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Innovative technology for the reuse of spent drilling fluids in production well drilling using a hydraulic disperser

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Abstract

This article explores an innovative approach to the disposal of used water-based spent drilling fluids (SDF) utilized in the drilling of production wells at uranium deposits, with a case study based on the operations of SD «Inkai». A technological solution is proposed, centered on the use of a hydrodynamic disperser that enables efficient phase separation of drilling fluids, reduction of residual moisture in solid fractions, and the potential for reuse of the liquid phase. The geological and hydrogeological conditions of the deposit are examined in detail, along with the composition and properties of the drilling fluids, challenges associated with their accumulation and disposal, and the legal and regulatory framework of the Republic of Kazakhstan governing drilling waste management. The design of the proposed disperser is presented, the technological process is described, and its advantages over traditional disposal methods are substantiated. The article also analyzes the ecological, operational, and resource-saving aspects related to the implementation of the proposed technology within existing drilling systems.

Keywords: Design features, Extraction efficiency, Hydraulic disperser, Improving efficiency, Reagent consumption, Spent drilling fluids (SDF).

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1. Introduction

Drilling fluids are an indispensable component of the well construction process, performing critical functions such as cuttings removal, borehole wall stabilization, and cooling and lubrication of the drilling tool. Effective management of drilling fluids becomes particularly important during the drilling of process wells at uranium deposits using the in-situ leaching (ISL) method, where strict compliance with environmental and radiological safety regulations is required.

The disposal of spent drilling fluids (SDF) poses a complex engineering and environmental challenge, especially under the conditions of large-scale uranium mines such as the «Inkai» SD, located in the southern part of the Republic of Kazakhstan. As in most countries with a developed uranium mining industry, Kazakhstan is experiencing a growing trend toward reducing the environmental impact of drilling waste through the implementation of closed-loop technological cycles, the reuse of drilling fluids, and the localized disposal of the solid sludge phase.

Modern requirements demand not only minimizing the volume of spent drilling fluids (SDF), but also enabling their recycling and reuse. This necessitates the use of efficient equipment capable of phase separation, reduction of residual moisture, and dispersion of clay particles to a state suitable for restoring the technological properties of the fluid.

One of the effective technologies involves separating SDF into liquid and solid phases by using chemical reagents (flocculants and coagulants) and ensuring their proper mechanical mixing with the spent fluid through a hydraulic disperser – an installation designed for fine grinding, activation, and redistribution of SDF components in an aqueous medium.

The aim of this article is to develop and describe an innovative technology for the disposal and reuse of clay-based drilling fluids during the drilling of process wells, with a focus on a specialized technological scheme utilizing a hydraulic disperser as a key element of the fractionation and recovery system. The study is based on the analysis of the technical conditions at the «Inkai» SD, current regulatory requirements, and a comparative evaluation of existing methods for drilling waste management.

Geological and Hydrogeological Features of the «Inkai» SD Uranium Deposit. The «Inkai» SD uranium deposit is located within the Chu-Sarysu uranium province, in the Turkestan Region of the Republic of Kazakhstan. It represents a classical sandstone-type deposit, classified as a stratiform-infiltration roll-front uranium accumulation, formed at the oxidation-reduction interface within permeable aquifer sandstones overlain by clay-rich sediments.

Mineralization is associated with the Mynkuduk and Inkuduk horizons of the Upper Cretaceous, composed of fine and medium-grained sands and siltstones interbedded with clay layers. The ore bodies are located at depths ranging from 350 to 600 meters, have an elongated subhorizontal geometry, and are localized along the contact line between oxidized and reduced zones. The most economically valuable accumulations are roll-front shaped deposits, extending for tens of kilometers along the strike of the aquifer.

The ore-bearing, water-saturated horizons are under hydrostatic pressure, resulting in an artesian flow regime. The filtration properties of the formations, composed primarily of sandy-clay sediments, vary widely and necessitate careful well design and cementing to prevent inter-aquifer crossflows.

Oxidizing conditions are generated by the infiltration of oxygen-rich surface and groundwater from the east and northeast, leading to the leaching of uranium from the parent rock and its precipitation at the redox front. This creates favorable conditions for the accumulation of uraninite, coffinite, and other uranium-bearing mineral phases.

