DEVELOPMENT OF LIQUID COMPOSITIONS TO INCREASE THE EFFICIENCY OF DRILLING HARD ROCKS

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Annotation. The methods of weakening rocks to increase the efficiency of drilling hard rocks are presented, and an attempt was made to develop a composition of drilling fluid. The purpose of the work is to create compositions of drilling fluids that increase the efficiency of destruction of hard rocks. The article contains experimental studies of the compositions of drilling fluids and their main structural-rheological and filtration characteristics. Also, the created stand assessed the effect of various solutions, including the developed one, on the process of destruction of hard rocks. The results of the studies show that the composition and characteristics of the developed drilling fluid have a positive effect on the process of destruction of hard rocks. The use of clay-free drilling fluids with additives of anionic surfactant compositions allows to increase the productivity of drilling operations by increasing the mechanical speed of drilling and penetration per bit.

Keywords: rock, weakening of rocks, microcracks, well, deformation, reagents-detergents, surfactants, drilling fluid, adsorption, destruction of rock, clay-free solution.

Introduction. As is known, the process of drilling a well is complex and pursues many tasks. Technical and economic indicators of drilling rocks largely depend on the perfection of well flushing technology, the composition and properties of drilling fluids, their physicochemical treatment and compliance with the rocks being drilled. The issue of choosing the optimal composition of the drilling fluid is especially acute when drilling in hard rocks, since in addition to the main functions, such as creating hydrostatic pressure, cleaning the bottomhole, removing cuttings, etc., it is necessary to regulate the surface forces that allow applying the effect of adsorption hardness reduction (preliminary weakening of the rock).

Methods. For practical reduction of the surface tension of a solid, one can use:

- internal adsorption effect, i.e. adsorption of surface-active substances (SAS) on the internal surfaces of the interface of embryonic microcracks of destruction;
- the effect of reducing the surface tension of a solid when polarizing it in strong electric fields; the possibility of practical use of this effect requires research on its influence on the strength properties of rocks.

An important factor in the intensification of the drilling process of rocks is the effect of surfactants on them. The surface-active environment affects the nature of deformation and destruction of solids, mainly in the vicinity of sharp (dead-end) ends developing cracks. Thus, in the areas of deformation of a solid, the adsorption effect of the environment leads to a change in the effective surface energy per unit surface area, which causes a change in the strength properties of the solid. The greatest adsorption effects occur when new surfaces arising in the process of destruction have time to become covered with adsorption layers. From this point of view, the effectiveness of surfactants in percussion rotary drilling and in drilling with roller bits is higher than in rotary drilling - crowns and cutting bits.

The basic position that the influence of the external environment and adsorbed substances on the deformation and destruction of a solid is due to their penetration into microcracks to a fairly significant depth in the pre-destruction zone developing in a solid during its deformation was confirmed by a number of works by laboratories of the Colloid-Electrochemical Institute of the USSR Academy of Sciences [5]. Here it is necessary to note the works in which the "elementary acts" of deformation or destruction of individual crystals were studied. The following were studied: cleavage of calcite crystals by cleavage, bending and other deformations of mica leaflets. It was shown that the addition of adsorbent substances in small concentrations sufficient to saturate the adsorption layer almost 2 times reduces the force of cleavage of calcite crystals 1-2 mm thick (N.E. Markova) compared to the force of cleavage in pure water. This effect of hardness reducers increases significantly with prolonged aging of the crystal in a given liquid, especially in a loaded state close to the strength limit. The effect of residence time in a given medium increases significantly when the greatest activity of the liquid in relation to the solid is achieved, i.e. at the optimal concentration of the hardness reducer, which convincingly proves the main role of the penetration of the medium into the pre-destruction zone.

Methodology of work and processing of experimental results. In the presence of hardness reducer additives, the pre-fracture zone develops, and the fracturing in it increases - microcracks become deeper and their number per unit volume increases. This causes the greatest (depending on the concentration) facilitation of crystal splitting, and the greatest effect is achieved after a longer period of time.

