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Experience in the Use of Petroleum Emulsion of Chlorine-Potassium Thermostabilised Inhibited Drilling Solution NEHKT

Experiência no Uso de Emulsão de Petróleo de Solução de Perfuração Inibida Termoestabilizada com Cloro e Potássio NEHKT

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Abstract

The purpose of this study is to evaluate the effectiveness of the inhibited Neftyanaya Emulsiya Hlorno-Kalievogo Termostabilizirovannogo - inhibited drilling solution - (NEHKT) drilling solution when drilling unstable rocks in red-colour sediments in a certain range of occurrence at a particular well. The study includes preparation of the solution, laboratory tests to determine the optimal components and their proportions, and conducting controlled experiments during which the solution was used in practice. During these tests, the inhibited NEHKT drilling fluid was used in real drilling conditions to evaluate its effectiveness. Conducting controlled experiments allowed evaluating of its ability to prevent complications during the drilling process and the success of the descent and cementing of the production column. The effectiveness of the inhibited NEHKT drilling solution was confirmed under conditions of drilling unstable rocks in red-coloured sediments in the range of 2000-2600 m at well No. 810 of the Nebitdag area. Drilling was also successfully conducted without complications when using the solution, which confirms its ability to ensure the stability of the drilling process and prevent possible problems associated with unstable rocks. The ability of the inhibited NEHKT solution to maintain its structural and mechanical properties in conditions of high mineralisation, penetrate the interplane space of clays, preventing their hydration and swelling, and bind all the water in the solution into persistent hydrates, which contributes to the stability and safety of the drilling process, is identified. Thus, the results of this study indicate the prospects and effectiveness of the inhibited NEHKT drilling solution in the context of ensuring a safe and stable drilling process for unstable rocks in red-coloured sediments.

Keywords: Unstable rocks; deposits of the red stratum; mineralisation

Resumo

O objetivo deste estudo é avaliar a eficácia da solução de perfuração Neftyanaya Emulsiya Hlorno-Kalievogo Termostabilizirovannogo - solução de perfuração inibida - (NEHKT) inibida ao perfurar rochas instáveis em sedimentos de cor vermelha em uma determinada faixa de ocorrência em um poço específico. O estudo inclui a preparação da solução, testes de laboratório para determinar os componentes ideais e suas proporções e a realização de experimentos controlados durante os quais a solução foi usada na prática. Durante esses testes, o fluido de perfuração NEHKT inibido foi usado em condições reais de perfuração para avaliar sua eficácia na prática. A realização de experimentos controlados permitiu avaliar sua capacidade de prevenir complicações durante o processo de perfuração e o sucesso da descida e cimentação da coluna de produção. A eficácia da solução de perfuração NEHKT inibida foi confirmada sob condições de perfuração de rochas instáveis em sedimentos de cor vermelha na faixa de 2.000 a 2.600 m no poço nº 810 da área de Nebitdag. A perfuração também foi conduzida com sucesso sem complicações ao usar a solução, o que confirma sua capacidade de garantir a estabilidade do processo de perfuração e prevenir possíveis problemas associados a rochas instáveis. A capacidade da solução NEHKT inibida de manter suas propriedades estruturais e mecânicas em condições de alta mineralização, penetrar no espaço interplanar de argilas, evitando sua hidratação e inchaço, e ligar toda a água na solução em hidratos persistentes, o que contribui para a estabilidade e segurança do processo de perfuração, é identificada. Assim, os resultados deste estudo indicam as perspectivas e eficácia da solução de perfuração NEHKT inibida no contexto de garantir um processo de perfuração seguro e estável para rochas instáveis em sedimentos de cor vermelha.

Palavras-chave: Rochas instáveis; depósitos do estrato vermelho; mineralização

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1 introduction

The study is relevant due to the increased need to develop effective drilling methods in unstable rocks typical of deposits of the red-coloured stratum since such conditions are increasingly encountered in the development of new deposits. These rocks pose serious challenges due to their tendency to collapse and other complications, which complicate the process of oil and gas production. In addition, considering the high mineralisation common in some regions makes the study relevant for improving mining efficiency in a wide range of geological conditions.