The hydrogeological structure of the deposit requires stringent control during well drilling, as the intrusion of drilling fluids into aquifers can alter the redox environment, reduce uranium leaching efficiency, and disrupt the chemical balance of groundwater. These features impose high requirements on the quality of drilling operations, the formulation of drilling fluids, and methods for their removal and disposal – particularly in the context of environmental safety.

Properties of Drilling Fluids and Environmental Risks. During the drilling of process wells at the «Inkai» SD site, clay-based water drilling fluids are predominantly used. These fluids typically consist of bentonite, natural and modified clays, and polymer additives that enhance rheological properties. Such fluids demonstrate good performance in stabilizing borehole walls, efficiently transporting cuttings, and controlling filtration losses, which is particularly important under conditions of heterogeneous formations and permeable aquifers.

From an environmental perspective, water-based clay drilling fluids are generally considered less hazardous compared to oil and synthetic-based fluids. Nevertheless, improper disposal of even these fluids can pose a threat to the environment. The primary risks involve the contamination of groundwater, degradation of soil cover, and potential radioactivity of the drill cuttings generated when penetrating uranium-bearing formations.

Spent drilling fluids (SDF) may contain residual industrial oils, diesel fuel, elevated concentrations of dissolved salts and chemical reagents, various heavy metal contents, and other pollutants. Therefore, the chemical and mechanical composition of the drill cuttings must be carefully considered. It is especially important to prevent such fluids from entering the environment through seepage from sludge pits or accidental spills.

The disposal of clay-based SDF is also complicated by their high viscosity and significant solid content, which make them difficult to treat using conventional methods. In addition, the presence of polymer additives such as CMC (carboxymethyl cellulose) or polyacrylamide increases the resistance of these fluids to natural degradation, thereby extending their environmental hazard in soil or water ecosystems.

Thus, despite their relative ecological safety compared to other types of drilling fluids, clay-based SDF require a specialized approach for collection, treatment, and reuse.

One promising solution is the use of a hydrodynamic disperser, which allows for the reduction of waste volume and enables the recirculation of the liquid phase [1-4].

The challenges of disposing spent drilling fluids at uranium deposits like «Inkai» SD are driven by several factors: large volumes of SDF, radioactive nature of the host rocks, specific geological conditions, and the remote location of sites far from developed infrastructure. Conventional methods such as burial or pit accumulation do not guarantee full waste isolation, especially under seasonal thawing and high filtration rates in sandy formations.

Challenges of Spent Drilling Fluid Disposal at Uranium Mining Sites. The relevance of the problem lies in the current lack (or high cost) of specialized equipment capable of separating spent drilling fluids (SDF) into liquid and solid phases. This issue remains insufficiently studied, which determines the theoretical and practical importance of the topic and defines the focus and structure of this article. The analysis of disposal methods for spent clay-based drilling fluids can be conducted in various contexts, such as uranium mining, geological exploration, or borehole construction.

The disposal process of spent clay-based drilling fluids during uranium well drilling is quite complex and depends on various factors such as fluid composition, volume, and chemical properties. SDFs in uranium mining without ore-bearing layers typically consist of a mixture of water, clay, and specialized chemical reagents that were used to reduce the permeability of flushing fluids into the rock formation. Depending on the drilling method and the purpose of the wells, SDFs may vary in concentration and physical composition, which is also influenced by the geological characteristics of a given deposit.

One of the main challenges is preventing the contamination of groundwater. During uranium drilling, weak rock formations and tectonic fault zones can facilitate the migration of SDFs into aquifers. Even minimal radionuclide content or residual chemical reagents may alter the redox conditions of the formation, disrupt natural geochemical balance, and reduce the efficiency of in-situ leaching (ISL) – currently the most common method for uranium extraction.

Another serious concern is the high content of fine dispersed particles in drilling sludges, which form stable suspensions. When stored in open pits, the liquid phase slowly evaporates, while the solid phase remains exposed to wind erosion. Once dried, such sludges may become a source of dusting, especially hazardous in the presence of natural radionuclides (e.g., radium – 226, uranium – 238), potentially leading to the formation of secondary pollutants – aerosols and alpha-active dust.

Transporting SDFs to distant disposal sites is often not feasible due to high logistical costs, the need for specialized equipment, regulatory licensing, and lengthy approval procedures. Consequently, the need arises for localized treatment and disposal methods that can be integrated directly into the drilling process [5, 6].

Therefore, the disposal of SDFs at uranium mining sites must aim to:

- Minimize waste generation;
- Prevent environmental migration;
- Reduce waste volume;
- Increase recovery potential.