The results of the studies showed that the most effective strength reducers are anion-active surfactants in an alkaline medium, which is in good agreement with the data obtained in studying the effect of surfactants on the contact strength of sandstones. In this regard, the creation of compositions of drilling fluids with additives of reagents that reduce the hardness (detergents) of rocks seems to be a very urgent task, especially when drilling wells in hard rocks.

It should be noted that a rock of high hardness changes its mechanical properties little under the influence of high pressure and temperature values that occur at great depths. On the contrary, sedimentary rocks of low hardness and density at great depths under the influence of high pressures and temperatures are compacted and their hardness can increase by 3-4 times, accordingly, the drillability index will change. It is known that with a decrease in the density of the drilling fluid, the mechanical rate of penetration increases. If the clay solution is replaced with water, the drilling speed increases by 20 - 30%. An even greater increase (2-5 times) in the drilling speed is achieved by replacing the drilling fluid with gas [2, 3]. This indicates the need for research in the field of using low-density drilling fluids based on various polymers.

Analysis of previously conducted studies allows us to draw the following conclusions:

- when destroying rocks, it is more advisable to use surfactants that will spread better over the surface, i.e. have the smallest contact angle of wetting and low surface tension values, this will allow the drilling fluid with the addition of surfactants to penetrate deeper into the formed microcracks, creating a wedging pressure on their inner surface;

- to increase the efficiency of rock destruction at the bottomhole, it is necessary to strive to reduce the specific electrical resistance of drilling fluids;

- when choosing a drilling fluid, it is necessary to conduct studies to measure the main strength properties of rocks (e.g. tensile strength, microhardness, dynamic strength).

During the experimental studies of the wetting angle (using the Easy Drop drop shape analysis system) on the surface of a solid rock sample, aqueous surfactant solutions with a concentration of 0.05 and 0.1% were used:

- anionic - sodium linear alkyl benzene sulfonate (sodium LABS);

- cationic - catamine-AB;

- nonionic - OP-7.

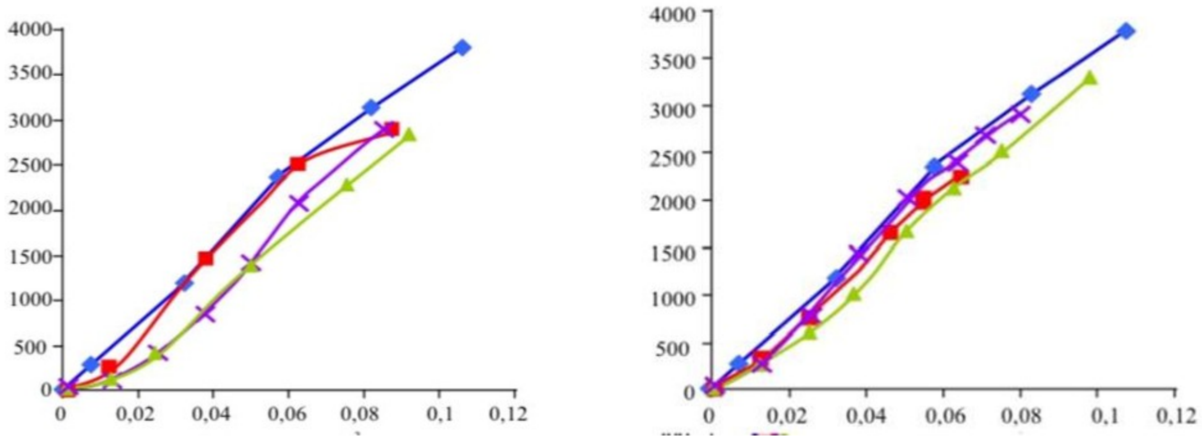


Fig. 1. Deformation diagrams of a rock sample in a surfactant environment with a concentration of 0.05% (a) and 0.1% (b) 1 – dry sample; 2-4 – aqueous solutions (2 – sodium LABS, 3 – catamine-AB, 4 – OP-7).

A similar dependence is observed when analyzing the effect of surfactants on the hardness of rocks (Figure 2). Thus, for all the studied surfactants at a concentration of 0.05%, the decrease in hardness is on average 25%, and with an increase in concentration to 0.1%, a decrease in hardness is observed when the rock is exposed to only anionic surfactants and this indicator decreases by more than 40%.

