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APPLICATION OF NANOSTRUCTURED SYSTEMS IN THE ISOLATION OF LOST CIRCULATION ZONES

G. Sh. Asadova

Azerbaijan State Oil and Industry University, Baku, Azerbaijan

A B S T R A C T

This article is devoted to the development of improved drilling fluid formulations designed to combat complications encountered during deep well drilling. One of the key problems under such conditions is the presence of lost circulation zones, which lead to wellbore instability, sticking of drilling tools, and significant technological and material losses. The composition and properties of drilling fluids play a major role in this process. However, despite numerous studies, issues related to sealing properties still require experimental investigation of the isolating capacity of drilling fluids. Based on this, the article presents the results of experimental studies on changes in the resistance factor as a parameter characterizing the sealing properties of the fluid. During the research, the fundamental principles of experimental design theory were applied, along with statistical data processing methods to determine the significance of key factors and to model individual processes through calculations based on data analysis. In particular, correlation analysis using specialized software made it possible to study patterns occurring during the regulation of the composition and properties of drilling fluids and chemical reagents used to enhance wellbore stability and integrity during drilling. Laboratory tests were conducted, and sediment-gel-forming compositions based on metallic and organic clusters and polymers were proposed to combat circulation losses. Experimental dependencies of the sealing capacity of the studied compositions on the concentration of these particles, polymer content, and medium permeability were obtained, enabling the selection of optimal combinations to achieve maximum efficiency in isolating loss zones.

Keywords: nanotechnology; drilling fluid; lost circulation; wellbore stability; reservoir isolation.

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1. Introduction

Drilling production wells in conditions of a complex geological section structure is one of the most scientifically intensive and critically important tasks in the modern oil and gas industry. This is especially true for wells drilled through unstable clay formations with water-sensitive and deformable properties. Such formations are widespread in both onshore and offshore geological settings and are often the cause of serious complications, including wellbore instability, drilling fluid losses, sticking of drilling tools, and destruction of the cement sheath. In offshore operations, additional complicating factors include downhole conditions – pressure and temperature in these zones are significantly higher than in conventional intervals, and the physico-mechanical properties of formations may change sharply over short vertical distances [1-3]. Geomechanical heterogeneity and geological uncertainty of the formation further amplify the risks of accidents and non-standard situations. A particular threat in these conditions is posed by clay strata, which are capable of active water absorption, swelling, and destruction of their crystalline structure upon contact with the aqueous phase of drilling fluids. As a result of such interactions, significant changes occur in the physico-mechanical properties of the rock – it loses strength, becomes unstable, and prone to deformation and failure [4, 3]. In this regard, the problem of improving well construction quality by ensuring borehole stability and integrity, as well as the study and application of new compositions for drilling fluid treatment, remains highly relevant and continues to be an important research and industry priority.

2. Current state of research on improving drilling fluid compositions for complicated conditions

As noted above, the justification of the required composition and properties of drilling fluids plays an important role in the process of drilling wells under complicated conditions. To date, a large number of studies have been accumulated proposing drilling fluid formulations based on modern technologies; however, despite this, complications still occur during deep drilling. These require improvement of existing technologies, taking into account both the lithological-reservoir properties and the thermobaric characteristics of the geological sections of drilling areas. Formations at great depths, characterized by abnormal (low and high) formation (pore) pressures, have a number of specific features. In particular, in Azerbaijan, Kazakhstan, and some regions of Russia, unstable clay deposits in the geological section

****E-mail:*** gulshan.asadova@asoiu.edu.az
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are highly hydrophilic. As a result, when in contact with the aqueous phase of drilling fluid, they swell under the influence of hydrostatic pressure, 18% of hydrodynamic pressure, and 74% of physicochemical processes occurring in the annular space [5]. In recent years, the widespread use of hydrocarbon-based drilling fluids as well as emulsion drilling fluids has shown several advantages compared to previously used technologies [5]. The use of hydrocarbon-based fluids such as oil, diesel fuel, emulsions, etc., as drilling mud requires solving complex environmental and technological problems related to their neutralization. To address this issue, several studies propose technological schemes for reinjecting drilling cuttings into the formation, finding ways to reuse treated water for technical purposes, and using economically efficient, environmentally safe, non-toxic, and non-flammable hydrocarbon compounds for drilling fluid preparation. Recently, synthetic hydrocarbon-based drilling fluids have also been used. Companies propose various synthetic drilling fluid systems, including: Ecogreen – a system based on esters; Paraland – an environmentally friendly non-aqueous system for improved drilling performance; Nova systems – environmentally safe alternatives to conventional drilling fluids; Rheliant – a non-aqueous system with flat rheology that reduces costs associated with the loss of expensive fluids. "Baker Hughes Drilling Fluids" offers the SYN-TEQ CF drilling fluid. This fluid is recommended for deepwater drilling and also shows optimal performance in offshore operations. The ENCORE fluid from Baroid Drilling Fluids is based on a high-performance isomerized olefin, while INNOVERT™ is a drilling fluid based on liquid paraffins or mineral oils. ANCO-2000 is a highly inhibitive system based on Polyvis-2; it is a non-toxic, synthetic, biodegradable hydrocarbon-based drilling fluid. Synthetic-based drilling fluids are widely used in Norway, Germany, and other countries due to strict environmental regulations. These fluids are particularly suitable for highly deviated wells because they do not affect clay rocks, which are prone to swelling, plastic deformation, and brittle failure upon contact with water. The main limitation of synthetic-based drilling fluids (SBDF) is temperature; most fluids have an upper limit of approximately 176 °C.

