Anuário do Instituto de Geociências
Universidade Federal do Rio de Janeiro
https://revistas.ufrj.br/index.php/aigeo/

ISSN 0101-9759
e-ISSN 1982-3908

Inhibited Solutions for Wells in Complicated Geological Conditions in the Areas of South-Western Turkmenistan

Soluções Inibidas para Poços em Condições Geológicas Complicadas nas Zonas do Sudoeste do Turquemenistão

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Abstract

Shortcomings in methods for assessing the condition and composition of clayey rocks and shales lead to lower drilling cycle rates and profits and do not allow for proper quality of well construction in difficult geological conditions. The purpose of this study was to develop an optimal method of selecting the drilling mud composition when drilling wells in clay rock deposits. The following methods were used in the study: method of X-ray diffraction analysis of clay minerals; comparative analysis; method of mathematical statistics; side-tracking method. It was found that at equal wetting ability of clays, the fixing properties of the ALCAR-1 system are 3.5-4 times higher than those of the lime-potash system. Thus, with the same degree of stability, the water yields as well as drilling speeds may be higher with ALCAR than with the lime-potash system. The study of clayey rocks from the section of well No. 5 in the Bugdaily area showed that they have colloidality high enough for deep-seated clays, as they have a high content of montmorillonites. Drilling mud characterisation study found that mud samples No. 1, 2, and 3 had a strong inhibitory effect. The most effective sample was No. 3, which was able to ensure a stable state of clayey rocks for 90-100 days. The study of interaction of drilling fluid system ALCAR-3 with clayey rocks, carried out in the fields of south-western Turkmenistan, found that the inhibitory effect of the No. 3 sample can be further enhanced by the addition of 3% potassium chloride. The findings of this study can be used for successful drilling operations of deep wells in the areas of fields with complicated conditions associated with wellbore instability in the preparation of inhibited drilling fluids.

Keywords: Composition; Clay capacity; Clay rock

Resumo

As deficiências nos métodos de avaliação do estado e da composição das rochas argilosas e dos xistos conduzem a taxas de ciclo de perfuração e lucros mais baixos e não permitem uma qualidade adequada da construção de poços em condições geológicas difíceis. O objetivo deste estudo foi desenvolver um método ótimo de seleção da composição da lama de perfuração ao perfurar poços em depósitos de rochas argilosas. Foram utilizados os seguintes métodos no estudo: método de análise de difração de raios X de minerais de argila; análise comparativa; método de estatística matemática; método de rastreio lateral. Verificou-se que, com igual capacidade de molhagem das argilas, as propriedades de fixação do sistema ALCAR-1 são 3,5-4 vezes superiores às do sistema cal-potássio. Assim, com o mesmo grau de estabilidade, o rendimento em água, bem como as velocidades de perfuração, podem ser mais elevados com o sistema ALCAR do que com o sistema cal-potássio. O estudo das rochas argilosas da secção do poço n.º 5 na área de Bugdaily mostrou que têm uma coloidalidade suficientemente elevada para argilas de profundidade, uma vez que têm um elevado teor de montmorilonites. O estudo de caraterização das lamas de perfuração revelou que as amostras de lama n.º 1, 2 e 3 tinham um forte efeito inibidor. A amostra mais eficaz foi a nº 3, que conseguiu assegurar um estado estável das rochas argilosas durante 90-100 dias. O estudo da interação do sistema de fluido de perfuração ALCAR-3 com rochas argilosas, realizado nos campos do sudoeste do Turquemenistão, concluiu que o efeito inibidor da amostra n.º 3 pode ser reforçado com a adição de 3% de cloreto de potássio. Os resultados deste estudo podem ser utilizados para operações de perfuração bem sucedidas de poços profundos nas áreas de campos com condições complicadas associadas à instabilidade do poço na preparação de fluidos de perfuração inibidos.

Palavras-chave: Composição; Capacidade de argila; Rocha argilosa

Received: 3 April 2024; Accepted: 8 August 2024

1 Introduction

The specifics of the West Turkmen Depression make it one of the most important oil and gas-bearing provinces in Turkmenistan. Turkmenistan, located in Central Asia, is characterized by a complex geological structure that includes significant hydrocarbon deposits, particularly in the western and southwestern parts of the country. The West Turkmen Depression is known for its rich oil and gas fields, such as Goturdepe and Cheleken, which provide a significant portion of the country's oil production. The geological features of the region, such as complex rock formations and the presence of significant volumes of clay, require special attention to the selection and use of drilling fluids. The high clay content and other geological features pose significant challenges for well stability and drilling efficiency.