This requires innovative technical solutions such as dispersion and recycling systems for clay-based drilling fluids.

In this regard, the development of environmentally efficient treatment methods and dedicated equipment is a highly relevant challenge in the drilling process flow. The proposed method involves the fractionation of SDFs into solid and liquid components, followed by reuse of the separated liquid phase. This approach will reduce the volume of sludge pits and settling tanks, cut down the time and cost of collection and transport, and enable on-site SDF treatment.

To minimize environmental and health impacts, SDFs must be collected and treated in compliance with applicable safety standards and environmental regulations. Therefore, this research is based on a comprehensive theoretical and experimental framework, involving:

- The rational selection of chemical reagents and flocculant concentrations;
- The use of electrolytes for ultra-flocculation processing to enhance sedimentation;
- The design of specialized equipment to increase dispersion efficiency and intensify solid-liquid separation.

This will enable a water purification efficiency of up to 76%, facilitating the creation of a closed-loop water system in drilling operations by returning the maximum possible volume of treated liquid phase (technical water) back into the drilling cycle [7, 8].

2. Materials and Methods

In recent years, ultraflocculation treatment has been increasingly applied in the separation technology of industrial suspensions. The efficiency of flocculants in sedimentation and filtration phase separation processes largely depends on the hydrodynamic treatment regime of the suspension (i.e., the velocity gradient of the medium) after the flocculant solution has been introduced. Proper selection of the ultraflocculation regime can significantly enhance the performance of settling tanks and substantially reduce the suspended solids content in the overflow. It can also increase the throughput of vacuum and belt filter presses by 1.5–2 times while considerably lowering the consumption of costly flocculants.

To implement the proposed method, a special unit has been designed for the treatment of spent drilling fluids (SDF). This unit is a complex of equipment intended for the neutralization and purification of SDFs generated during borehole drilling at uranium deposits. A distinctive feature of the proposed unit is the use of a specially designed dispersing device – a disperser – which accelerates the flocculation and sedimentation processes of suspended solids in the fluid by increasing the efficiency of SDF dispersion (see Figure 1) [8-10].

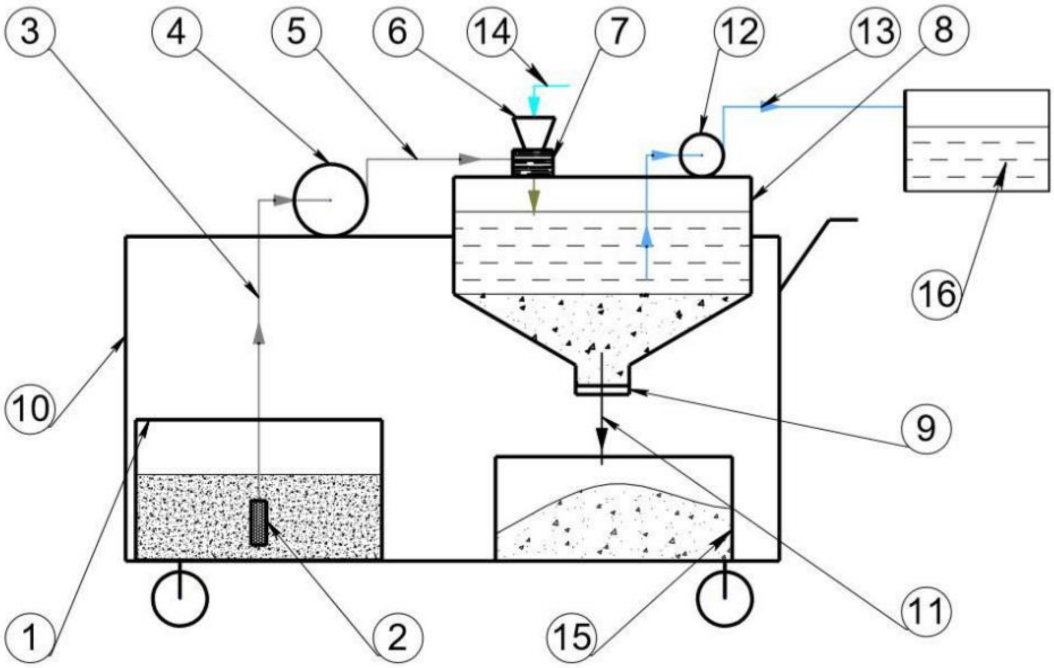

Figure 1.
Process flow diagram of the unit for separating spent drilling fluid into liquid and solid phases: (1) sump; (2) suction funnel; (3) suction line; (4) slurry pump; (5) discharge line; (6) dosing unit; (7) disperser; (8) settling tank for solid fractions of the mixture; (9) slide gate valve; (10) skid (base frame); (11) service ladder; (12) jet pump.