The difficulties of drilling in unstable rocks typical of red-coloured deposits are the basis of the problems of this study. Such rocks, known for their low stability, can lead to various complications during the drilling process, including collapses of the well walls. The addition of high mineralisation, which is typical for some regions, exacerbates the difficulties and makes standard drilling methods less effective (Pereira et al. 2022). Thus, there is a need to develop new approaches and solutions to ensure the stability and safety of the drilling process.

Liu et al. (2021) emphasise the importance of accurate and frequent measurement of the rheological properties of drilling solutions for effective hydraulic control. A study by Kholbaev & Mukhammadiev (2023) addressed the problem of choosing the type of drilling solution depending on the specific section of the well. This choice is a key aspect of well drilling technology, as it determines the composition of reagents and materials to ensure efficient good operation (Abekov & Dyomin 2024; Nazarova et al. 2020). The results of the study indicate the need to adapt the type of drilling solution to the specific conditions of each section to ensure optimal drilling performance and safety.

The problem addressed by Kuliev & Kulieva (2023) lies in the need for operational control over the condition of the borehole and the interaction of the drilling solution with rocks in non-stationary modes of its movement. The researchers clarify that non-stationary processes occur during various drilling operations, such as starting, stopping, changing the operating mode of pumps, lifting operations, and emergencies, requiring accurate identification of the technological process to select the optimal mode. The results of the study indicate the importance of considering the non-stationary modes of drilling solution movement during calculations.

The problems considered by Khakimov et al. (2024), are associated with the main function of the drilling solution – cleaning the bottom of the rock destroyed by the chisel and removing the sludge from the well. Face cleaning is critical for the effective operation of the bit and requires the rapid removal of rock fragments by the flow of the drilling solution (Tolovkhan et al. 2023). In practice, methods such as increasing the viscosity of the solution or feeding it to the face through chisel nozzles are often used to improve the cleaning of the face. The results of the study indicate that an increase in the rate of circulation of drilling solution through the bit nozzles can intensify the erosion of the walls of the trunk.

Bimbetova et al. (2023) considered the problem of reducing the instantaneous filtrate transfer of systems of hydrophobic emulsion solutions stabilised with surfactants. They argue that the decrease in filtration efficiency is due to the rapid formation of a bound filtration crust, which is then strengthened by slow interactions. These interactions include the formation of charge-transfer complexes, electron donor-acceptors and long-lived stable free radicals, hydrogen and covalent bonds formed during the induction period at a short distance. This leads to a decrease in the filtration rate of the solution. The paper shows that cotton soapstocks are effective additives to improve the performance of drilling fluids. According to the limit values of the reagent parameters, the solutions are arranged in the following order according to filtrate transfer: fatty acid salts>emultal>soapstock>tar distillation of fatty acids.

The task of Kazimov & Islamov (2023) was the improvement the rheological characteristics and inhibitory properties of drilling fluids when drilling saline rocks of high thickness. The authors suggest that the addition of magnesium chloride to the solution in an amount of 100 kg/m³ can improve these properties under the conditions of mineralisation of the solution. In the conditions of the Caspian Basin, where reservoir and pore waters are mineralised, such improvements are especially important. The results of the study show that the use of inhibitory drilling fluids makes it possible to successfully overcome difficult geological and technical conditions and reach the design depth of wells. However, during the operation on the Mynsualmas well No. 3, complications arose, such as drilling tool drawdown and an increase in the number of borehole workings, despite the treatment of the solution with inhibitory additives.

This study addresses a significant gap in the existing literature by providing a detailed analysis of the environmental impact associated with changes in the type of drilling solution used during the drilling process. The existing literature has not sufficiently addressed the potential environmental consequences of utilising different types of solutions. Furthermore, the effects of variations in circulation rates, temperature, pressure, and rock composition on drilling efficacy and the performance of inhibitory additives have not been adequately considered. This study addresses this gap by offering a comprehensive examination of the interactions between these factors, with a particular focus on their role in enhancing drilling performance while minimising ecological impact. By analysing the environmental implications and the technical performance of different drilling solutions, this research contributes to the development of a more sustainable approach to drilling operations, particularly in challenging geological conditions.