In the 1970s, potassium-based drilling fluids began to be used and continue to be improved. These fluids have a more effective inhibiting effect on clay formations, especially montmorillonite and hydromica [6]. Since potassium chloride (KCl) is inexpensive and widely available, potassium-based drilling fluids are widely used worldwide for unstable clay formations. In recent years, oil companies have successfully used potassium chloride polymer clay and non-clay drilling fluids. These fluids contain thickeners, various polymer modifications, and pre-hydrated bentonite. Their action is based on three principles: inhibition of clay hydration, low solid content, and polymer coating effects [7]. In the cited work and other studies, authors attempt to explain the mechanism and physicochemical nature of polymer-potassium fluids on rock stability. High-molecular copolymers of acrylamide and sodium acrylate are usually used at concentrations of 0.15-0.215 % by volume. Studies show that, to ensure stabilization of clay formations, the volumetric fraction of polymers in potassium chloride polymer fluids should be minimal. However, the following conclusions were made [4]: anionic polymers effectively protect wellbore walls composed of shale at low temperatures; cationic polymers do not stabilize them; nonionic polymers at sufficiently high concentrations help maintain clay stability. Stabilization of clay formations is explained by the anionic nature of the polymer and its low effective concentration, which causes adsorption not over the entire clay surface but only on positively charged sites. The adsorption process in shale is accelerated in the presence of potassium chloride at concentrations above 2%. Polyacrylamide-potassium chloride drilling fluids are affected by multivalent cations, which deteriorate fluid properties and reduce efficiency. At VNIIKRneft, long-term studies of drilling and cementing fluids were conducted. In particular, an alumina–potassium-based fluid was developed, providing inhibition of non-hydrated clay formations at temperatures of 150-200 °C. This is explained by dual inhibition from potassium and aluminum ions. Potassium ions prevent water penetration into the interlayer space of clay minerals, while aluminum hydroxide adsorption increases bound water content, forming stronger protective layers. All these fluids have a high solid content, which deteriorates reservoir properties, reduces rate of penetration, and increases overall drilling costs. Therefore, nondispersive and low-solid-content drilling fluids have recently become more widely used. To prevent swelling and dispersion of clay minerals, polymers and soluble salts are used. At VNIIBT, reagents such as polyacrylamide, metas, and methyl methacrylate were proposed. The polymer binds clay particles and slows osmotic processes. When rock particles enter a polymer solution, they become coated and do not disperse, reducing solids content and increasing penetration rate. In terms of rock interaction mechanism, polymer fluids are comparable to oil-based drilling fluids. In polymer systems based on complex reagents containing two or more polymers, some act as flocculants while others act as stabilizers. Researchers proposed treating polymer-clay fluids with complexing agents (complexones – organic compounds forming complexes with metal ions) such as NTF and $Al_2(SO_4)_3$ to regulate structural and mechanical properties [8-10].

Laboratory studies [1] showed that polymer protection alone is insufficient to prevent swelling; therefore, soluble salts, especially potassium chloride (KCl), must be present to reduce dispersion of clay particles.