The process is carried out as follows: spent drilling fluid is pumped from the sump (1) through the suction strainer (2) and suction line (3) by the slurry pump (4), then through the discharge line (5) into the dosing unit (6), and further into the disperser (7), where it is treated with coagulant and flocculant. The optimal concentration of coagulant and flocculant from the dosing unit (6), in solution form, together with the spent drilling fluid, is pumped by the slurry pump (4) into the proprietary disperser (7), where it undergoes intensive turbulent flow under an optimized and controlled hydrodynamic velocity.

After dispersion, the reagent-treated mass flows into the settling tank (8) for solid phase separation. In the tank (8), the optimal concentration of coagulant and flocculant solution is intensively mixed with the spent drilling fluid at an optimal velocity gradient of 1500 $\mathbf{s^{-1}}$. Within 10–12 seconds after exiting the unit, the drilling fluid suspension settles, and the residual solids content in the discharge is less than 25 mg/L. At the optimal flocculant dose, the suspension settles within 30 minutes, with the solid content ranging from 300–700 mg/L.

As a result, coagulant molecules and flocculant macromolecules are evenly adsorbed on the surface of the suspended solids in the drilling fluid, leading to effective phase separation into liquid and solid fractions within a short period of time.

This results in immediate separation into two phases: a solid phase (comprising clay, sand, and rock fragments) and a liquid phase (water recovered from the drilling fluid). The separated water is then pumped out by a jet water pump (12) for further use, while the thickened sludge is discharged through a slide gate valve (9) into a collection pile.

The entire unit is mounted on a skid-mounted frame structure (10). Maintenance of the pump systems located on the upper platform is performed using the service ladder (11), and the separated water is pumped out using a compact water pump (11-12).

The study utilized samples of Kemira – brand flocculants, including:

- Nonionic: N-100;
- Anionic: A-150 and Magnafloc;
- Cationic: C-494.

The stock solutions of flocculants were prepared at a concentration of 0.1% (1 g/L). Subsequently, working solutions with concentrations of 0.01% and 0.001% were obtained by dilution.

Spent drilling fluid (SDF) with an initial solids concentration of 300 g/L was selected as the research subject.

For laboratory experiments aimed at improving the sedimentation process of SDF, suspensions were prepared with a reduced solids concentration of 100 g/L. Preliminary sedimentation results in the presence of various flocculants are presented in Table 1.

Table 1.
Sedimentation characteristics of spent drilling fluid (SDF) with a solids concentration of 100 g/L in the presence of various flocculants. Settling time: 30 minutes.

<table>
<tr><th>Flocculants</th><th>Clarified layer height, cm</th><th>Sediment height, cm</th><th>Visual characteristics of the clarified layer</th><td rowspan="5">– Initial suspension concentration: 100 g/L
– Flocculant dosage: 66.7 g/ton
– Pulp clarification time: 30 minutes
– Measurement of the clarified layer height was carried out in 250 mL graduated cylinders</td></tr>
<tr><td>N-100</td><td>5.5</td><td>7.4</td><td>Transparent</td></tr>
<tr><td>Magnafloc</td><td>6.5</td><td>6.3</td><td>Slightly Turbid</td></tr>
<tr><td>C-494</td><td>6.1</td><td>6.8</td><td>Clear</td></tr>
<tr><td>A-150</td><td>6.6</td><td>6.3</td><td>Turbid</td></tr>
</table>

As shown in Table 1, in the presence of the nonionic flocculant N-100, the clarity of the supernatant is the highest (5.5 cm of clarified layer), and the height of the compacted sediment is also the greatest (7.4 cm) compared to other flocculants. For all samples, the sedimentation time was 30 minutes with an equal flocculant dosage of 66.7 g/t. Therefore, the N-100 flocculant demonstrates the most effective flocculating performance on the SDF (Spent Drilling Fluid) suspension compared to the other flocculant samples.

The height of the compacted sediment can be used to assess its filtration properties – the greater the sediment height, the looser its structure and the easier it is to filter. The cationic flocculant C-494 also performs well and is slightly inferior to N-100 in terms of effectiveness.