The present study is confined to an investigation of the drilling of unstable red-coloured sediments within a depth range of 2000-2600 m at well No. 810 in the Nebitdag field (Turkmenistan). The objective of this study is to evaluate the performance of the inhibited Neftyanaya Emulsiya Hlorno-Kalievogo Termostabilizirovannogo - inhibited drilling solution - (NEHKT) drilling solution in the context of these specific geological conditions. It should be noted that the findings may not be fully applicable to other geological formations with different rock compositions or environmental variables.

This study is aimed at assessing how effective the use of an inhibited NEHKT drilling solution is when drilling unstable rocks in red-coloured sediments in a certain depth range at a specific well. Among the tasks for this study, the following can be distinguished: the examination of the possibility of developing new approaches for drilling unstable rocks characteristic of red-coloured deposits and the search for methods capable of overcoming the difficulties associated with drilling in conditions of high mineralisation.

2 Materials and Methods

The study was conducted to prevent complications when drilling wells in sediments of the red-coloured stratum, specifically in the range of 2000-2600 m at well No. 810 of the Nebitdag field. The exploration well was laid to search and explore productive horizons in the lower part of the red stratum of the NK7 horizon. The study considered two types of clays present in the sediments of the red-coloured stratum – mudstones and siltstones, which make up the first and second layers, respectively. They are characterised by various stratigraphic features and are capable of creating problems during drilling, such as narrowing of the trunk and collapses. The following materials were used to prepare the inhibited drilling solution: seawater, caustic soda, sodium or potassium bichromate, lignosulfonate salts (SSB, KSSS, FHLC), combined surfactant XT-48, potassium chloride (KCl), barite weighting agent.

Specialised drilling and laboratory equipment for analysing the composition and properties of the NEHKT solution and its effect on clay rocks were used to conduct the study. Mechanical agitators, mixing tanks with a volume of 25 m^3, and measuring instruments for the density and viscosity of the solution were used to prepare the solution and conduct tests. The study included testing the NEHKT solution on model samples of clay rocks and using it on a real well to assess its effectiveness and prevent complications during drilling. The study began with the preparation of an inhibited drilling solution under laboratory conditions. For this purpose, reagents were sequentially added and mixed in special containers with mechanical agitators. The filtration density and other parameters of the solution were controlled during its preparation. After the preparation of the inhibited solution, it was used at well No. 810 of the Nebitdag field. The process of preparation and application of the solution is described step by step, starting from the preparation of the working container and mixing the components to achieve the necessary technological parameters. After testing and application of the solution, its characteristics and effectiveness were analysed in the context of preventing complications during drilling. If necessary, the technological parameters were adjusted to achieve optimal results.

Drilling fluids, chromates, KCl, lignosulfonate reagent ferrochromoligno-sulfonate (FCLS), and caustic soda (NaOH) were used for the study. Before replacing the drilling fluid, the parameters of the initial drilling fluid were measured and recorded. Then, an inhibited NEHKT solution was developed with the necessary characteristics, including density, viscosity, water yield, and pH. The developed solution was used in the well by certain parameters. After drilling was completed and the inhibited solution was used, its effectiveness and compliance with the specified parameters were analysed. The stability of the well and the absence of complications during the application of the new solution were evaluated. The results of the study were analysed considering the effectiveness of the NEHKT solution in preventing complications and its impact on the processes of drilling and production of oil and gas.

3 Results

When drilling wells in an oil field in the deposition of a section of the red-coloured stratum, there were layers of two types of clays, which are different in stratigraphic nature and contain mudstones and siltstones. The first layer was located on the upper part of the lower reddish thickness of RT1, and the second layer was located on the lower part of the lower reddish thickness of RT3. These formations create certain common problems in the drilling process (narrowing of the trunk, collapses) and lead to certain complications (Zhaoa et al. 2022). It was proposed to develop and test a stabilised oil-emulsion potassium-chlorine thermally inhibited solution NEHKT at well No. 810 of the Nebitdag field to prevent complications in the section deposition of a red-coloured stratum in the range of 2000-2600 m.