Studies [2, 3] indicate that inhibition can also be achieved using hydrolyzed polyacrylamide (HPAA), while potassium salts have no significant effect on preventing hydration and dispersion of clays. Polymer non-clay drilling fluids are water-based systems containing polymer additives that improve rheological and hydrodynamic properties. They are mainly applied in stable formations with minor clay interbeds, while polymer-salt non-clay fluids can be used for weakly plastic clay formations. The use of polymer systems helps maintain wellbore stability; however, this is not always possible due to the intrinsic stabilization mechanisms of clays. Currently, leading companies increasingly use polysaccharide-based polymer fluids (biopolymers such as polyanionic cellulose and modified starch), which have strong inhibiting properties and colmatating acid- or water-soluble solid phases. For example, in 1991, M-I Drilling Fluids Co. tested the Flo-Pro mud in Alaska for horizontal and highly deviated wells [11]. Its inhibiting ability and compatibility with formation fluids are maintained through NaCl, KCl, NaBr, and other salts.

NPO "Drilling" developed highly inhibitive systems such as RAGIPOL (a solids-free gel-based fluid) and RINPOLIS (a polysaccharide-based fluid containing surfactants, mineral salts, and complexing agents). The choice of inhibiting fluid depends on clay occurrence conditions and company capabilities. The problem of isolating lost circulation zones can be addressed through nanotechnology-based approaches [12-16], requiring nanostructured systems and investigation of their behavior in porous media. This enables better control of drilling in complex conditions and improves efficiency. A supramolecular catalytic system based on metallic and organic clusters was developed [14, 17], capable of transport into the formation via hydrophobic macrocyclic receptors. Recent studies [1, 15, 16] using metal nanoparticles demonstrated effects allowing control of tribological properties of drilling fluids [1]. Experimental studies were also conducted to evaluate the effect of nanoparticles on inhibiting properties of water-based fluids. Our experiments investigated the ability of the nanostructure developed in [14, 17] to modify permeability for water shutoff and loss circulation control. Thus, the literature review shows that unstable formations are a key feature of most studied fields. This necessitates chemical treatment and often weighting of drilling fluids, which negatively affects penetration rate and field development efficiency. Therefore, proper selection of fluid density requires a comprehensive geological analysis and drilling parameter evaluation. The analysis of literature allowed formulation of research objectives and methodological principles.

3. Materials and methods

The aim of this study was to determine the relationship between medium permeability and the required nanoparticle concentration that ensures the maximum residual resistance factor. A porous medium with permeability allowing flow of an aqueous solution containing metallic nanoparticles was considered. A solution with nanostructure concentration of 2-10% in fresh water was used. The solution was injected into the porous medium in a volume equal to one pore volume. Experiments were conducted on a packed core model filled with a mixture of crushed quartz sand and clay. Required permeabilities were created by varying clay content (5, 10, 15 and 20 %) in quartz sand. The use of nanotechnology in drilling fluids and lost circulation control systems represents a significant advancement in drilling efficiency and reliability [18-20]. Such technologies require interdisciplinary approaches including geomechanics, chemistry, nanophysics, and materials engineering. A laboratory porous medium model with variable permeability was used. The model consisted of a compacted cylindrical cell filled with sand-clay mixtures. Permeability was controlled by adjusting clay mass fraction (5 %, 10 %, 15 %, 20 %). Effective permeability was measured using Darcy's method before and after fluid injection. Fluids were suspensions of nanostructured systems with active phase concentrations of 2-10 % by mass. Injection volume corresponded to one pore volume.

4. Experimental studies of the effect of nanostructured system on porous medium permeability

A water-based nanostructured system was developed, containing metallic and organic clusters, including Fe_3O_4 – β-cyclodextrin systems. The system is capable of targeted transport through pore spaces due to hydrophobic cavities in macrocyclic receptors which enable selective encapsulation. The system structure is formed by non-covalent interactions such as hydrogen bonding, π–π stacking, van der Waals forces, and coordination bonds. This ensures stability in aqueous media and reversible interaction with porous media components. The main objective was to study the effect of the nanostructured system on filtration and reservoir properties, including permeability reduction. The experimental results show a significant decrease in permeability, especially in models with higher clay content. This is attributed to enhanced binding of nanoclusters to mineral surfaces, leading to partial pore blocking and formation of temporary isolation barriers. The relationship between clay content and permeability is shown in figure 1. The results also confirmed a reduction in displaced fluid volume, indicating potential application for water shutoff operations. Further research will focus on optimizing system composition for specific field conditions.

5. Processing and discussion of results

Experimental studies were carried out on samples of porous media with gradually decreasing initial permeability in order to comprehensively investigate the relationship between permeability and the nanoparticle concentration required for effective pore blockage. In particular, for a sample with an initial permeability of 1.46 μm², the maximum tested nanoparticle concentration was 9% by mass. This limitation arose because at a concentration of 10%, a significant reduction in filtration rate was observed, up to almost complete pore blockage, which prevented further flow of the solution through the medium and halted testing at this concentration level. This phenomenon clearly demonstrates the high blocking capacity of the system at relatively moderate nanoparticle loadings.