The oil production industry in Turkmenistan is a key sector of the country's economy, providing significant revenue from oil and gas exports. Due to the decrease in pressure in reservoirs that have been exploited for a long time, there is a need to develop new drilling technologies and use more effective drilling fluids to maintain well stability and increase production efficiency. In this context, the study of the properties of drilling fluids, such as the ALCAR system, is of great importance for the further development of Turkmenistan's oil production industry. The ALCAR system has shown significantly higher fixing properties compared to traditional lime-potassium fluids, which can substantially impact drilling efficiency and well stability under the complex geological conditions of the West Turkmen Depression. Deryaev (2023) considered aspects related to the study of the use of drilling fluid "Versadril" on a hydrocarbon basis, preventing clay swelling and stabilising the well.

In the Pribalkhan geological zone of oil and gas accumulation, drilling is confined to the upper and middle Pliocene sediments of the Apsheron and Akchagyl stages in the red beds; in the Gogerendag-Okarem zone – to the lower red beds. Deposits are mainly represented by embedded, tectonically shielded deposits. A characteristic feature of the structure of oil and gas bearing reservoir structures is the wide development of disjunctive dislocations of both local and regional nature. The large tectonic disturbance of the structures creates prerequisites for various complications. A distinctive feature of the Apsheron Stage sediments is their tendency to absorb drilling mud. Highly colloidal "black" clays of the Apsheron Stage are plastic and unstable, which leads to wellbore constriction (Deryaev 2023; Prakash et al. 2023). Clay deposits of red beds are very sensitive to changes in density of drilling fluids: increase of density above a certain limit leads to absorption and seizure of drill strings under the action of difference between hydrostatic and reservoir pressure and decrease of density leads to intensive water-gas-oil manifestations. Drilling below the red beds in the underlying (Miocene) sediments is complicated by the presence of clays and siltstones in the section, which are prone to scree and rockslides, making it impossible to run drill strings down to the bottom hole and contributing to abundant mud removal during penetrations and frequent seizures (Agaliyev and Sopiyev 2021).

Deryaev (2023a) noted that for the Versadril system having a 70/30 diesel/water ratio with electrical stability maintained at 800-1500 V, the water flow rate should be 3 ml/30 min and emphasised that this would significantly reduce the possibility of reservoir rock damage and drilling tool jamming. A. Prakash et al. (2023) conducted geological and technical analyses and selected best types of drilling fluids for enhanced reservoir recovery. Agaliyev and Sopiyev (2021) developed a formulation of sulphur concrete to improve its properties. Organic plasticisers reduce the melting point of sulphur, slow down its crystallisation, while the absorption coefficient of drilling and cement slurries into the formation was not more than 1%, and therefore it was recommended to use additional compositions of organic plasticisers of sulphur concrete such as cyclopentadiene, styrene, dipentene separate and mixed. Suleimanov and Huseynova (2023) proposed a method for rapid assessment of the current reservoir pressure distribution from the data of normal well operation. It was recommended to use the results of calculation of hydrodynamic parameters distribution to determine the pressure distribution in the porous medium of the productive formation, which contains moving fluid.

The subject under study needs to be investigated because one of the major problems in well drilling is to ensure the stability of clayey rocks during drilling. The problem of the study is that the existing shortcomings in physical and chemical methods of assessing the state and composition of clayey rocks and shales do not allow effectively influencing the fixing, lubricating, and anti-seizing properties of drilling fluids during well construction. The problematic of the study is confirmed by the fact that drilling wells in the fields of the West Turkmen Depression is associated with complex conditions of their conduction, caused by complications of mining and geological conditions during technological impacts on the massif, which, above all, includes the frequency of encountering strata with abnormally high formation pressure (AHFP). Therewith, reservoir temperature and hydrostatic pressure increase with increasing well depth, and swelling occurs in thick clays, argillites, and ordinary clays, which leads to borehole jamming and, as a result, wellbore stability problems.

Currently, insufficient attention is paid to the development of best methods of drilling fluid selection for deep well construction in unstable clay deposits. The purpose of this study was to select the best composition of drilling fluid for drilling directional and horizontal wells, regulation of its structural-mechanical and colloidal-chemical properties in the areas of the south-western part of Turkmenistan.