To visually illustrate the above results, a photograph of the samples was taken (see Figure 2).

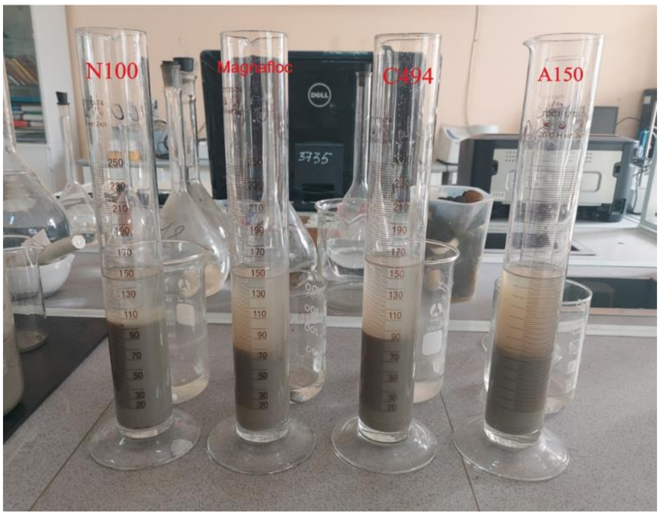

Figure 2.
Comparison of flocculant samples.

As a sedimentation intensifier, an original hydrodynamic disperser (Figure 3) was used in this study, developed and manufactured based on a patented design, for which a positive result of the formal examination has been received.

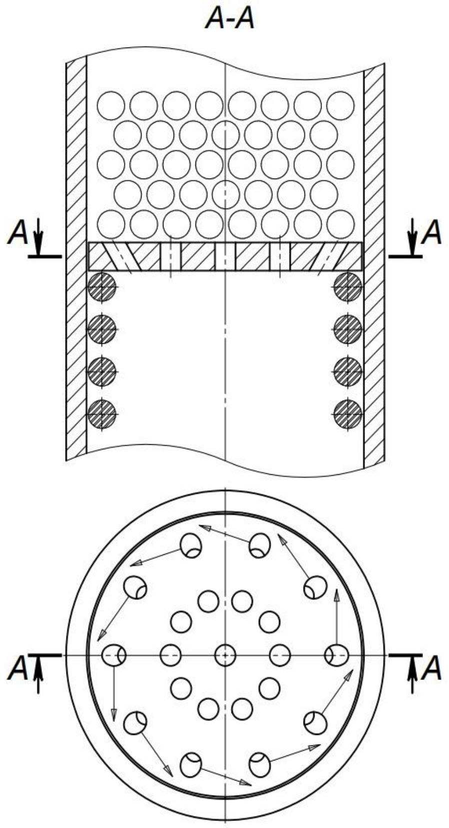

Figure 3.
Hydrodynamic Disperser.

In the design of the hydrodynamic disperser, which includes a vertical cylindrical body, horizontally oriented movable discs with perforations are freely mounted and positioned along the height of the cylinder on cylindrical guides. Between the discs, steel balls are placed, and the peripheral row of holes in the discs is angled slightly to ensure that the high-velocity fluid jets emerging from them induce a swirling (vortex) motion in the flow.

Under the influence of the resulting centrifugal forces, not only is the directed movement of the steel balls ensured, but also an increase in their impact interaction with the contact surfaces of the internal cylindrical wall of the housing. As a result, some of the balls operate similarly to those in a traditional drum-ball mill.

The intense collision of the balls with the walls of the cylindrical housing and their rolling enhance the dispersion process by utilizing the kinetic energy of the liquid flow more effectively, while preventing the formation of stagnant zones [11-13].

The overall pressure drop across the disperser, and consequently the required hydraulic power of the pump, is determined by the diameter of the balls, the number of holes in the disks, as well as the thickness of the ball layer in each cascade and the number of cascades.

The ratio of the length of these cylindrical inclined channels to their diameter must be sufficient to generate a high-velocity flow within the channel. In our case, it is L = (4…5)d, where L is the length of the channel (orifice), and d is the diameter of these orifices.

The inclination angle α of the channels is related to the flow rate Q and the number of holes in the disk n by the following relationship:

$$\alpha = \frac{Q}{(n \times d)} \leq 35 \ldots 45 \text{ degrees} \quad (1)$$

This disperser allows not only to determine the optimal type and dosage of flocculant, but also to establish the optimal mode of hydrodynamic treatment for a specific suspension.