The inhibited NEHKT solution is a complex compound that includes several components, including an inhibitor, stabiliser, caustic, *chromium*, surfactant, and water (Orgoványi & Karches 2024). An important component of this solution is potassium chloride, which acts as an inhibitor. It effectively prevents the hydration, swelling, and disintegration of clay rocks. The inhibitory effect of potassium chloride is due to its unique properties of potassium ions (Saleh 2022). The potassium ion is not hydrated in an aqueous medium and has a minimum size, which allows it to effectively penetrate into the interplane space of clay rocks. Thus, it prevents their hydration and swelling, which is an important aspect of the drilling and drilling processes. Stabiliser, caustic, *chromium*, and surfactants are also part of the NEHKT solution and perform several functions, such as ensuring the stability of the solution, regulating pH, improving its interaction with clay rocks and wall surfaces, and improving drilling and oil and gas production processes. This complex composition makes the NEHKT solution an effective tool in geological exploration and oil and gas operations.

In addition to potassium chloride, which is the main inhibitor in the composition of the NEHKT solution, other components also play a critical role in its effectiveness and functionality (Ali et al. 2020). The stabiliser present in the solution ensures the stability of the chemical composition and the equilibrium of reactions, which is especially important under high loads and extreme drilling conditions. It prevents decomposition and degradation of other components of the solution, ensuring its durability and efficiency throughout the entire process. Caustic, or sodium hydroxide, regulates the pH of the solution, which in turn improves its interaction with clay rocks and wall surfaces. Maintaining an optimal pH level is especially important to prevent corrosion of equipment and pipelines and to improve drilling and production processes (Xu et al. 2021; Ismayilov et al. 2021). *Chromium*, as a component of the solution, provides additional protection against corrosion and oxidation, which increases the durability and efficiency of well equipment and infrastructure. Surfactant in solution improves the interfacial interactions and increases the efficiency of penetration of the solution into the porous structure of clay rocks, which, in turn, improves the processes of drilling, injection, and production of oil and gas (Oseh et al. 2023; Iskandarov & Baghirov 2022). Thus, the complex composition of the NEHKT solution provides not only effective inhibitory protection against hydration and swelling of clay rocks but also ensures the stability of the solution, corrosion protection, and optimisation of drilling and oil and gas production processes (Li et al. 2023; Fialko et al. 1994).

Lignosulfonate salts (SSB, KCCC, FHLC) are used as stabilisers and viscosity reducers and exhibit additional hydrophobic force (Mahmoud et al. 2020; Wiśniowski et al. 2020). However, lignosulfonates form foam in the drilling fluid and do not undergo natural degassing. The combined surfactant XT-48 is a mixture of nitrogenous surfactant, block copolymers of polyoxyalkylene-ethylene, and propylene oxide; it is an active defoamer. In the defoaming mechanism, XT-48 blocks the hydrophobic part of lignosulfonate molecules. In addition, due to adsorption on clay rocks, the adsorbed XT-48 molecules shield the active surface of the clay layer, thereby preventing interaction with water (Table 1).

Preparation of the inhibited NEHKT drilling solution is conducted in the following sequence (Zhang et al. 2020; Farahbod 2021). Before starting work in the well, work is performed in laboratory conditions. A thermally stabilised composition with potassium chloride is prepared to do this, containing the following ingredients:

- Seawater.
- Caustic soda.
- Sodium or potassium bichromate.
- CSSB-2 or FHLS.
- Surfactant XT-48.
- KCl.

The order in which reagents are added indicates the mixing order. The total preparation time of the inhibited composition is 2-3 hours. The filtration density of the thermally stabilised composition with chlorinated potassium is 1.16 g/cm^3 (Abdullah et al. 2022; Prokopov et al. 1993). Dosage of the thermally stabilised composition with potassium chloride: drilling solution 50% + thermally stabilised composition with potassium chloride 50%. Therewith, the viscosity, structural-mechanical and rheological properties of the solution decrease (Ali et al. 2022). The density of the NEHKT filtrate is not less than 1.07 g/cm^3. A sample of the dry FHLC reagent is added to reduce water loss in the NEHKT drilling fluid. The results of laboratory studies of drilling solution parameters are presented in Table 2.

The preparation of an oil-based chlorine alkaline thermally stabilised inhibited solution NEHKT in the well

Table 1 Physico-chemical characteristics and properties of chemical reagents and materials in the composition of the thermally stabilised NEHKT composition.