2 Materials and Methods

The study employed the methods of researching inhibitory properties of chemical reagents of drilling fluids at a choice of the correct composition of a working fluid, use of which was established by Act No. 208-III of Turkmenistan (2008). The study applied the method of X-ray diffraction analysis of clay minerals to determine the mineralogical composition of clays. A comparative analysis was performed to compare the properties of the ALCAR-1 system in terms of wetting capacity and fixing properties with those of the lime-potash system. Method of mathematical statistics for statistical substantiation of the reliability of metrological standards, including repeatability, reproducibility, and error. standards (repeatability, reproducibility, error). A side-tracking method was used to determine the marble colmatant content in drilling sludge removed by centrifuges from KCL/Polymer drilling mud in the field. To increase the stability of well walls and prevent complications, the research centre of Turkmenistan Institute "Nebitgazylmytaslama", with the help of these methods, developed and introduced into production compositions of inhibited systems – ALCAR (alumocalcium solution). The system is stabilised with lignosulphonates. Alkaline and acid hydrolysates of portland cement and slag portland cement containing simultaneously anions (chromates, aluminates, ferrates, ferrites) and cations (potassium, calcium, magnesium) were accepted as complex inhibitor. As a hydrophobising surface-active agent (SAA), a wax deposit inhibitor in petrochemical technology (PAWHT-48) was proposed, which performs simultaneously the functions of SAA, defoamer, and lubricating additive.

Any fluid system can be converted to ALCAR systems. It is expedient to transfer drilling fluid to the inhibited ALCAR system at a depth of 1500-2000 m. The choice of this depth is dictated by the fact that if drilling fluid is transferred to the ALCAR system at a shallower depth, there may be a shortage of fluid during further deepening of wells. At overestimated values of viscosity and static shear stress (SSS) of the initial solution (VV=80-120 s and SSS=50/80-100/150 g/cm^2), it is reasonable to add water to the solution together with the inhibiting composition. After single or twofold treatment of the solution with reagents, additional liquefaction with viscosity reducers is possible. The content of inhibitor ions in the filtrate was Ca^{+2}=900-1500 mg/l; K^+ aluminates=400-500 mg/l. Depending on the density, the conditional viscosity of the solution should have the following parameters: ρ=1.3-1.45 g/cm^3, T"=30-45 s; ρ=1.45-2 g/cm^3, T"=45-60 s; ρ=2-2.35 g/cm^3, T"=60-90 s; ρ=2.3535> g/cm^3, T"=90-140 s.

Regardless of the drilling fluid density and viscosity values, the SSS for 1/10 min should be within 3-6/10-20 mGs/cm^2 and the hydrogen value (pH) should be 10 or higher. Graphite was injected along with the inhibitor. As the density of the drilling fluid decreased, it was weighted (in parallel or in series) to the desired density value. The frequency of treatment was specified according to the content of inhibiting ions in the filtrate and drilling fluid parameters. The following equipment was used for sampling and measuring drilling fluids:

- **Density measurement:** drilling fluid areometer (ADB-1)
- **Conditional viscosity determination:** drilling fluid viscometer (VBR-1)
- **Rheological parameter measurement:** rotary viscometer (VIAM)
- **Clay mineral analysis:** X-ray diffractometer (SHIMADZU XRD-7000 104-00035)
- **Marble colmatant content determination:** manometric carbonatometer KM-NT 0.16/0.6 with MTI manometer
- **Drilling fluid stability determination:** stability cylinder (CS-2) and measuring laboratory cylinder with a base made of chemically resistant borosilicate glass (XC grade)

3 Results

The diversity of drilling conditions is primarily conditioned by the increasing depths of wells. This has led to various requirements for the quality of the drilling fluid, most notably its stability in the well, i.e., its resistance to temperature, pressure, and mineralisation. The drilling fluid quality management system included a task, the main purpose of which was to maintain the required structural, rheological, and filtration properties of drilling fluids. The main requirement for the flushing fluid during drilling (penetration) of the pay zone was low filtration and static shear stress. In this case, the composition of the drilling fluid should prevent the clay particles from changing into a colloidal state (Skorokhod et al. 1994). The drilling fluid filtration index under reservoir conditions should not exceed 20 cm^3, while the static shear stress should be close to zero values. These indicators can be provided by chemical treatment with high molecular weight compounds of multifunctional action. To prevent collapse in clayey rocks when drilling "depleted" reservoirs, the drilling fluid density should be designed considering the stability of the well walls. In this case, the density of the flushing fluid is restricted within the limits that provide an allowable depression on the borehole walls equal to 10-15% of the effective skeletal stresses. The zone of penetration of drilling fluid filtrate is determined according to geophysical methods and should not exceed the length of the perforation tunnel. Considering the technical data of perforators, the zone of filtrate penetration should not exceed two-three diameters of the borehole. Oil and gas fields in long-term operation have experienced a drop in reservoir pressure, which places additional demands on the quality of flushing fluid and the need to use drilling fluids of reduced density (Baishemirov et al. 2016).