For the sample with a permeability of 1.176 μm², experimental tests were conducted up to a maximum nanoparticle concentration of 8%. Beyond this value, the suspension began to lose fluidity and mobility, indicating unfavorable rheological properties of the solution for injection and creating practical limitations on achievable concentrations. This highlights the relationship between nanoparticle concentration and flow dynamics in a porous medium.

With a further decrease in permeability to 0.547 μm², the minimum nanoparticle concentration that ensured a significant increase in the residual resistance factor (R_{ost}) was

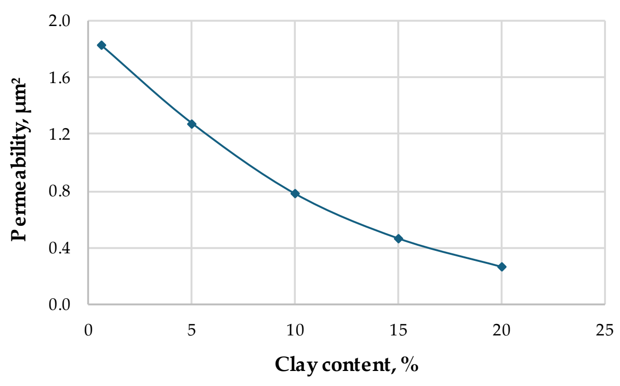

Fig. 1. Dependence of the permeability of a porous medium on the clay content

Table

Values of residual resistance factor, success coefficient, and permeability corresponding to various combinations of particle concentration and initial medium permeability

C, % / K_{before}, μm²	2	3	4	5	6	7	8	9	10
1.8	1.2	1.38	1.5	1.89	2	2.2	2.57	3	**3.214**
	16.67	27.78	33.33	47.22	50	55	61.11	66.67	**68.89**
	1.5	1.3	1.2	0.95	0.9	0.81	0.7	0.6	**0.56**
1.46	1.46	1.72	2.85	2.25	2.52	2.92	3.65	**4.17**	
	31.51	41.78	52.05	55.48	60.28	65.75	72.6	**76.03**	
	1	0.85	0.7	0.65	0.58	0.5	0.4	**0.35**	
1.176	1.4	1.84	2.35	2.94	3.36	5.11	**6.18**		
	28.57	45.58	57.48	65.99	70.24	80.44	**83.84**		
	0.84	0.64	0.5	0.4	0.35	0.23	**0.19**		
0.547	1.76	5.11	9.94	**15.63**					
	43.33	80.44	89.95	**93.6**					
	0.31	0.107	0.055	**0.035**					
0.447	3.725	8.94	**22.35**						

6%. It is particularly noteworthy that for the sample with the lowest tested permeability—0.447 *μm²*—a substantial blocking effect was achieved at a concentration of only 4%. This indicates an inverse relationship between initial permeability and the nanoparticle loading required to achieve optimal blocking performance.

The summarized data, systematically presented in table, demonstrate a clear and consistent trend: as the initial permeability of the porous medium decreases, the required concentration of nanosuspension to achieve the maximum residual resistance factor also decreases. This pattern highlights the increased efficiency of the supramolecular nanostructured system in selectively targeting low-permeability zones with reduced material consumption.

The obtained results confirm the high selectivity and adaptability of the developed supramolecular catalytic nanostructured system, which operates through mechanisms specific to the pore-scale environment of the reservoir. The controllable blocking efficiency of this system opens up prospects for its application as a controlled isolation agent, especially in heterogeneous reservoirs with pronounced permeability contrasts. Such capabilities are critically important for optimizing fluid flow control, limiting unwanted water influx, and enhancing oil recovery.

Further research is planned to optimize the composition and injection parameters of the nanostructured system in order to maximize its efficiency under various lithological and operational conditions, thereby expanding the applicability of this technology to a wide range of reservoirs.

As can be seen from table 1 and figure 2, with an increase in the concentration of the nanostructure in the solution, the permeability of the porous medium decreases for all values of initial permeability. Moreover, the lower the initial permeability, the stronger the reduction effect after treatment with the nanostructured solution.

The treatment efficiency was evaluated using two key indicators:

- Residual resistance factor (R_{res}) – the ratio of permeability before and after treatment with nanoparticles, reflecting the degree of reduction in the filtration capacity of the medium.