Thus, the research results indicate the prospects of using anionic surfactants in the compositions of the developed drilling fluids as detergents.

It is known that drilling fluids have the greatest positive effect on the efficiency of rock destruction at the well bottom through their ability to prevent the closure of microcracks formed during the impact of the bit structure elements.

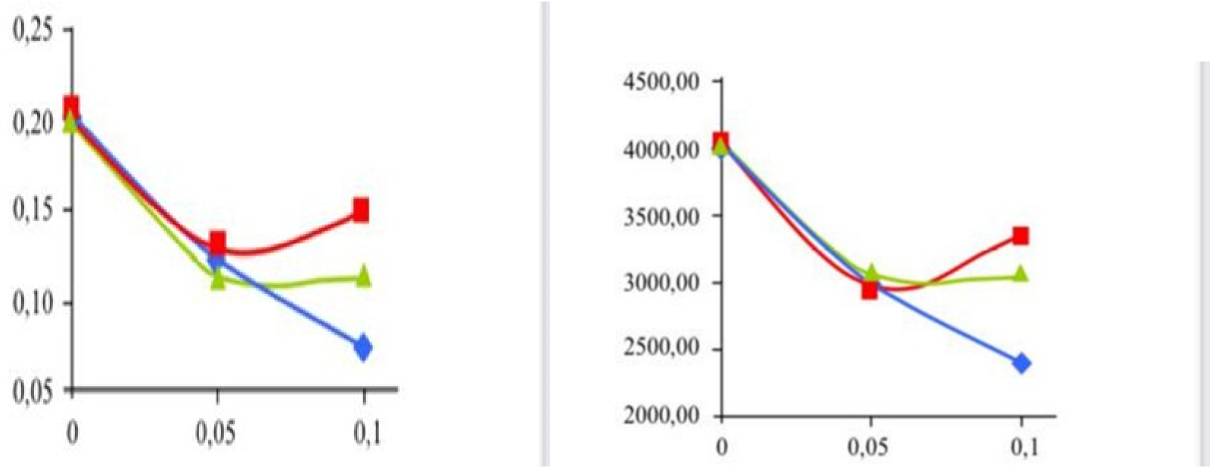


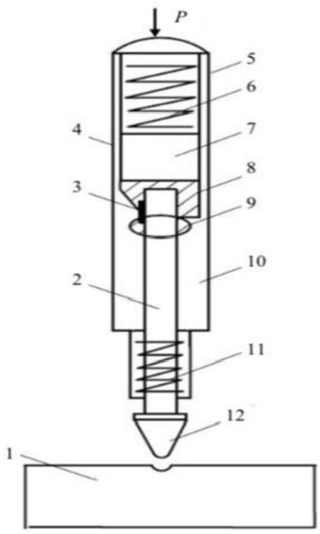
Fig. 2. Dependence of the elastic deformation work (a) and rock hardness (b) on the surfactant concentration 1 – sodium LABS; 2 – catamine-AB; 3 – OP-7

Some researchers believe that the drillability of hard rocks is significantly affected by the difference between the hydrostatic and formation pressures at the bottomhole. It is noted that the pressure difference depends on the physical properties of the rocks being drilled, the composition and properties of the drilling fluid, its chemical treatment, the content of the solid phase, etc. Others argue that the main factors in increasing the drillability of rocks are the water loss of the drilling fluid, the composition of the filtrate, its viscosity, as well as the structural and mechanical properties of the flushing medium. The depressing pressure on the bottomhole can be reduced by reducing the density of the drilling fluid, and to reduce the surface energy - by adding surfactants to the solution.