The use of light drilling fluids is associated with a decrease in back pressure on the open-hole well walls, which causes the risk of loss of rock stability. Light drilling fluids refers to drilling fluids that have a lower density compared to traditional drilling fluids. These fluids are designed to exert less pressure on the wellbore walls, which can help in managing wellbore stability, particularly in formations with low pressure. Examples of light drilling fluids include those based on water with reduced concentrations of weighting agents, air or foam-based fluids, and oil-based fluids with lightweight additives. This is accompanied by intensification of cavern formation process, intensive removal of large-block cuttings, deterioration of borehole cleaning, accumulation of drilled rock in caverns, which is observed during field operations at the Altykui field in the south-western part of Turkmenistan. It was found that the loss of borehole wall stability is related to the intervals of clayey rock occurrence. The formation of caverns is inherent in clay penetration and intensifies when drilling directional wells (Prokopov et al. 1989; Prokopov et al. 1993). The process of cavitation was accompanied by a decrease in the quality of the wellbore and washing fluid and resulted in additional time consumption, which had a negative impact on the efficiency of penetration of reservoirs containing clayey rocks. To increase well productivity and oil recovery rates in the fields of Western and South-Western Turkmenistan, it is necessary to develop directional and horizontal well profiles. According to the author, the development of Turkmenistan's fields through the use of horizontal wells will provide an opportunity to decompact the well network, reduce capital investments in drilling and well construction, and by increasing the length of drainage system channels it will be possible to increase the intensity of well operation in intensive modes and increase the share of hard-to-recover oil reserves development (Kharlamov et al. 2014).

Geological and technical conditions of opening a reservoir with abnormal reservoir pressure (ARP) determine the requirements to the quality and concentration of flushing fluids. The key requirement is the creation of an optimised drilling fluid composition that factors in the prevention of well wall erosion and collapse, absorption, filtration occurring in the reservoir and well upon drilling and the prevention of hydraulic fracturing (HF) of rocks when the drill string and casing are run into the well. As the drilling fluid density decreases, efficient turbine operation, wellbore cleaning at high inclinations, cuttings transport, geophysical studies of well sections, and cementing operations must be carefully controlled. Hydrophobising solutions based on organosilicon liquids have been effectively utilized. These solutions, comprising water, clay, polymer stabilizers, and optionally supplemented with lubricants, flocculants, thinners, weighting agents, and hydrophobising fluids, have demonstrated successful outcomes (Liang et al. 2023). The conducted studies suggest that the developed formulation of drilling fluid on hydrocarbon base, including diesel and water (in the 85/15 ratio) was actively used in ultradeep drilling of exploration wells in conditions of abnormally high reservoir pressures. Polymerised clay-free drilling fluids included a mixture of water with a facilitating polymer addition to the plugging and drilling fluids (often non-hydrolysed polyacrylamide (PAA) is used) that improves its rheological properties, cutting-carrying capacity and flocculates the drilled rock; aqueous solutions of polymers (carboxymethylcellulose (CH2CO2H), oxyethylcellulose (C29H52O21), PAA, methas) transformed by transition metal salts into hydrogels; brines of various mineralisation treated with polymer reagents.

When applying the flushing method in production drilling of wells of the field with access to the reservoir roof up to 1500 m with horizontal completion of the borehole in the Sortymsky formation, for conductor drilling and surface casing drilling, intermediate string and polymer-clay drilling fluid were used. For production string drilling, polymer-clay inhibited solution was used. An inhibited drilling fluid was used under the liner, which proved itself well when drilling wells in fields with analogous geological section, such as the Goturdepe and Cheleken fields. To drill long-length boreholes in the intervals of unstable rocks characterised by low strength, prone to sharp changes in mineralogical composition, including to prevent complications when drilling large-diameter sidetracks (406 mm and 324 mm in the open-hole well) in the upper part of the section, measures aimed at increasing the transporting, inhibiting properties of the drilling fluid and preserving its geological properties during continuous circulation of the flushing fluid, which, circulating in the wellbore, captures and raises to the surface cuttings particles from the borehole wall through the string.