- Isolation coefficient (W) – the proportion of experiments that resulted in achieving the target permeability reduction without structural damage to the medium or breakthrough of the solution.

Based on the obtained data, a clear correlation was established between the initial permeability of the porous medium and the required concentration of nanoparticles. The higher the initial permeability of the model, the greater the nanoparticle concentration required to effectively reduce permeability. This is explained by the fact that more permeable reservoirs contain a larger volume of free pore space that must be filled to achieve sufficient flow resistance.

The experimental results clearly demonstrate the high efficiency of using nanostructured systems as isolation agents. Due to their ability to penetrate reservoir pores, form spatial structures, and adapt to the geometry of the pore space, these systems provide reliable permeability reduction even under complex geological conditions. Thus, nanotechnology represents a promising direction for developing modern drilling solutions aimed at minimizing losses and improving process stability.

6. Correlation analysis of experimental results

To quantitatively evaluate the effectiveness of nanostructured systems on the permeability of porous media, a correlation analysis of the obtained experimental data was carried out. As a key parameter characterizing changes in the filtration properties of the medium after treatment, the residual resistance factor (R_{ost}) was selected, which represents the ratio of permeability before and after the injection of nanostructures. It is calculated using the following formula [2]:

$$R_{res} = \frac{K_{before}}{K_{after}} \tag{1}$$

where:

K_{before} and K_{after} are the permeability values of the porous medium before and after nanostructure treatment, respectively.

The higher the value of R_{res}, the more effective the permeability reduction is considered, as this indicates a significant hindrance to filtration through the porous medium model after the introduction of nanoparticles.

Based on the values of R_{res}, the isolation coefficient (W) was also calculated, which shows the relative reduction in permeability as a percentage:

$$W = \frac{K_{before} - K_{after}}{K_{before}} \times 100\% \qquad (2)$$

The coefficient W allows the efficiency to be visualized as a percentage and serves as a convenient parameter for comparing different concentrations and treatment conditions [21-24]. Based on the obtained experimental data, the values of R_{ost} and W were calculated and are presented in table 1. Analysis of the results showed that with an increase in nanoparticle concentration in the solution, a consistent decrease in the permeability of the porous medium is observed for all studied initial permeability values. A particularly pronounced effect was observed in the case of low initial permeability (0.547 and 0.447 µm²), where nearly complete blockage of the pore structure occurred already at nanoparticle concentrations in the range of 5-6 %. This indicates a high sensitivity of low-permeability media to the introduction of nanostructured systems. The graphical representation of the dependence of permeability on nanoparticle concentration under different initial conditions made it possible to identify patterns and optimal application ranges. The data are presented in figure 2, where a clear trend of exponential decrease in permeability with increasing concentration of nanomaterials can be observed. Thus, the conducted correlation analysis confirmed that:

- the blocking efficiency directly depends on the initial permeability of the medium;
- there exists an optimal concentration range for each permeability value, beyond which complete blockage occurs, making further measurements impossible;
- the residual resistance factor is a reliable indicator of structural changes in the pore space under the influence of nanostructures. These results can be used in the development of engineering methodologies for selecting drilling fluid compositions, taking into account geological characteristics of the formation and target filtration parameters.

The dependence of the residual resistance factor on nanoparticle concentration for the initial permeability values is illustrated in figure 3.

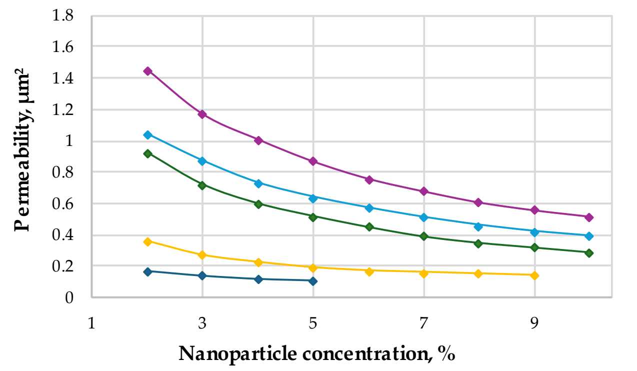

Fig. 2. Dependence of medium permeability on nanoparticle concentration at initial permeability: 1 - 1.8 µm²; 2 - 1.46 µm²; 3 - 1.176 µm²; 4 - 0.547 µm²; 5 - 0.447 µm²

Correlation analysis of the relationship between initial permeability and the required nanoparticle concentration

Within the framework of the conducted study, a correlation curve was constructed describing the quantitative relationship between the initial permeability of the porous medium (K_{pr}) and the required nanoparticle concentration (C) to achieve effective isolation. This relationship was approximated by the following empirical equation:

$$C = 7.0357 \cdot K_{pr}^{0.6426}$$

where:

C – optimal nanoparticle concentration, % of pore volume;

K_{pr} – initial permeability of the medium, µm².

