of termal stability of mixtures used in drilling oil and gaz wells" 2024, pp.17-23. https://dspace.kstu.uz/xmlui/bitstream/, Innovative Technologies Scientific journal.

13. Bozorova, Z., Burkhanov, A.U., Djuraqulov, S., Nurimbetov, R., Khurramova, M., Rasulov, Z.J., Saitkamolov, M., Khadjaev, R., Ganiyeva, N., Rahimova, K., Makhmudova, M., Jalilova, A., Bobojonov, O. 2025 from a cost-effective perspective: Sustainable management

of soils contaminated with drilling wastes on the Absheron Peninsula of Azerbaijan. Citation needed for this article: Caspian Journal of Environmental Sciences, 23. SCOPUS Q2 CJES_Volum e 23_Issue 3_Pages 635-642. Beyond oil: Assessing the viability of circular economy approaches for sustainable management of drilling waste contaminated soils in Apsheron Peninsula, Azerbaijan.

14. N.N. Yodgarov, A.M. Murtazayev, I.Q. Haydarov Obtaining Lightweight Bounding Drilling Fluids Applied In Wells # 202 At The "Alan" Deposit Using Industrial Waste “Turkish Online Journal of Qualitative Inquiry” (TOJQI)Volume 12, Issue 6, July, 2021: 5314 –5317 https://www.tojqi.net/index.php/journal/article/view/3786

15. N.N. Yodgarov, A.M. Murtazaev, I.K. Khaidarov. "Development and Implementation of New Environmentally Safe Drilling Fluid Formulations." Oil and Gas Technologies.Scientific and Technological Journal, No. 5 (124). 42 pages. Moscow. 2019. www.ntu.ru.