Based on practical experience gained during drilling operations at analogous fields, a directional (0-80 m interval), conductor (0-450 m), and technical string (0-1500 m) drilling was used and mixed with polymer clay mud with optimisation of its pseudoplastic properties. The solution was uncomplicated to prepare, maintain, and process and had good load-bearing characteristics, which are necessary for quality cleaning of a large diameter bore. In preparation for conductor drilling, drilling fluid in a small amount of ~60 m^3 was prepared, which was replenished with aqueous solutions of high molecular weight polymers upon further drilling. In the preparation of the fluid, API-A modified bentonite clay powder of high quality, designed for the preparation of fresh drilling fluids, was used as an ingredient. The portion of the fluid contaminated during cementing and drilling was disposed of, while the remaining fluid was reprocessed and used as the initial volume upon spudding surface casing and technical string. The main technological solutions were aimed at preserving the well walls under disturbed thermal conditions and ensuring efficient sludge disposal.

Upon conductor drilling and surface casing drilling, the inlet temperature of the drilling fluid was maintained at no more than 10°C to prevent thawing of perennially frozen rock (PFR) and reduce clay hydration. Inhibited drilling fluid was used to further deepen the wellbore. Preparation of the drilling fluid was carried out in the field using available instruments. All necessary chemical reagents for the work were pre-delivered to the drilling site. At the beginning, a clay slurry was prepared and treated with a filtration reducing agent. The remaining chemical reagents were dissolved and introduced into solution in the trough system either individually or together. The drilling fluid was gradually treated with phosphonic acid salt complexone during the enrichment of the drilled rock (Drizhd et al. 2019).

The number of treatments required was determined directly on the drilling platform during analysis. To ensure quality cleaning of drilling mud from the drilled rock, a four-stage cleaning system including vibrating screens, sand separators, sludge separators, and centrifuges should be applied. The rheological characteristics of the drilling fluid were determined according to standard methods on the equipment. The drilling fluid should have been treated with recommended chemicals after a three- or four-stage cleaning process. Based on the technical results of this solution, improvements in the anchoring, lubricity, initial permeability recovery ratio, adhesion and anti-seizing properties of filter cake in water-based drilling fluids containing aqueous fluid were observed. This did not result in the formation of caverns (i.e., a groove-shaped oval) (Tanekeyeva et al. 2023; Tolovkhan et al. 2023).

Once the interval was completed, the maximum amount of mud could be stored and used to drill the next well, or an analogous well in another cluster. A range of major technological solutions were aimed at ensuring the possibility of wiring a long-length (3084-3114 m (3700-4700) horizontal shaft with angles of 87.6-89˚ and avoiding difficulties in opening the pay zone with the shaft (with the length of the horizontal section up to 1000 m)). The nature of interaction of bentonite and clays in sediments underlying the red-coloured strata with complex-inhibited systems ALCAR-1, ALCAR-2, and ALCAR-3 was evaluated in the laboratory. The properties of ALCAR-1 in terms of wetting capacity and fixing properties were compared with those of the lime-potash system and are presented in Table 1.

According to the data of Table 1, it can be concluded that with equal wetting capacity of clays, the fixing properties of ALCAR-1 system are 3.5-4 times higher than the lime-potassium fluid system. Thus, with equal stability, the water yield, and with it the drilling rates, may be greater with ALCAR than with the lime-potash system. A possible explanation for this advantage is that ALCAR contained water-soluble binders extracted from cement in addition to lime and K^+ (albeit in smaller amounts). In contrast to ALCAR-1 and ALCAR-2 systems, the component composition of ALCAR-3 system included chrompik reagent, which enhanced its fastening properties 3 times more than ALCAR-1. This can be judged by the magnitude of moisturising capacity and qualitatively similar properties. The properties of the ALCAR-3 system are investigated and considered from the position of possible use of this system for drilling wells on sediments of the Mesozoic complex.

The Bugdaily area is located in Turkmenistan, a country in Central Asia. This region is characterized by its arid climate and predominantly desert landscape, forming part of the larger Karakum Desert. The area is important for its natural resources and agricultural potential, despite the challenging environmental conditions. The Institute's laboratory analysed three drilling fluid samples taken from drill No. 5 of Bugdaily area and core materials from intervals 2677-2690 m, 2772-2784 m, 2973-2987 m, 3111-3116 m, 3254-3259 m, and 3336-3331 m (Table 2).

Table 1 Properties of fluids.

Solution	Clay moistening rate, 1/h	Strength of samples after exposure to fluids, kg/cm^2
Lime-potassium $Ca(OH)$-0.5-1%+KCL-3%	0.02	1.54-1.7*10^{-3}
ALCAR-1	0.02	6*10^{-3}

Source: compiled by the author of this study.

Table 2 Characterisation of clays from the section of well No. 5 of Bugdaily area.