The flocculation process using coagulants and flocculants in the unit proceeds as follows: the spent drilling fluid is first fed through a reagent dosing system into the disperser, where it is mixed and treated with a coagulant and a flocculant.

The coagulant facilitates the aggregation of fine particles into larger ones, thus simplifying their subsequent filtration. The flocculant then binds the aggregated particles into larger flocs, making it easier to separate solid fractions from the liquid.

The resulting mixture is directed into a settling tank, where the solid fractions settle to the bottom and can be removed. The liquid phase can be discharged from the system and reused.

The treatment process of spent drilling fluids with flocculants involves several stages: first, the fluid is collected in a tank; then, coagulants and flocculants are added to the solution, leading to the formation of flocs (aggregates) of solid particles. These solids settle to the bottom, while the clarified liquid remains on the surface.

The treated drilling fluid products can then be reused in the drilling process, reducing the need for fresh fluid purchases and minimizing environmental impact [14-16].

A more detailed and substantiated description is as follows. A prepared flocculant solution was introduced into the test suspension sample using a pump. Both the suspension and the flocculant were simultaneously passed through a hydrodynamic disperser, where they were mixed and treated in a hydrodynamic flow for approximately 5 seconds.

At the outlet, the treated sample passed through an optical sensor, which analyzed it and determined the efficiency of the flocculation process. By controlling the operation of the pump (at a constant pulp flow rate of 1$\mathbf{cm^3}/_{\mathbf{s}}$), it was possible to vary the flocculant dosage. In addition, by adjusting the discharge rate of the mixture from the disperser, the intensity of the hydrodynamic treatment of the suspension could be regulated.

This allowed for the control of the average velocity gradient in the medium, ranging from 150 to 4000 $\mathbf{s^{-1}}$.

The results of comparing the flocculation efficiency of nonionic, cationic, and anionic flocculants for the suspension of spent drilling fluid demonstrated the advantage of the nonionic flocculant. The preferred flocculant is the nonionic type «N-100». This selected flocculant provides significantly better flocculation performance compared to other flocculants used. The cationic flocculant C-494 showed moderate activity, while the anionic flocculant A150 proved to be weak. The results are presented in Tables 2–5.

The first stage of the laboratory study aimed to select the most effective flocculant. The best results in terms of clarified water quality – specifically, optical density (D) – were achieved with the addition of flocculant N-300 (Table 2). When using N-300, the optical density (D) decreased by 1.5–2 times compared to other flocculants. The least effective flocculant was A-150, which resulted in a high optical density, indicating a high turbidity of the filtrate [17, 18].

Table 2.
Results of Changes in Filtrate Clarity (Optical Density) of Spent Drilling Fluid Suspension with 100 g/L Solid Concentration in the Presence of Various Flocculants.

Flocculant dosage (g/t)	**Flocculant name**			
	A-150 (D)	**Magnafloc (D)**	**C-494 (D)**	**N-100 (D)**
25	0.75	0.45	0.31	0.19
33	0.55	0.37	0.22	0.15
48	0.35	0.31	0.21	0.17
67	0.31	0.21	0.20	0.15

Table 3.
Change in Filtrate Clarity (Optical Density) of Spent Drilling Fluid Suspension with 100 g/L Solid Concentration Using a Hydrodynamic Disperser in the Presence of Flocculant N-100 (Treatment Time: 30 Seconds).

Flocculant N-100 dosage (g/t)	**Hydrodynamic treatment rate, G, $\mathbf{s^{-1}}$**		
	500 $\mathbf{s^{-1}}$ (D)	**1000 $\mathbf{s^{-1}}$ (D)**	**1500 $\mathbf{s^{-1}}$ (D)**
25	0.14	0.12	0.16
33	0.11	0.03	0.12
48	0.12	0.07	0.11
67	0.18	0.05	0.09

As shown in Table 3, at an optimal hydrodynamic treatment rate of 1000 $\mathbf{s^{-1}}$ and a treatment time of 30 seconds, the use of flocculant N-300 leads to a fivefold reduction in optical density at an optimal dosage of 33 g/t. At the same time, the required flocculant dosage is reduced by half compared to the case without hydrodynamic disperser treatment (see Tables 2 and 3).

Another important indicator of flocculation efficiency is the solid content in the filtrate, i.e., the degree of water clarification from the sludge particles of the spent drilling fluid.