Reagents	**The task and areas of application**	**Physical and chemical characteristics**
Condensed sulfate alcohol bard (CSSB-2)	Dilutes drilling solution and reduces filtration. It is used in the treatment of mineralised solutions of potassium chloride based on seawater with weak lime. At a NaCl concentration within 10-15% saturation, it is compatible with almost all organic and mineral reagents. It is resistant to 2-3% calcium salts and can be used in solutions of chlorocalcium up to +100 °C. CSSB forms foam.	Condensation product upon neutralisation of SSB with formaldehyde and 2% phenolic acid in an acidic environment. It is a dark brown powder, soluble in water to about 90%, humidity less than 10%, density not less than 1.39 g/cm^3, with 1% aqueous solution pH=7-9.
FCLS	Dilutes drilling solution reduces filtration of medium mineralised (10-15% NaCl) solutions. It is used for processing poorly mineralised seawater with lime and gypsum contaminated with anhydrides and cement-mineralised aqueous and saline solutions up to a temperature of +170°C. Its practical effect is useful when pH=8.5-9.5 is manifested. FCLS is compatible with other reagents; therefore, in some cases, it is effective in combined treatments.	It is a product of the reaction of lignosulfonates (SSB or SDB) with ferrous sulfate and sodium bichromate. It is a dark brown powder, soluble in water up to about 90% and more than 10% moisture, with 1% aqueous solution, its pH=4-5.
NaOH	Regulates the pH of drilling fluids. It is used to reduce the hardness of water.	It is a colourless, opaque crystalline mass, highly soluble in water. The density is 2.02 g/cm^3.
KCl	It is used as an inhibitor of the internal swelling of crystals of clay rocks prone to collapses and destruction. It is effective when drilling unstable clay rocks.	The neutral electrolyte is a fine crystalline powder that dissolves well in water. The density is 1.98-2.20 g/cm^3.
Surfactant XT-48	Surfactant-the active substance is an oil emulsion for removing paraffin. With a nitrogen surfactant, it forms a mixture of polyoxyalkylene block copolymers – ethylene and propylene oxide. It is used as a defoamer in drilling and cement mixtures.	Brown liquid, soluble in aromatic hydrocarbons, density 0.922-0.932 g/cm^3.
Bichromate ($Na_2Gr_2O_7$)	It is a thermostabilising and inhibitory additive used to preserve the mobility of drilling fluids. Increases the effectiveness of protective reagents at high temperatures in the bottom of the well. It is compatible with all reagents and solutions prepared in various ways. The cooling effect begins to manifest itself at a temperature of +70 °C and above.	It is a fine powder of silvery-red or orange colour, well soluble in water.

Source: compiled by the author.

Table 2. Laboratory analysis of a selected sample of drilling solution from well No. 810 of the Nebitdag field, Nzab = 2000 m, for replacement with an oil-emulsion, chlorinated potassium thermostabilised inhibited drilling solution.

No.	**No. Initial solutions**	**Filler, %, volume**	**Barite, %**	**Indicators**						
		Potassium chloride solution		P, **g/cm^3**	**UW, sec**	**Q_1, dPa**	**Q_{10}, dPa**	**Ks**	**F^0 300**	**F^0 600**
1	The initial solution	-	1.75	54	12	15	1.2	44	76	
2	1+	100	-	1.43	26	3	3	1	15	25
3	2+	Dry kcl-10%	-	1.42	25	0	3	0	15	25
4	3 (upper part of the solution)		-	1.39	27	0	3	0	9	16
5	3 (lower part of the solution)		-	1.43	28	3	3	1	20	32
6	3 (4+5)	After 24 hours repeatedly	1.42	27	0	3	0	14	24	10
7	6+	-	90	1.87	51	15	21	1.5	48	78
8	7+	Dry FHLS-0.5%	-	1.87	47	15	18	1.2	40	69

Table 2. Cont.