Coring interval (m)	Visual characterisation	Humidity, (%)	Colloidality coefficient K (by methylene blue)
2677-2690	Clay dark grey, greasy to the touch, layered	5	0.25
2772-2784	-»-	4	0.25
3101-3116	-»-	4	0.22
3326-3331	-»-	5	0.25

Source: compiled by the author of this study.

Based on the data of Table 3, it was found that the clayey rocks in the section of well No. 5 of Bugdaily area had colloidality high enough for deep-lying clays, which indicated a high content of montmorillonites in them. Wetting rate index is close to bentonite. The results of sample analyses on the interaction of ALCAR-3 drilling mud with clayey rocks are presented in Table 3.

According to the data in Table 3, all the submitted fluid samples (No. 1, 2, 3) had a strong inhibitory effect. The most effective of them was sample No. 3, which, depending on the drilling fluid density, provided stable condition of clayey rocks (at pore pressure gradient in the equivalent of the fluid density of 2.4 cm^3) for 90-100 days. The inhibitory effect of sample No. 3 can be further enhanced by the addition of 3% potassium chloride, which helps to reduce the wetting rate index to 0.095 1/h and increases the steady state time to 120-135 days. A longer period of stability is difficult to obtain and the amount of geological and geophysical work in clayey sediments should be minimised. If for some reason it is not possible to ensure the passage of the underlying sediments in 120-130 days, then it is necessary to provide for overlapping of a part of the underlying sediments by the tail pipe.

Table 3 Interaction of ALCAR-3 drilling fluid system with clayey rocks.

Solution	Humidification rate indicator P, 1/h		Steady state time at a pore pressure gradient in solution density equivalent – 2.4 g/cm^3	
	Bentonite K – 0.54	Core from the interval 2677-2690 m, K – 0.25	Mud density during drilling, g/cm^3	Days
No. 1	0.0172	0.0183	2.25	67.5
No. 2	0.0172	0.0183	–	–
No. 3	0.0134	0.0142	2.25	90
No. 3	0.0134	0.0142	2.35	94
No. 3	0.0134	0.0142	2.4	96
No. 3	0.0134	0.0142	2.5	100
No. 3+3% KCL c=2.2 g/cm^3, B=1 cm^3	0.0095	–	2.25	120
No. 3+3% KCL c=2.2 g/cm^3, B=1 cm^3	0.0095	–	2.5	135

Source: compiled by the author of this study.

4 Discussion

Based on the obtained findings it was concluded that the proposed composition of the new inhibited drilling fluid ALCAR showed high inhibiting ability, contributed to slowing down the rate of hydration process (chemical reaction between the fluid and water) and swelling of clay deposits, allowed the mud to prevent, suspend, and promptly reduce the probability of deformation processes occurring in the bottomhole zone.

Oseh et al. (2023) investigated the use of polymer nanocomposites as an additive to drilling fluid. To improve the situation, it was proposed to incorporate the addition of nanocomposites derived from a synergistic combination of polymer and nanoparticles to address the problem of non-uniform and inhomogeneous dispersion in the polymer matrix. When the results of the study were compared, it was found that they were not completely consistent. This is explained by the fact that the study focuses on the inhibitory effect of drilling fluids, while researchers focus on rheological properties and minimising fluid loss. Saleh and Nur (2023) conducted a thermogravimetric analysis to reveal the thermal stability of graphene nanosheet materials with grafted polymer acting as a water-based drilling fluid inhibitor. Based on the observations made, the results showed that graphene with polymer can be in a stable state up to a temperature of 240°C. It was found that the developed graphene with grafted polymer was more effective than pure polymer and potassium chloride inhibitor (KCl), as graphene nanosheets have better ability to resist the penetration of water and drilling fluid into the reservoir. The results of the study revealed differences conditioned by the fact that the analyses conducted do not factor in the use of graphene, which was a major component in this work.

Tchameni et al. (2023) presented the development of a new thermosensitive Janus nanosilica, exhibiting zwitter-ionic nature, as a shale stabiliser at hot temperatures. As a result, the developed thermosensitive nanosilica Janus showed favourable colloidal stability and considerably improved the stability of shale formation during drilling operations. To obtain attractive characteristics of thermosensitive Janus nanosilica in drilling practice, it is recommended to maintain a pH value of about 8 in the solution in an alkaline environment (Shirin et al. 2011). The following inconsistencies were identified: the research conducted focuses on the chemical composition of drilling fluids and their effect on clayey rocks. While the scientists' research focuses on using the new nanosilica to improve various characteristics of drilling fluids. Mohamed et al. (2021) demonstrated the efficacy of laponite, a synthetic clay, in preventing drilling fluid sagging with barite in vertical and directional wells at high temperatures. They found that adding laponite improved fluid stability by reducing static and dynamic deflection, enhancing filtration properties, and minimizing formation damage, reducing total filtrate by 15% and filter cake thickness by 20% (Kondrat et al. 2023; Koroviaka et al. 2023). While both studies address fluid sagging, they employ different approaches and materials (synthetic clay vs. ALCAR systems). Nonetheless, they both conclude that the addition of materials mitigates fluid sagging, albeit with variations in methodology and materials. Thus, these findings complement and expand current knowledge in the field, without direct overlap with the referenced study.

