Development of an inhibitory drilling mud to reduce environmental pollution

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Abstract. During the drilling of oil and gas wells, drilling fluids are used to transport the drilled cuttings to the surface. The most commonly used drilling fluids are water-based with the addition of various polymers. Such mud systems are used not only for transporting cuttings, but also for drilling in unstable formations. When drilling clay rocks, they are hydrated and then dispersed, which leads to various accidents. Therefore, there is a need for the correct selection of the composition of the drilling fluid with high inhibitory properties. Since polymer solutions contain a large number of toxic chemical reagents, in order to reduce harm to the outside world, it is necessary to select a solution that performs all the necessary functions, but with a smaller amount of toxic chemical reagents. This paper discusses modern drilling fluids that are currently used in production, as well as developed new compositions of more environmentally friendly fluids.

1. Introduction
Currently, the number of wells drilled in Russia is increasing annually. During drilling, different drilling fluids are used to perform different functions. One of the most important functions is maintaining the nominal borehole diameter. This problem is especially acute when drilling in unstable clay formations. Drilling fluids used in production can be water-based or oil-based. Oil-based drilling fluids have good inhibiting properties, however, due to their high cost and disposal problems, water-based drilling fluids are more commonly used. When the drilling fluid comes into contact with clayey formations, an interaction occurs between the water contained in the drilling fluid and the clay in the formation. The clay is moistened and subsequently destroyed. To avoid these problems, various chemicals are added to the drilling fluid that bind water and prevent it from penetrating deep into the rock [1].

It is also very important to correctly calculate the amount of polar reagents in the solution. The increase in pore pressure is the main reason for the destruction of the clay structure of the rock. The difference in polar reagents of only 0.25 mol / liter leads to a significant increase in pore pressure around the wellbore, which leads to a decrease in the stability of the wellbore walls. To decrease this pressure, it is necessary to increase the concentration of polar reagents.
It is most difficult to control the process of stabilization of the borehole walls in non-plastic clay rocks (shales, mudstones). The swelling pressure builds up over time and eventually causes an explosive increase in the borehole diameter.

Practical experience shows that the development of hydration stresses can be prevented if fluids with low ion-molecular properties or non-polar fluids are used as the dispersion medium of the drilling fluid. Water is most often used as the dispersed phase of the drilling fluid, due to its low cost and safety. In such cases, water activity must be reduced to stabilize the clay in the wellbore.

Currently, various polymers are most commonly used in production to bind water in drilling fluid, such as polyanionic cellulose, carboxymethyl cellulose, and sodium and potassium silicates (also known as "water glass"). These reagents impart high inhibitory properties to the solution, but their problem lies in their difficult subsequent disposal. To dilute one cubic meter of waste drilling fluid, more than 2000 cubic meters of clean water is required [2,3].

Drilling fluids cause significant damage to water bodies both during drilling and during repair work on wells. Backfilling of earthen pits with mortar and cuttings after the completion of well drilling is not justified as an environmental measure due to the thixotropy of drilling fluids. Earthen pit do not harden after filling for several years, and this piece of land has been a source of soil and water pollution for a long time.

Particularly dangerous is the pollution of reservoirs and under-channel waters in the regions of the Far North, where microbiological activity is suppressed by the action of low temperatures. These areas are most susceptible to disruption of the natural ecological situation due to the inhibition of oxidation and evaporation processes, and a slowdown in the restoration of the natural environment.

The impact of production processes of geological exploration on small watercourses is observed in an area from 5 to 10 km. Level wastewater is a stable multicomponent suspension containing mineral and organic impurities, oil and oil products [4].

Another problem with polymer drilling fluids is that when the formation is penetrated by groundwater, they become contaminated, and even a small amount of drilling fluid can cause enormous harm to the environment. When drilled cuttings get into water bodies, the turbidity of the water increases, which worsens the aquatic habitat. The maximum concentration of drill cuttings in the aquatic environment varies from 0.8 to 1.25 g / dm3, and the harmless concentration for fishery facilities is 0.4-0.45 dm3. Toxic substances adsorbed on the particles of drill cuttings are washed out in the aqueous medium, accumulating and dissolving in it.

The aim of this work is to create new compositions of inhibiting drilling fluids that are less harmful to the environment.

2. Materials and Methods

Analysis of production data showed that silicate drilling mud is most often used as a polymer inhibiting fluid. It can contain up to 40% sodium silicate. In current studies, instead of sodium silicate, it is assumed to use polyvinylpyrrolidone as the main structurant, while maintaining the inhibitory capacity of the solution. There are several ways to determine the inhibitory ability of a bouvure mortar. In the current work, the studies will be carried out using the Fann LSM 2100 linear swelling tester (figure 1). Initially, 20 grams of clay are measured on a balance. The resulting sample is poured into a compactor and a pressure of 6 MPa is injected, thereby forming a sample. The sample is under pressure for two hours. After that, the sample is taken out, installed in LSM 2100 and poured with the test drilling fluid. The change in the linear swelling of the sample is measured automatically within 48 hours [5,6].