The obtained expression indicates a non-linear nature of the relationship: as permeability increases, a greater amount of nanoparticles is required to achieve the blocking effect; however, the growth in concentration occurs at a decreasing rate (the exponent is less than 1). This means that for low-permeability media, even a slight increase in concentration can lead to complete blockage, whereas more permeable media require carefully selected dosing.

Figure 4 presents a graphical interpretation of the obtained relationship. It can be seen that at low values of K_{pr} (for example, 0.447-0.6 µm²), isolation is achieved at concentrations of about 4-6 %. At the same time, for permeabilities above 1.2 µm², 7-10 % of nanoparticles are required to achieve a comparable effect. The reduction in

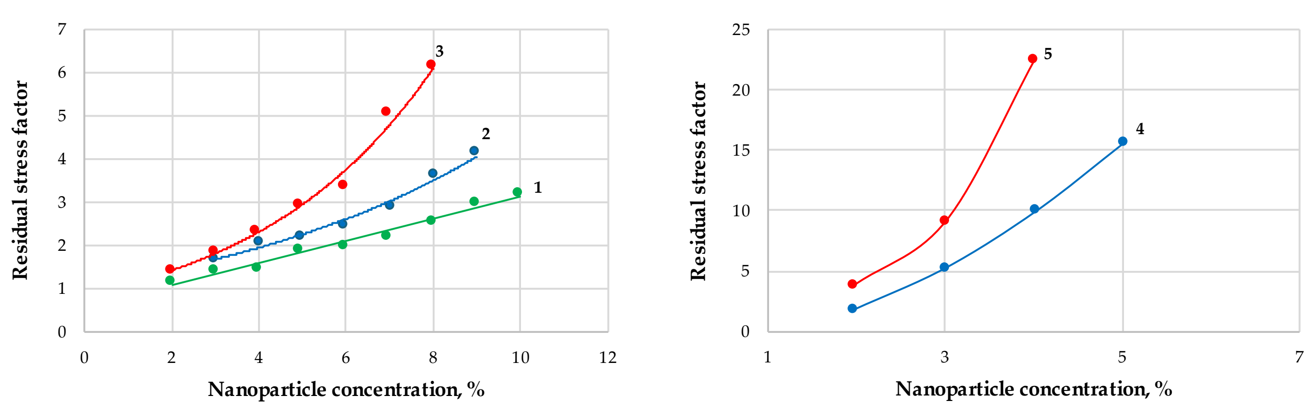

Fig. 3. Dependence of the residual resistance factor on nanoparticle concentration at initial permeability: 1 - 1.8 µm²; 2 - 1.46 µm²; 3 - 1.176 µm²; 4 - 0.547 µm²; 5 - 0.447 µm²

nanoparticle concentration required for effective isolation in low-permeability media can be explained by the following factors: smaller pore sizes, which facilitate blockage even with a small number of nanoparticles; increased capillary forces that retain nanoparticles within narrow pores; and enhanced adsorption interactions between nanoparticles and rock minerals, improving sealing efficiency. Conversely, in highly permeable media, a larger amount of nanoparticles is required to form stable aggregates and restrict filtration through larger channels. This curve is an important tool for engineering calculations because it:

- allows prediction of the required concentration of nanostructured agents depending on the filtration properties of the rock;
- reduces the risk of reagent overconsumption or incomplete blockage in cases of incorrectly specified parameters;
- contributes to the optimization of technological processes during isolation operations in wells and modeling of loss zones. Thus, the presented relationship emphasizes the critical importance of a tailored approach when selecting nanoparticle concentration depending on the geophysical characteristics of the medium. This is especially relevant for offshore and hard-to-recover reservoirs, where the effectiveness of lost circulation control directly impacts the cost and safety of drilling operations.