To obtain visual results of the effectiveness of surfactants, experiments were conducted on the introduction of a metal indenter into a glass sample in an aqueous medium and a surfactant solution with a different number of impacts. The operating principle of the spring mechanism (Fig. 4) is based on the compression and instantaneous release of the spring. It has a three-part screwed housing, which contains springs 6, 11, rod 2 with indenter 12, striker 7 with shifting biscuit 9 and flat spring 3. When pressed by the tip of the indenter, the inner end of rod 2 rests against the biscuit, causing the striker to move upward and compress spring 6. Resting against the edge of shoulder 8, the biscuit shifts to the side and its edge comes off rod 2. At this moment, the striker, under the action of the force of compressed spring 6, strikes the end of the rod with the indenter. Immediately after this, spring 11 restores the initial position of the indenter. The impact force (10-15 N) is adjusted by screwing in or unscrewing stop cap 5. The test solution is fed into the contact zone with sample 1. Glass was chosen as the object of research, since it is an isotropic material. Experimental studies were conducted with different numbers of indenter impacts. The results show that with a single indenter impact, the increase in the destruction zone in a medium of 0.1% aqueous solution of anionic surfactant reaches 50% compared to water. With a greater number of impacts, this difference increases more than 2 times. The next stage of research is aimed at developing a composition of a clay-free drilling fluid, the main components of which are proposed to be xanthan biopolymer, a reagent based on acrylic polymers and a composition of anionic surfactants.

The main parameters of solutions with different concentrations of biopolymer were measured. It was found that clay-free drilling fluids have a lower density than clay ones, which has a beneficial effect on increasing the efficiency of destruction of hard rocks. For clay drilling fluids, viscosity is always minimized, since its reduction reduces energy costs for drilling fluid circulation, improves bottomhole cleaning, makes it possible to implement greater hydraulic power on the bit, and reduces pressure losses in the annular space of the well. For clay-free drilling fluids, the requirement to reduce viscosity may not be so categorical, since they have the property of liquefaction at high shear rates.

The conditional viscosity of the studied solutions (Fig. 3) ranges from 17 to 85 s. The next parameter characterizing the quality of the solution is water loss. Water loss of solutions with a biopolymer content of 0.1 to 0.3% is much higher than that of solutions with concentrations of 0.5 and 0.7% (Fig. 3).



Static shear stress (SSS) should be minimal, but sufficient to keep drilled rock particles and weighting agent suspended in a resting drilling mud. It has been established that the SSS value of clay-free solutions varies from 1 to 14 dPa (Fig. 3). The SSS value of solutions is very low. As is known, dynamic shear stress (DSS) is the force that must be applied to the solution to cause laminar flow of the latter, so it is inappropriate to increase its value. From Fig. 3 it follows that with an increase in the biopolymer concentration to 0.7%, the SSS value reaches 12.7 Pa. Based on the obtained results, it is logical to conclude that for further research it is necessary to use xanthan biopolymer "KK-Robus", the concentration of which should be at least 0.3% and not more than 0.6%. Based on general considerations, drilling fluid with predominantly structural viscosity, i.e. with a high ratio of ultimate dynamic shear stress to plastic viscosity or with a low nonlinearity index, is best suited for cleaning the wellbore and reducing possible pressure losses.

In this regard, studies were conducted on the Rheotest rotational viscometer to measure the nonlinearity index of drilling fluids of various compositions.

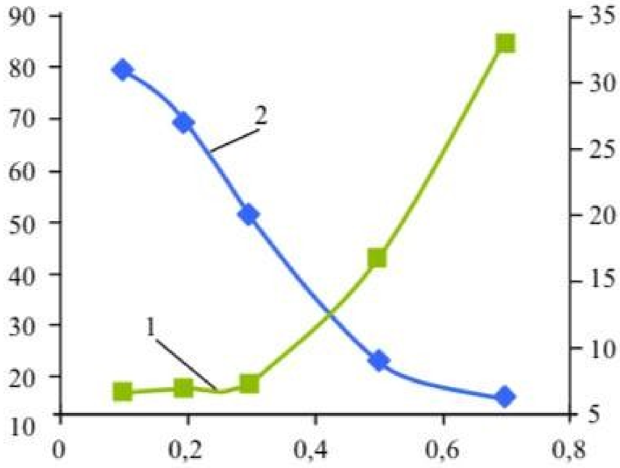


Fig. 4. Dependence of conditional viscosity (1) and water loss (2) on the concentration of the biopolymer "KK-Robus"