The movement of water is due to the activity of the elements of the salts contained in it and the number of electrons contained in the rock. The current will flow in the direction from the area where the salinity is lower to the area where the salinity is higher, thus characterizing the activity of the system. Guy-Châtel put forward a theory about the influence of water filtered into the depths of the rock on the thickness of the double diffusion layer:
\[ \mathcal{G} \propto \sqrt{\frac{kT}{c\nu^2}}, \quad (1) \]

where \( k \) is the dielectric constant of the pore fluid, \( T \) is the absolute temperature, \( c \) is the concentration of ions, \( \nu \) is the valence of the ions of the pore fluid.

With an increase in the size of the double dielectric layer \( z \), the volume of bound water entering the basal surfaces of the clay changes, its physical and mechanical properties change accordingly, and the initial structure is destroyed. An increase in the amount of dissolved electrolytes leads to an increase in osmotic pressure. It is very important to control the amount of ions in the solution, and the following formula is used to determine the values of osmotic pressure:

\[ \frac{\partial \Phi}{\partial t} = C_c[\nabla(K \cdot \nabla \Phi)], \quad (2) \]

where \( \Phi \) is the water potential of the rock, \( t \) is the time, \([s]\),

\[ C_c = \frac{\partial \Phi}{\partial \theta_w} = \frac{1}{(M_v + \phi/K_w)}, \quad (3) \]

\[ M_v = \frac{1}{(K_v + 4/3 G_r)}, \quad (4) \]

where \( \theta \) is the volumetric water content, \( M_v \) is the coefficient of change in the volume of the rock, \( K_v \) is the volumetric modulus of elasticity of the rock, \( G_r \) is the shear modulus, \( \phi \) is the porosity of the rock, \( K_w \) is the volumetric modulus of elasticity of water, \( K \) is the coefficient of permeability of the rock. The effect of osmotic pressure on pore fluid flow is taken into account by including in the expression the spatial gradient of the water potential of the rock as the driving force of the pore fluid flow. The interaction between drilling fluid and pore fluid, including material transport, dispersion and diffusion, can be described by the equation:

\[ \frac{\partial \phi C}{\partial t} = -\nabla(C \cdot q - \theta_w D_s \cdot \nabla C - \theta_w D \cdot \nabla C)(1 - \alpha), \quad (5) \]

where \( \phi \) is the porosity of the rock, \( q \) is the density of the water flow, \( t \) is the time, \([s]\), \( C \) is the concentration of pore fluid in the solution, \( D_s \) is the dispersion coefficient, \( D \) is the coefficient of molecular diffusion, \( \alpha \) is the coefficient taking into account the filtration of the solution through the membrane, \( \theta_w \) is the volumetric water content.

With the wrong choice of chemical reagents, when the drilling fluid interacts with the rock walls, the electrolytes interact. This leads to a significant increase in pore pressure, a change in the volume of the rock and the subsequent destruction of its original structure. Ultimately, this leads to various complications, such as jamming of the drilling tool, caving, etc. To prevent such problems, it is necessary to correctly select the amount of polar compounds in the solution.

3. Results and Discussion

In figures 1 and 2 shows the results of the calculation to determine the effect of the drilling fluid on the stability of the rocks around the wellbore, depending on the difference in the concentration of polar reagents (equations 4 and 5). From the graphs it follows that if the initial concentrations of polar compounds in the solution \( C_p \) and in the rock \( C_n \) are not balanced, then with an increase in the interaction time between them, a change in pore pressure occurs and, as a result, a decrease in the stability of the rocks that make up the borehole walls.
An increase in the concentration of polar compounds in the drilling fluid in comparison with their concentration in the rock $C_p > C_p$ by 0.25 mol / L (see figures 1 and 2), can significantly reduce the pore pressure around the wellbore due to the transfer of free water molecules from rock formation in the drilling mud.

As a result, the stability of rocks around the wellbore increases in comparison with the initial conditions. Parabola goes to note that the amplitude of changes in the values of pore pressure and concentration of polar reagents in the rock around the wellbore is most significant at a distance of one radius from the well, since as the filtrate penetrates into the depth of the rock, the activity of the growth of pore pressure decreases.