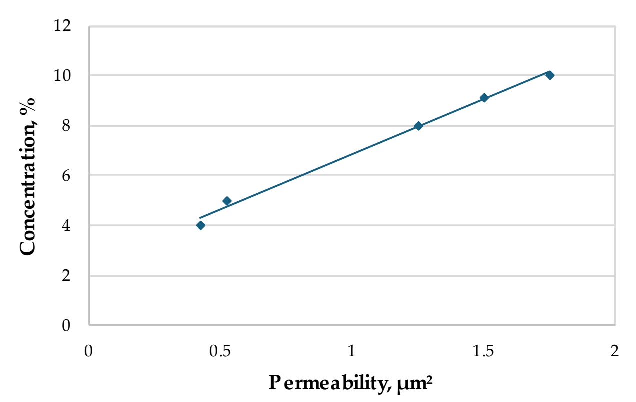

Fig. 4. Correlation between initial medium permeability and the required nanoparticle concentration

Analysis of the influence of porous medium permeability on required nanoparticle concentration

Analysis of the graphical data presented in Figure 4 allows drawing important conclusions regarding the relationship between the initial permeability of the medium and the required nanoparticle concentration to achieve an effective isolation effect.

The observed relationship shows that as permeability decreases, a lower concentration of nanostructures is required to achieve the desired reduction in filtration properties. This can be explained by the following factors:

1. The pore and channel sizes in low-permeability media are significantly smaller than in highly permeable ones. Therefore, even a small amount of nanoparticles (e.g., 4-5 % of pore volume) can significantly reduce permeability by blocking critical flow paths.
2. The reduction of the hydrodynamic pore radius occurs faster in compact structures, since nanoparticles interacting with clay and quartz components of the rock can form aggregates that effectively block fine capillaries and disrupt flow continuity.
3. In addition, low-permeability reservoirs are dominated by fine pores with a high proportion of wetted surface, which enhances adsorption interaction between nanoparticles and rock minerals, increasing plugging efficiency even at low concentrations.

In contrast, high-permeability media are characterized by larger pore structures, where wide channels require higher nanoparticle concentrations (up to 9-10 % of pore volume) to form stable blockages and limit water or drilling fluid filtration. Otherwise, the suspension passes through large pores without forming sufficient plugging points.

The conducted correlation analysis confirmed the dependence of blocking efficiency on the initial permeability of the medium and made it possible to obtain an empirical relationship for predicting the optimal nanoparticle concentration.

Thus, it can be stated that the effectiveness of the isolation effect of nanostructures is largely determined by the scale and geometry of the pore space. Therefore, the selection of the optimal nanoparticle concentration should be based on a preliminary determination of the filtration properties of the medium and an accurate assessment of its permeability.

The results of the study can be used to develop protocols for selecting nanoparticle concentrations for different types of reservoirs, which will reduce the risk of incomplete blockage or reagent overconsumption. Further research will focus on studying the influence of other factors (mineral composition of the rock, temperature, pressure) on the efficiency of nanostructured systems for isolating loss zones.

This conclusion emphasizes the importance of preliminary laboratory experiments and correlation analysis, on the basis of which maps of optimal nanoparticle concentrations depending on geophysical reservoir conditions can be developed. Such data are especially important when drilling in complex geological formations and offshore fields, where the possibilities for adjusting the composition of the injected system during operations are limited.

Conclusions

1. The conducted experimental studies confirmed the effectiveness of supramolecular nanostructured systems for isolating loss zones under conditions of reduced permeability and heterogeneity of the model porous medium. It was established that the formation of stable nanoparticle plugs in micropores leads to a reduction in filtration losses, which potentially contributes to improved wellbore stability and maintenance of hydrostatic balance.
2. As a result of laboratory experiments, optimal ranges of nanoparticle concentrations required for effective isolation of loss zones depending on the permeability of the model porous medium were determined. A correlation between initial permeability and required nanostructure concentration was identified, enabling targeted selection of suspension compositions for specific geological and technical conditions.

3. Despite the obtained results, fundamental and applied studies remain relevant, aimed at:

- evaluating the long-term stability and compatibility of nanostructures with drilling fluid components;
- studying the mechanisms of aggregation, sedimentation, and redispersion of nanoparticles in pore space;
- investigating the influence of nanomaterials on rheological, colloidal, and filtration properties of drilling systems under various thermobaric conditions;
- analyzing nanoparticle behavior under conditions simulating real reservoirs (high temperature, salinity, presence of organic matter).

4. The development of nanotechnology appears to be a promising direction for improving the reliability and economic efficiency of drilling and production operations, especially in complex geological conditions, including offshore fields. Further research in this area will enable the development and implementation of new technologies aimed at optimizing drilling processes and enhancing oil recovery.

References

1. Limanovsky, V. M., Masyukova, N. A., Garyan, S. A., et al. (1985). Studies on the effectiveness of complexing agents in drilling fluids. *Oil Industry*, 12, 17–18.