Basfar et al. (2020) evaluated the effectiveness of a mixture of barite and manganese tetraoxide (Micromax), which is used to eliminate the problem of solids settling that occurs when using drilling muds based on weighted invert emulsion. The results of the study show that Micromax additive improves the stability of drilling fluid by reducing its tendency to settle. The addition of 30% Micromax additive increased base fluid density by 5.4%, increased yield strength by 115%, maintained gel strength at 12 lb/100 ft^2 and reduced viscosity by 30%. The findings of both studies converge in some respects, such as improved drilling fluid stability and filtration efficiency. However, a comparison of the present study with scientific research by scientists showed that the results differed depending on the components and systems used and the specific characteristics of the drilling fluids. Ofei et al. (2020) presented a barite subsidence measurement method to investigate the effect of rheological and viscoelastic properties of typical oil-based drilling fluids. The deflection of barite in an oil-based drilling fluid sample before and after hot rolling was investigated. The use of chemicals activated by heating in the hot rolling fluid sample increased the viscosity and elasticity and reduced the tendency of barite to sag compared to the pre-hot rolling sample. The results do not contradict the researchers' findings; rather, they are complementary. Their study focuses on the physico-chemical properties of drilling fluids and their effect on barite sagging, while the study conducted goes more in-depth to describe the effect of inhibitory additives on clay rock stability (Zhumadiluli et al. 2018).

Ibrahim et al. (2022) reviewed the studies on the use of nanoparticles in drilling fluids in terms of filtration and reservoir damage. As a result of the conducted research, it was found that carbon nanoparticles make it possible to maintain the homogeneity of drilling fluid composition for a long time, to control the density of drilling fluid, to increase the level of its thermal stability. The studies differ in the following aspects: the study of the scientists addresses the importance of parameters such as size, concentration, type, and surface properties of nanoparticles in controlling the filtration of drilling fluid, whereas the present study conducted focuses on the characteristics of ALCAR-3 drilling fluid and its effect on clayey rocks. Dutta and Das (2021) presented a bentonite drilling fluid formulation using iron oxide nanoparticles as the only additive to replace other commercial additives. Nanobase has not been applied in the reservoirs of the upper Assam basin (north-east India) till date due to economic factors and impracticability of its application in the near future. The analysis results show that a small amount of iron oxide nanoparticles is highly effective in improving the rheology of the nanobase (Dzhalalov et al. 2021). The studies differ in the nanoparticle synthesis methods used and the particular additives to the solutions. This study emphasises the effectiveness of the ALCAR-3 system with potassium chloride supplementation, while the scientists' study focuses on the use of iron oxide nanoparticles.

Alam et al. (2021) investigated the influence of iron oxide nanoparticles (Fe_2O_3) on the properties of solutions used in field and laboratory conditions. The results show that the drilling fluid used in the field compared to the fluid prepared in the laboratory with 0.1% nanoparticles concentration showed higher viscosity, yield strength (1.61%), 100% gel strength after 10 s and 133.33% gel strength after 10 min. Both studies consider the use of nanoparticles in drilling fluids, but with different approaches. The presented study does not focus strictly on nanoparticles but discusses ALCAR systems and their efficacy. The findings of this study and the results of the scientists' research do not contradict each other. Instead, they provide additional data on various aspects of the borehole wall stability problem during drilling. Basfar et al. (2020a) investigated the degree of influence of synthetic water-based layered silicate on rheology. Furthermore, high pressure and high temperature filtration tests were also conducted to determine the filtration crust thickness and filtration volume (Moldabayeva et al. 2021). According to the results of this experiment, it was concluded that after the addition of 0.75 lb/bbl of layered silicate, the deflection coefficient in vertical and inclined positions decreased from 0.569 to 0.502 and from 0.58 to 0.51 to the 45º index. The researchers' results confirm the effectiveness of synthetic layered silicate, whereas the present study suggests an alternative approach using ALCAR-3 system and potassium chloride. Misbah et al. (2023) studied the effect of different temperatures on the stable state of the used polymer types during drilling with water-based drilling fluid. Two types of drilling fluid thickeners (Flowzan – type A and xanthan gum – type B) with different concentrations of potassium chloride were developed during the study. The presented data suggests that at 250˚F, the viscosity of polymer A increased by 87%, 100%, and 120% with potassium chloride concentrations of 3%, 5%, and 7%. As for polymer B, its viscosity improved by 118%, 112%, and 106% at 200 ºF. The findings of this study are related to the stability of clay rocks, while the researchers investigated the rheological properties of drilling fluid at different temperatures.