In non-plastic clayey rocks with a low amount of cohesive water, there is a sharp increase in swelling pressure. Very high swelling pressures can develop if they are isolated on all sides and in contact with water. When rock is excavated, diametral growth of tensile stresses occurs on the wellbore. When this stress reaches a critical value, characterized by a redistribution of clay fluidity, a sharp change in the volume of the rock occurs. According to the works of Chenewert, the destruction of the rock occurs in an abrupt manner. Over time, the pressure increases, and then a sharp collapse of the rock occurs, characterized by the rate of clay hydration. To simulate the conditions of interaction of clay rock with drilling mud, it is necessary to take into account the concentration of polar electrolytes in the drilling mud system and in the rock sample system, as well as the mechanism itself and the rate of hydration. Experience shows that hydration and the development of hydration stresses.

Figure 1. Distribution of pore pressure in the rock around the wellbore over time

Figure 2. Distribution of the concentration of dissolved ions in the rock around the wellbore over time
on the walls of wells composed of clay rocks can be prevented if fluids with low ion-molecular properties or non-polar fluids are used as the dispersion medium of the drilling fluid.

Polymerized water for various hydrates is capable of forming the following types of cavities: D, T, P, H, E, each of which has its own characteristic dimensions. The possibility of creating hydrated inclusion compounds is estimated from the condition of filling the water cavities with various ions and compounds. Hydrated inclusion compounds are stable when the degree of their filling of cavities in the structure of water molecules is from 70 to 100%. These parameters are due to the fact that in order to maintain stability, cavities must be impermeable to individual water molecules (table 1) [4,5].

**Table 1. The degree of filling of water cavities with various ions and fragments of hydrocarbon compounds (%)**

| Ion          | d, Å | D   | T   | P   | H   | E   |
|--------------|------|-----|-----|-----|-----|-----|
| Cl⁻+Na⁺      | 5.56 | 106.92 | 104.51 | **86.88** | **91.15** | **79.43** | **84.24** | 57.92 | **76.16** |
| Cl⁻+K⁺       | 6.38 | 122.69 | 119.92 | **99.69** | **91.14** | **96.67** | 66.46 | **87.40** |
| HCOO⁻+Na⁺    | 4.70 | **90.38** | **88.35** | **73.44** | **77.05** | 67.14 | 71.21 | 48.96 | 64.38 |

After reviewing the experience of previous studies, as well as production data on the currently used drilling fluid systems, the chemicals were selected. According to supramolecular chemistry, it is necessary to select inhibitory reagents with molecules of different weights that can give the solution a more stable structure. High molecular weight compounds were used as reagents capable of forming interstitial solutions - polyvinylpyrrolidone (PVP), triethanolamine, Barazan, PHPA, PAC LV + HV in combination with polar reagent - NaHCOO.

Samples treated with aqueous solutions of 5% HCOONa + 5% PVP shown in figure 3a, retained the integrity and strength of the rock in volume, however, cracks formed in the outer layer of the rock. This may indicate that the activity of the aqueous phase was sufficiently high, and the hydration process proceeded at a sufficiently high rate at which PVP molecules and polar compounds did not have time to create the structure of the interstitial solution. A similar process was observed in rock samples treated with solutions of polar compounds with PHPA in figure 5d and PAC LV + HV in figure 3f, however, in the solution with PAC LV + HV, the intensity of cracking is minimal. Samples treated with aqueous solutions of 5% HCOONa + 5% triethanolamine (figure 3b), 5% HCOONa + 0.5% Barazan (figure 3c), retained their integrity, but did not prevent their swelling and softening. After the selection of electrolytes, drilling mud systems were created and their inhibitory ability with the silicate used in production was tested.
Figure 3. Samples of clay rocks in aqueous solutions of inhibitors. 

- a – 5% HCOONa + 5% PVP; 
- b – 5% HCOONa + 5% triethanolamine; 
- c – 5% HCOONa + 0.5% Barazan; 
- d – 5% HCOONa + 0.5% PHPA; 
- f – 5% HCOONa + 1% PAC LV+HV, after 120 hours from the beginning of the experiment.

Figure 4. Samples of clay rocks in aqueous solutions of inhibitors.

The research results showed almost identical inhibiting ability of solutions. Since polydon has a 4th class of hazard for contamination (in contrast to silicate, which has a 3rd class), we recommend to use it in the preparation of inhibiting drilling fluids.
4. Conclusion
In the course of these studies, the dependence of the influence of the concentration of polar reagents on the stability of clay rocks during drilling was shown. Incorrect selection of reagents can lead to a significant increase in pore pressure and destruction of rocks. And also shows the methodology for the selection of reagents and their concentrations. Studies of the inhibiting properties of polydon-based drilling fluids have shown the possibility of their use instead of silicate ones. The advantage of the developed drilling fluids is a lower hazard class, which will significantly reduce environmental pollution. Also, the resulting compositions will reduce the likelihood of contamination of underground water sources.

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