2. Sidorov, N. A. (1982). Polymer drilling fluids. Oilfield Engineering and Technology Series, 18, 1-84.

3. Gray, J., Darley, G. S. G. (1985). Composition and properties of drilling fluids: a textbook for engineers. *Moscow: Nedra.*

4. Kharitonov, A., Pogorelova, S., Bakichi, M. A., et al. (2015). Lost circulation minimization strategy applied while drilling challenging profile well on Salym group of oil fields. SPE-176512-MS. In: *The SPE Russian Petroleum Technology Conference, Moscow, Russia, October.*

5. Kazimov, E. A., Suleymanov, A. B. (2016). Study of the inhibitory properties of copper nanoparticles in drilling fluids. *SOCAR Proceedings*, 2, 11–14.

6. Eaton, B. (1972). Graphical method predicting pressure worldwide. *World Oil*, 185, 151–156.

7. Koshelev, V. N. (2004). Scientific and methodological foundations for the development and implementation of technology for high-quality opening of productive formations under various geological and technical conditions. Doctoral Thesis. *Russia: Krasnodar.*

8. Mavlyutov, M. R. (1980). Some issues of applying potassium-based drilling fluids. *Drilling: RNTS / VNIIOENG*, 3, 24–27.

9. Novikov, V. S. (2000). Stability of clay formations during well drilling. *Moscow: Nedra*.

10. Alexandrovich, Kh. M. (1976). Fundamentals of reagent application in flotation of potash ores. *Minsk: Nauka*.

11. Ovchinnikov, V. P., Aksenova, N. A., Kamensky, L. A., Fedorovskaya, V. A. (2014). Polymer drilling fluids. Their evolution "from rags to riches". *Drilling and Oil*, 12, 24-28.

12. Khavkin, A. Ya. (2009). Nano-phenomena in oil and gas production. *Bulletin of the Russian Academy of Sciences*, 79(6), 519–522.

13. Sattarov, R. M., Sattarzade, I. R., Gusmanova, A. T. (2010). Nanomodelling of technological processes for development and operation of oil and gas fields. *Azerbaijan Oil Industry*, 1, 42–51.

14. Mirzadzhanzade, A. Kh., Magerramov, A., Yusifzade, Kh. B., et al. (2005). Study of the effect of iron and aluminum nanoparticles on the intensification of gas release and pressure for application in oil production. *News of Baku University*, 1, 5–13.

15. Yusifzade, Kh. B., Shahbazov, E. K. (2011). Development and implementation of nanotechnologies in oil and gas production. *Baku*.

16. Gasanova, U. A. (2003). Synthesis of multifunctionally substituted crown compounds and their application in stimulating organic reactions. Doctoral Thesis. *Baku*.

17. Shahbazov, E. K., Kazimov, E. A. (2010). Nanotechnologies for controlling tribological properties in drilling of oil and gas wells. *Azerbaijan Oil Industry*, 8, 31-34.

18. Khodnenko, I., Ivanov, S., Perets, D., Simonov, M. (2019). Detection of lost circulation in drilling wells using sensor data and machine learning techniques. *Procedia Computer Science*, 156, 300–307.

19. Sabah, M., Mehrad, M., Ashrafi, S. B., et al. (2021). Hybrid machine learning algorithms to enhance lost-circulation prediction and management in the Marun oil field. *Journal of Petroleum Science and Engineering*, 198, 108125.

20. Magzoub, M. I., Salehi, S., Hussein, I. A., Nasser, M. S. (2020). Loss circulation in drilling and well construction: significance of crosslinked polymers in wellbore strengthening. *Journal of Petroleum Science and Engineering*, 185, 106653.

21. Abbasov, M. T., Strekov, A. S., Efendiev, G. M. (2009). Improving the efficiency of limiting water influx in oil wells. *Baku: Nafta-Press*.

22. Moldabayeva, G. Z., Efendiev, G. M., Kozlovskiy, A. L., et al. (2023). Modeling and adoption of technological solutions to improve the efficiency of measures limiting water influx into oil wells under uncertainty. *ChemEngineering*, 7(5), 89.

23. Moldabayeva, G. Z., Efendiev, G. M., Kozlovskiy, A. L., et al. (2023). Study of rheological characteristics of sediment-gelling compositions for limiting water inflow. *Applied Sciences*, 13, 10473.

24. Yermenov, S. M., Bondarenko, V. P., Golubev, V. G., et al. (2025). Investigation of drilling fluid properties using compositions based on secondary resources from cottonseed oil production. *SOCAR Proceedings*, SI1, 10–16.