Rasool and Ahmad (2023) conducted an in-depth investigation of the synthesis and use of natural deep eutectic solvents based on potassium chloride as an additive in drilling fluid for studies on shale stabilisation and improvement of drilling fluid properties. The results showed that the natural potassium chloride-glycerol-based deep eutectic solvent formed a stable eutectic mixture at 1:8 ratio, 100 rpm and 60°C, with low acidity and stability up to 200°C. Optimal concentration of 3% potassium chloride – glycerol based on eutectic solvents increases the efficiency of drilling fluids by improving their rheological and filtration properties. Potassium chloride-based eutectic solvents have been recommended as a potential shale inhibitor (Metaksa, Moldabaeva and & Alisheva 2018). The results and methods of the researchers' study and the present study have some differences and complement each other. The findings of this study focus on the ALKAR-3 system and its interaction with clay rocks, while the scientists' research addresses the use of eutectic solvents based on potassium chloride and glycerol. Uduba et al. (2023) conducted an analysis to determine the effect of salinity on the rheological properties of sludge that was prepared with the addition of carboxylmethylcellulose and conventional polyanionic cellulose. The results show that as the salinity of the drilling fluid increases, the efficiency of the polymer decreases. The studies complement each other, as the development undertaken confirms the significance of inhibiting fluids for well wall stability, while the scientists' research highlights the effects of salinity and temperature on the rheological properties of drilling fluids.

Thus, the section conducted a literature review and reviewed the research on the application of polymer nanocomposites as an additive to drilling fluid, research on production methods used in synthesis of synthetic polymers, classification, and application of synthetic polymers in drilling fluids, presented the development of a new heat sensitive nanosilica Janus, research on the effectiveness of synthetic laponite clay.

5 Conclusions

In the conducted study, the development of formulation of inhibited systems – alumocalcium solution (ALCAR) for conducting wells in clayey sediments for fields with complex mining and geological conditions of South-West Turkmenistan was carried out. The analysis of the results of studies on the development of drilling fluid formulation for drilling directional and horizontal wells in complicated drilling conditions allowed to note that all three submitted samples of solutions had a strong inhibitory effect. The highest efficiency was shown by the sample No. 3, which, depending on the drilling fluid density, provided stable condition of clayey rocks (at pore pressure gradient in the equivalent of the fluid density of 2.4 cm^3) for 90-100 days. Notably, the inhibitory effect of sample No. 3 can be enhanced by the addition of 3% potassium chloride, which contributes to the reduction of the wetting rate index to 0.095 1/h and increases the stability time of the state to 120-135 days.

During the construction of exploration and production wells in the southwestern part of Turkmenistan, the inhibited ALCAR solution successfully passed industrial tests and was fully implemented. The use of ALCAR-1 and ALCAR-3 in complicated drilling conditions increased clay stability, conserved chemical reagents, and maintained optimal properties of the solution. This enabled the successful construction of wells over 3000 meters deep with horizontal completions in areas with unstable clays and shales. The solution improved fixing, lubricating, and anti-seizing properties, enhanced formation permeability recovery, and increased the stability of wellbores.

The main areas for further research in this industry in Turkmenistan may be the development and introduction of a magnetic treatment device, which will help to improve drilling fluid parameters and save chemical reagents. The device consists of a PVC pipe, reflectors, and a set of U-shaped permanent magnets. The solution is magnetised as it passes through the device in a closed loop wash cycle. The effectiveness of the innovation is proved by the fact that during the treatment of drilling fluid there is a reduction in water yield by 2 and more times and an increase in viscosity by 13% due to the use of magnetic treatment method.

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Author contributions

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

Conflict of interest

The author declares no conflict of interest.

Data availability statement

All data included in this study are publicly available in the literature.

Funding information

Not applicable.

How to cite:

Deryaev, A. 2024, 'Inhibited Solutions for Wells in Complicated Geological Conditions in the Areas of South-Western Turkmenistan' *Anuário do Instituto de Geociências,* 47:62860. https://doi.org/10.11137/1982-3908_2024_47_62860