The results obtained using the studied flocculants are presented in Table 4.

Table 4.
Results of Solid Content in the Filtrate (g/L) During Sedimentation of Spent Drilling Fluid Suspension with 100 g/L Solid Concentration.

Flocculant dosage (g/t)	**Flocculant name**			
	A-150 (g/L)	**Magnafloc (g/L)**	**C-494 (g/L)**	**N-100 (g/L)**
25	15	8	6	4
33	11	5	5	2
48	17	7	8	3
67	19	10	9	5

Table 5.
Results of Solid Content in the Filtrate (g/L) for a Suspension with 100 g/L Solid Concentration Treated Using a Hydrodynamic Disperser in the Presence of Flocculant N-100 (Treatment Time: 30 Seconds).

Flocculant N-100 dosage (g/t)	Hydrodynamic treatment rate, G (s^{-1})		
	500 s^{-1} (g/L)	1000 s^{-1} (g/L)	1500 s^{-1} (g/L)
25	3.4	1.12	2.1
33	3.11	0.5	1.12
48	3.6	0.6	1.17
67	3.5	0.8	2.01

It was established that the nonionic flocculant N-100 results in 1.5 to 4 times lower solid content in the filtrate compared to flocculants C-494, Magnafloc, and A-150 (Table 4).

The use of a hydrodynamic disperser at a shear rate of 1000 s^{-1} significantly reduces the solid content in the filtrate by nearly 3 to 4 times and reduces the consumption of the nonionic flocculant N-100 by half (Table 5). The treatment time was 30 seconds.

3. Results

The developed method for the disposal of spent drilling fluid and the corresponding treatment unit carry out the separation of solid particles from the liquid phase using a flocculant.

The technical result is the separation of water and concentrated solids (clay, sludge) from the spent drilling fluid mixture directly at the drilling site, enabling the reuse of the separated products for technical purposes. This leads to improved environmental conditions in the region, reduced transportation costs, and decreased labor demand for handling and logistics.

This is achieved by optimizing the concentration of coagulant and flocculant, which are fed as a solution via a dosing system, along with the spent drilling fluid pumped into the hydrodynamic disperser, where it is subjected to intensive turbulent motion at a controllable and optimal hydrodynamic velocity.

The hydrodynamic disperser is a specialized device designed for fine dispersion of the solid phase in spent drilling fluid and for restoring its rheological properties to enable subsequent reuse. The main operating principle of the device involves the application of a high-velocity hydrodynamic flow to break down particle agglomerates and ensure uniform distribution of components within the liquid medium. A key design feature is the presence of adjustable interchangeable discs that allow for control over the speed and degree of particle fragmentation, depending on the composition of the sludge. To activate clay components and enhance dispersion, chemical additives such as surfactants, salt buffers, and water-soluble polymers can also be introduced. The unit operates in a continuous mode, providing a high level of mechanical action without the use of grinding media. At the outlet, the system produces a finely dispersed, rapidly settling suspension and technical water suitable for recirculation in the drilling process [11-14].

If necessary, the liquid fraction – technical water – can be further filtered using vibrating screens or a centrifuge.

Thus, the hydrodynamic disperser performs a dual function: it enables both the separation of the solid phase and the recovery of the liquid phase for the preparation of fresh drilling fluid.

The advantages of the unit include the absence of moving cutting parts (which reduces wear), compact design, adaptability to various types of drilling sludge, and the possibility of integration into a mobile drilling module.

In the context of uranium deposits, the device can be operated directly at the drilling site, providing local treatment of spent drilling fluid (SDF) with minimal environmental impact.

The proposed innovative solution is aimed at creating a closed technological cycle for the reuse of water-based clay drilling fluids (SDF) with minimal generation of hazardous waste and a high level of environmental safety.

Its core concept is the integration of the hydrodynamic disperser into a modular drilling fluid treatment station operating directly at the drilling site.

This scheme makes it possible to achieve the following:

- Reduction in fresh water consumption through the reuse of the liquid phase;
- Decrease in the volume of accumulated drilling sludge by 60–70% compared to conventional methods;
- Improved removal efficiency of the fine-dispersed phase due to the use of cavitation-hydrodynamic dispersion;
- Minimization of time and costs associated with the transportation and disposal of solid residues;
- The technology is easily scalable and adaptable to various drilling conditions and can be implemented in both mobile and stationary formats.