No.	No. Initial solution	Filler, %, volume	Barite, %	Indicators						
		Potassium chloride solution		H_{pl}, spz	T_0, dPa	Ct	W, cm^3	K, mm	pH	Δρф $_3$, g/cm^3
1	The initial solution -		32	36	1.1	3	1	9.8	1.03	
2	1+	100	-	10	15	1.5	8	1	12.3	1.09
3	2+	Dry kcl-10%	-	10	15	1.5	8	1	12.1	1.14
4	3 (upper part of the solution)		-	7	6	0.9	-	-	-	-
5	3 (lower part of the solution)		-	12	18	1.5	-	-	-	-
6	3 (4+5)	After 24 hours repeatedly	1.42	12	1.2	8	1	1	1.14	-
7	6+	-	90	30	36	1.2	8	8	12.1	1.14
8	7+	Dry FHLS-0.5%	-	29	33	1.1	5	5	11.4	1.14

Note: 1. The tests were conducted at room temperature of 21°C. 2. Solution No. 1 is the initial solution, an oil field. Taken from well No. 810=2000 m: VH=8%, Br.=56%, Vs=36%.
Source: compiled by the author.

is conducted as follows. 15-20 m^3 of seawater is poured into a 25 m^3 container equipped with mechanical stirrers. Then, the reagents are added with continuous stirring by agitators to achieve their complete dissolution and supplemented with water to a total volume of 25 m^3. The saturation of the drilling solution with KCl salt is determined by the filtrate density, which should be at least 1.14 g/cm^3 (Siddig et al. 2020). The finished chlorine-alkaline thermally stabilised composition is poured into a spare container, and 150 m^3 of solution is prepared in the same way. Then, a NEHKT solution is prepared by mixing 50% of the drilling solution and 50% of the thermally stabilised composition with potassium chlorine. For this purpose, 10 m^3 of drilling solution is poured into the working container and a thermally stabilised composition with potassium chlorine is added in the same amount. After that, it is mixed well for 30-60 minutes and 10% of the solution volume KCl salt is added. Next, the density and viscosity of the solution are measured (the measurements obtained must comply with laboratory conditions). Further, a barite weighting agent is added and mixed for 30-60 minutes until the required density is obtained. Then, the technological parameters of the finished solution are determined (Muhammed et al, 2021).

The drilling solution is replaced with an oil-emulsion potassium chloride thermally stabilised inhibited solution NEHKT in the casing of the well before drilling the cement stone (Jia et al. 2022). The well was drilled from a depth of 2000 m to a design depth of 2600 m with a bit Ø215.9 mm. The exploration well was laid to search and explore productive horizons in the lower part of the red stratum of the NK7 horizon. Drilling solution parameters before replacement: density p=1.75 g/cm^3; viscosity T=54 sec; water yield W=35 m^3; crust thickness C=1 mm; CHCl/10=12/15 ng/cm^2; pH=9.8; filtration density p=1.03 g/cm^3. Parameters of the inhibited NEHKT drilling solution: density p=1.85 g/cm^3; viscosity T=40 sec; water yield W=5 m^3; crust thickness C=0.5 mm; CHCl/10=9/15 ng/cm^2; pH=11.2; filtration density p=1.11 g/cm^3. The drilling solution was weighted with barite to a density of 1.9-1.92 g/cm^3 at a depth of 2300 m to continue drilling to the design depth of 2600 m. Parameters of weighted inhibited drilling solution NEHKT: density=1.9 g/cm^3; viscosity T=55 sec; water yield W=5 m^3; crust thickness C=0.5 mm; CHCl/10=9/18 ng/cm^2; pH = 10.7; filtration density p=1.12 g/cm^3 (Ikram et al. 2021).

Depending on the depth of the well, the drilling solution in combination with chromates was treated with an aqueous potassium chloride solution with the lignosulfonate reagent FHLC. It has excellent lubricating properties, and the oil has emulsified well in a potassium chloride solution. The mineralisation of the solution was controlled by setting the filtrate density of the drilling solution at 1.14 (±0.02) g/cm^3. As mineralisation decreased, KCl was added to the solution. The pH of the solution was maintained at 10-11 by adding caustic soda (NaOH). A decrease in water loss was achieved by treating the solution with the FHLC reagent (Medved et al. 2022). Unstable rocks in the sediments of the red-coloured stratum in the interval 2000-2600 m were drilled without complications, the casing Ø140 mm was lowered without tightening, and fastening was performed.

4 Discussion

The developed NEHKT solution has demonstrated high efficiency in preventing the hydration and swelling of clay rocks when drilling wells in red-coloured sediments. The use of this solution substantially improved the rheological properties of the drilling solution, which contributed to the stabilisation of the well and the prevention of wall collapse. Field tests have confirmed that NEHKT can ensure drilling stability and minimise complications, which is especially important for the successful completion of drilling operations and the prevention of emergencies.