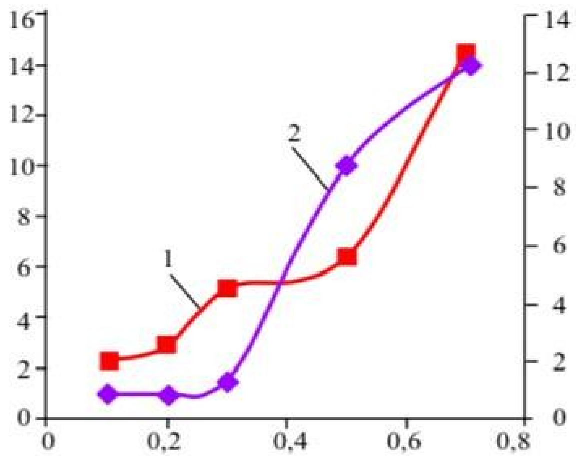
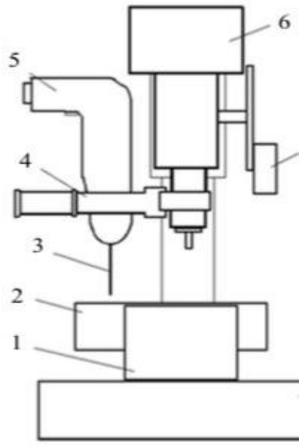


Fig. 5. Dependence of SNS (1) and DNS (2) on the concentration of the biopolymer “KK-Robus”.

The concentration of anionic surfactants in the developed solution of 0.1% was selected based on the results of previously conducted experiments. To reduce water hardness, 0.1% sodium hydroxide (caustic soda) is added to the solution. Thus, the optimal composition of the clay-free drilling mud can be represented by the following components: 0.4% biopolymer "KK-Robus"; 5% acrylic polymer

"KM-017"; 0.1% anionic surfactant (0.05% sodium lauryl sulfate and 0.05% potassium acetate); 0.1% sodium hydroxide.



Results: The results of the study show that at elevated ambient temperatures, the structural and rheological properties of the developed clay-free drilling mud remain within the permissible limits and, therefore, the solutions can be used for drilling deep wells. A rig (Fig. 5) and a methodology for conducting rig studies were developed to evaluate the efficiency of drilling hard rocks. During the experimental studies, the effect of anion-active surfactants and the developed composition of the clay-free drilling mud on the efficiency of drilling hard rocks was studied.

The methodology for conducting rig studies included:

- preparation of a fine-grained rock sample in the shape of a rectangular parallelepiped with polished surfaces;
- leveling and subsequent fixing of the sample in a clamping device;
- installation and fixation of axial load, impact frequency and rotation frequency of the rock-breaking tool (RBT);
- supply of the studied liquids directly to the point of contact of the RBT with the rock sample;
- destruction of the sample by the impact-rotational method; - measuring the depth of penetration of the impact drill into the sample for a fixed time.

Research conditions: rock sample dimensions – 30 × 8 × 6 cm; rock – diabase; axial load 180 N; rotation frequency 100 rpm; impact frequency 200 min–1;

impact drill arm – VK-8 hard alloy; impact drill diameter 8 mm; impact time 10 min.

An electric drill with impact-rotary action was used as the main drive unit of the stand, providing the ability to simulate the crushing-chipping mode of operation of the impact drill. The load acting on the impact drill 3 is created by a movable loading device 6, an impact rotator 5 located in a clamp 4 and a load 7. The mass of the movable loading device 6 and the impact rotator 5 are constant, the load can only be changed by increasing or decreasing the mass of the load 7. Experiments were conducted on the developed stand. The presented data show that the use of sodium LABS increases the destruction efficiency by 7%, and sodium lauryl sulfate by 23%.

The clay-free solution containing the surfactant composition increases the studied parameter by 18%. The results of the conducted studies (experimental and bench) show that the composition and properties of the developed drilling fluid have a positive effect on the process of destruction of hard rocks. The use of clay-free drilling fluids with additives of anionic surfactant compositions allows to increase the productivity of drilling operations by increasing the mechanical drilling speed and penetration per bit.

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