The innovative aspect of this approach lies in the combination of dispersion technology with on-site fluid treatment, allowing for adaptation to the specific conditions of a given drilling location.

The treatment station can be mounted on a chassis or in a containerized format, ensuring mobility and rapid deployment.

This development has strong potential for broad application not only at uranium drilling sites, but also in other areas of mineral exploration.

Preliminary estimates indicate that disposal cost reductions may reach 30–40% while maintaining drilling fluid quality in compliance with State Standard.

Operational and Environmental Advantages.

From an environmental perspective:

- The volume of solid drilling waste requiring burial or long-term storage is significantly reduced;
- The risk of soil and groundwater contamination is minimized through the elimination of liquid phase discharges into the environment;
- The accumulation and drying of sludge capable of generating dust containing radionuclides and heavy metals is prevented;
- The consumption of natural resources (such as water and mineral additives) is minimized, which is especially important in regions with limited water availability [18].

Thus, the use of a hydrodynamic disperser as a key component in drilling fluid treatment contributes to the formation of a closed, environmentally sustainable drilling cycle. This aligns with the strategic objectives of sustainable subsurface resource management and enables operators to comply with the current environmental protection legislation of the Republic of Kazakhstan as well as international ecological standards.

Considering the combined operational, economic, and environmental indicators, the proposed technology outperforms standard solutions and can serve as a foundation for modernizing the management system of spent drilling fluids in the uranium mining industry.

Regulatory and Legal Aspects of the Republic of Kazakhstan. The management of drilling waste in the Republic of Kazakhstan is regulated by a number of normative documents, including the Environmental Code of the Republic of Kazakhstan, the Code on Subsoil and Subsoil Use, and sanitary norms and rules governing the handling of industrial waste. In the case of uranium deposits, additional requirements are applied regarding radiation safety and the monitoring of radionuclides in the environment.

According to Article 397 of the Environmental Code of the Republic of Kazakhstan (as amended in 2021), subsoil users are obligated to ensure the disposal and neutralization of waste generated during drilling operations. Priority is given to technologies aimed at reducing waste volumes and reusing resources, in line with the «zero discharge» principle.

The handling of drilling fluids is classified as the management of waste belonging to hazard classes IV–V. However, when wells intersect ore-bearing horizons, the resulting waste may contain naturally occurring radionuclides, and its management must comply with sanitary regulations on radiation safety. In particular, temporary storage is permitted only with approved project documentation and with engineered measures in place to prevent the infiltration of contaminants.

The reuse of drilling fluids is regulated by technical regulation standards and must be accompanied by an internal quality control system, including parameters such as viscosity, density, solid phase content, and radiological indicators. Recycling of fluids is permitted if a specialized dispersing and filtration unit is available, provided that the reused fluids do not alter the radiation background at the site.

The proposed technology complies with the waste management hierarchy established in Article 329 of the Environmental Code, which prioritizes waste prevention, recycling, and reuse over disposal. In addition, it aligns with the principle of impact localization, as waste is processed and reintegrated into the cycle on-site, minimizing the risk of contamination of other areas.

The implementation of a mobile unit for the processing of spent drilling fluids (SDF) can be incorporated into project documentation as part of the waste management system. This would enable the subsoil user enterprise to reduce environmental risks, improve sustainability indicators, and align with the goals of the national «Green Economy» strategy [19-21].

4. Conclusion

The disposal of spent water-based clay drilling fluids during the drilling of process wells at uranium deposits, such as those at «Inkai» SD requires the implementation of modern and environmentally safe solutions.

The technology presented in this article, based on the use of a hydrodynamic disperser, enables the creation of a closed-loop system for the reuse of drilling fluids. This significantly reduces waste generation, minimizes the risk of environmental contamination, and lowers costs associated with resource procurement and disposal.

The analysis results demonstrate that the proposed system exhibits high technological flexibility, is suitable for both mobile and stationary deployment, and complies with the current regulatory and sanitary standards of the Republic of Kazakhstan.

In terms of environmental impact, economic efficiency, and operational performance, this solution offers clear advantages over conventional disposal methods such as reserve pit storage, landfill transportation, or single-use drilling fluids.

Therefore, the implementation of a spent drilling fluid treatment system using a hydrodynamic disperser can be recommended as an effective strategy for modernizing the drilling process in the uranium industry.

Future research directions include system scaling, automation of control processes, and integration with drilling fluid quality monitoring systems [22, 23].

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