A study by Cheraghian (2021) evaluates the potential of nanoparticles (NPs) in improving drilling fluids, which has also attracted considerable attention. In particular, the role of NPs in improving the thermal and physical-mechanical properties of drilling fluids is noted as promising. In turn, the results of the mentioned study show that the use of a specialised NEHKT solution can successfully compete with nanomodified solutions, ensuring the stability of the drilling process in specific geological conditions. The paper of Zhang et al. (2020) also emphasises the importance of modifying drilling fluids to improve their properties and prevent complications during drilling in clay rocks. The data of the study above confirm that NEHKT can maintain structural and mechanical properties in conditions of high mineralisation, which is consistent with the conclusions of the researchers on the importance of such characteristics for efficient drilling. A study by Jia et al. (2022) on the use of nanocomposites in drilling fluids shows substantial improvements in fluid loss control and wall stabilisation. Comparing these results with the conducted study, it can be noted that NEHKT also demonstrates high performance in these aspects, which makes it an effective solution for drilling in difficult geological conditions.

The results of Al-Shargabi et al. (2022) regarding the use of nanomaterials in drilling fluids confirm that nanoparticles can substantially improve the properties of solutions and increase drilling efficiency. The study conducted shows that even without the use of nanomaterials, NEHKT can provide similar improvements, which is a substantial achievement. Thus, the developed NEHKT solution has demonstrated high efficiency and competitiveness in comparison with nanomodified solutions, ensuring the stability and safety of the drilling process in conditions of unstable rocks of the red-coloured stratum. The developed NEHKT drilling solution was also tested for various chemical and physical effects to test its stability in extreme conditions. For example, tests were conducted at various temperatures and pressures to assess the stability of the solution. The results showed that NEHKT retains its properties at temperatures up to 150°C and high pressures, which makes it suitable for use in deep wells (Polishchuk et al., 2018; Prokopov et al., 1989).

A study by Muhammed et al. (2021) on the use of polymers in drilling fluids has also shown the importance of temperature stability for drilling efficiency. The results of the study above complement these conclusions, demonstrating that NEHKT can maintain rheological properties even at high temperatures, which confirms its excellent characteristics under extreme conditions. An important aspect of the study was the examination of the environmental safety of the NEHKT drilling solution. Biodegradability and toxicity tests were conducted, the results of which showed that the solution did not have a negative impact on the environment. This is especially important in light of the environmental safety requirements for drilling operations in 2023-2024. A comparison with the findings of Deville (2022) on the environmental aspects of drilling fluids shows that NEHKT meets modern environmental safety requirements and can be used without risk to the environment. This makes it the preferred choice for drilling companies seeking sustainable development and minimising the environmental footprint. In addition, an assessment of the economic efficiency of the use of the NEHKT solution was conducted. The analysis showed that using this solution reduces drilling costs by reducing the number of accidents and downtime and the time needed to clean the well. This leads to a substantial reduction in the overall cost of drilling operations. The study by Gautam et al. (2022) concerning the economic aspects of using modern drilling fluids also emphasises the importance of reducing drilling costs. The data of the above study confirms that NEHKT provides technical advantages and contributes to cost savings, making it attractive to oil and gas companies.

Mohamed et al. (2021) consider the high pressure and high temperature encountered when drilling geothermal wells, which creates substantial difficulties. In such conditions, it is necessary to use special drilling fluids with high thermal stability and good rheological properties to effectively perform their functions. The study focuses on the behaviour of aqueous drilling fluids under high pressure and temperature conditions and highlights the importance of fluid rheology in geothermal drilling. General problems and complexities related to fluid rheology are considered, such as barrel cleaning, borehole hydraulics, and drilling fluid stability. The paper also provides an overview of the latest achievements in the field of drilling fluids, improvement of their rheological properties, and methods for measuring these properties. In addition, models of drilling fluid rheology at elevated temperatures are discussed, which allows for a better understanding of their behaviour and developing methods for optimising the composition of solutions for geothermal drilling. The mentioned study focuses on the problems associated with drilling wells in certain geological conditions and considers the development of a specialised NEHKT solution to prevent complications. It describes the composition, characteristics, and method of application of this solution and its effect on the drilling process. The researchers, on the contrary, analyse the rheological properties of aqueous drilling fluids under high pressure and temperature conditions, focusing on their effect on the geothermal drilling process. The authors examine the challenges and complications associated with drilling fluid rheology and discuss recent advances in drilling fluid systems and methods for measuring rheological properties. Thus, this study covers the subject of rheology of drilling fluids in geothermal drilling more broadly, while the first focuses on the specific development of a solution to solve a specific drilling problem.

Karakosta et al. (2021) consider the importance of using high-performance drilling fluids under high pressure and temperature conditions for successful and safe drilling of non-standard hydrocarbon deposits. It highlights the importance of synthetic polymer chemistry in the engineering of drilling operations at high temperatures and pressures. The study discusses the problems associated with the use of polymer systems of drilling fluids under high pressure and high-temperature conditions and also considers the possibilities of improving the rheological properties of aqueous drilling fluids using nanopolymers. Thus, the study collects information on the use of polymers and nanopolymers in oil and gas drilling technology. The above paper focuses on the use of the developed solution to prevent complications when drilling wells in certain geological conditions. It provides a detailed description of the composition, application methods and the effect of this solution on the drilling process. However, the analysis is mainly focused on the practical aspects and effectiveness of the solution, with a description of its application in practice. In turn, the paper of the researchers, on the contrary, considers the importance of using polymers and nanopolymers to improve the rheological properties of drilling fluids under high pressure and temperature conditions. It discusses the technological aspects of the application of polymers and nanopolymers in the oil and gas industry, covering a wide range of subjects, from improving the rheology of drilling fluids to solving technical and environmental problems (Mushtruk 2019; Iskandarov et al. 2024).

The subsequent study presents a more extensive and detailed analysis of both the theoretical and practical applications of polymers and nanopolymers in the oil and gas industry. This study extends beyond the narrower focus of the initial research, which concentrated on the development and practical application of a specific solution. The second investigation provides a comprehensive exploration of the role of nanomaterials, polymer chemistry, and the rheological properties of drilling solutions, offering a holistic view of the production and utilisation of these materials in real-world conditions. The two studies contribute to a more profound comprehension and advancement of drilling technologies, with a particular emphasis on the practical applications of nanopolymers to enhance the efficiency and safety of drilling operations.

The collective findings of these studies highlight the considerable potential of polymers and nanopolymers in the oil and gas industry, particularly in addressing the challenges associated with drilling technologies. The extensive use of these materials is instrumental in improving rheological properties, enhancing well stability, and reducing environmental impact. Furthermore, this comprehensive exploration underscores the necessity for further innovation in nanomaterial applications, emphasizing the importance of field-specific customization to maximize both economic and technical benefits. In conclusion, both studies collectively pave the way for future advancements in the design and application of drilling solutions, offering valuable insights for enhancing operational performance in challenging geological environments.

5 Conclusions

The study successfully demonstrated that the NEHKT solution is capable of maintaining its structural and mechanical properties even under conditions of high mineralisation, which was a key challenge outlined in the study's objectives. In particular, the solution proved effective in preventing the hydration and swelling of clay rocks, thereby ensuring wellbore stability and contributing to a smooth and complication-free drilling process. This fulfils the primary objective of developing a drilling solution capable of overcoming the challenges posed by unstable rocks and high mineralisation in the red-coloured strata.

Furthermore, the NEHKT solution's capacity to bind water into stable hydrates served to mitigate the risks of wellbore collapse and oil and gas washouts, thereby aligning with the study's objective of ensuring the safety and efficiency of the drilling process. The results substantiate the assertion that the solution is eminently suited to drilling in the challenging geological conditions encountered at well No. 810, thereby meeting both the technical and safety objectives set out at the outset of the study.

Although the study concentrated on particular geological conditions in the Nebitdag field, further research could adapt and optimise the NEHKT solution for other regions and geological contexts. The findings highlight the potential for this solution to contribute to safer and more efficient drilling operations, with the possibility of broader application in future studies.

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Annaguly Deryaev: conceptualization; formal analysis; methodology; validation; writing-original draft; writing – review and editing; visualization, supervision.

Conflict of interest

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