Improving energy efficiency in well construction through the use of hydrocarbon-based muds and muds with improved lubricating properties

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Abstract. During the construction of directional wells in spatially curved sections of the barrel, large contact loads and huge resistance to the movement of the drill string during lifting can occur, which leads to increased wear of the drill pipes and high energy costs. One of the directions for increasing the energy efficiency of drilling such wells was the reduction of friction at the metal-metal, metal-rock, and metal-filter cake boundaries. This result can be achieved by introducing special lubricating additives or by switching to a hydrocarbon solution during drilling. The article presents the study of drilling fluids with the introduction of lubricating additives on a lubricity tester Fann EP / Lubricity Tester Model 212, a device for determining the coefficient of clay cake KTK-2, a rotary viscometer Fann 35SA, pH meter Crison GLP 21 to reduce the coefficient of friction of a pair “metal – metal” in a clay solution, which amounted to 70-75%, in an aqueous solution - up to 65%. The optimal concentration of the additive according to the study in different drilling fluids was about 1.5-2%. The results of a study of the effect of the speed and time of mixing a hydrocarbon-based solution during its preparation on the electrostability of the emulsion obtained are carried out on a BVD device, which showed a significant increase in the stability of the washing liquid to 24%, which leads to a decrease in the number of complications associated with pipe wear and a decrease torque when rotating the column.

1. Introduction

Energy consumption is a serious factor affecting operating costs for drilling, since it accounts for 10 to 30% of all costs, so reducing energy consumption is an important area of research and development. This is especially important when developing large fields, in particular, with hard-to-recover reserves, which include drilling projects with large vertical waste, including offshore in the Arctic.

Drilling directional wells, including those with horizontal completion, is one of the ways to increase oil recovery by increasing the drainage zone. At the same time, the profile of the wellbores is complicated, which leads to a mismatch between the actual and design loads on the bit [1,2]. This problem is especially acute when drilling using rotary steerable systems (RSS). The use of RSS involves the rotation of the drill string along its entire length, which increases the wear of the drilling tool. Use of lubricants significantly improves the technical and economic characteristics of these systems. In addition, difficulties caused by high torque and tension forces are also observed in such wells. The drill
string lies on the bottom wall of the well and has a large contact area with the rock and casing. Under such conditions, frictional forces between contacting surfaces increase significantly, which leads to an increase in the likelihood of various complications and leads to increased wear of drilling equipment. It is possible to reduce the energy intensity of the drilling process in various ways, however, the introduction of lubricating additives [3] into drilling fluids and the use of hydrocarbon-based solutions are the least expensive way to conduct research and development, as well as to introduce them into the production process.

Currently, the most effective oil-based fluid systems such as invert emulsion mud (IEM). There are several types of invert emulsion mud: HIEM (highly concentrated invert emulsion mud); TIEM (thermo-resistant IEM); emulgel (IEM containing iron sulfate); HEM (hydrophobic emulsion solution) and from foreign the most common are M-I SWACO, Baroid, Baker Hughes. Invert emulsion muds are characterized by the constancy of properties and stability, which are fairly well predicted and thereby the possibility of their modeling.

A further task is to study lubricating additives for introducing into an aqueous and clay solution with the aim of developing new effective domestic reagents and improving the lubricating properties of solutions, as well as measuring the electrical stability and rheological characteristics of an invert emulsion solution for switching to it during well drilling.

2. Materials and methods

Studies conducted at the Department of Well Drilling showed that the inclusion of lubricating additives in the composition of drilling muds or the replacement of a hydrocarbon-based solution can lead to a decrease in the friction coefficient by 35–75%, which will minimize the number of complications associated with pipe wear [4], and reduce torque when rotation of the string, as well as an increase in the service life of drill and casing pipes.

The technique for studying the lubricity of a solution consists of several stages: preparation of water and clay solutions with a density of 1.03 g / cm$^3$ and with additive concentration 1%; assessment of the quality of drilling mud preparation; determination of the coefficient of friction on the KTK-2 device; measurement of rheological parameters on the Fann 35SA device; filtration of the solution on a BM-6 device to assess the pH of the filtrate on a Crison GLP 21 and the friction coefficient at the metal-clay cake interface on a Fann EP/Lubricity Tester Model 212. To assess the optimal concentration of the introduced additives - the same set of studies with different concentrations.

In invert emulsions, as well as in water-based solutions, for trouble-free operation, the technological parameters of the drilling fluids are maintained at intervals specified by the design documentation. One of the main technological parameters of hydrocarbon-based solutions is electrical stability. Electrical stability is an indicator of the ability of the aqueous phase to form a finely dispersed emulsion in an oil or synthetic base [5,6]. High electrical stability indicates high emulsion stability and fluid stability. Oil and synthetic fluids do not conduct electricity.

The electrical stability of the emulsion was measured on a BVD (breakdown voltage device) in the laboratory of the department of well drilling at St. Petersburg Mining University. The principle of operation of the BVD is based on measuring the voltage of electrical breakdown between the electrodes located at a certain distance from each other and immersed in an emulsion drilling fluid. The voltage supplied to the electrodes grows at a constant speed at a current equal to $(61\pm3) \mu A$, the voltage growth stops, and it is recorded on a digital display. The parameters of the electrostability of hydrocarbon and synthetic-based drilling fluids are recommended for analysis of the dynamics of their properties. A clearly observed downward trend or a sharp drop in the indicator of electrical stability is a sign of a decrease in the stability of the emulsion [7].

Mixing of the solution was carried out in a HAMILTON BEACH mixer. Mixing speeds were 11000, 14000 and 17000 rpm, respectively. Measurements of electrical stability were made after mixing after 15, 30, 45 and 60 minutes. Each measurement was made 3 times and the average breakdown voltage is taken as true. The viscosity of the solution was also measured. After 24 hours, the breakdown voltage
parameter was also measured. The current value at the time of breakdown of the emulsion was 61 ± 3 μA, the voltage measuring range was from 0 to 1500 V.

Studies were conducted with an emulsion mud of the following composition: synthetic oil – 600 l/m³; water – 160 l/m³; CaCl₂ – 60 kg/m³; CaO – 15 kg/m³; Surfactants of the 1st kind – 29 kg/m³; Surfactants of the 2nd kind – 12 kg/m³; Gilsonite – 5 kg/m³; Bentonite – 15 kg/m³; CaCO₃ – 80 kg/m³. Technological properties: density – 1.03-1.05 kg/l; conditional viscosity – 60-100 sec/quart; plastic viscosity – 20-40 mPa·s; DSS (dynamic shear stress) – 15-40 lb/100ft².

3. Experimental
Currently, a significant range of lubricating additives is presented in production, most of which are foreign, therefore the development and research of new effective reagents is relevant and economically feasible. The authors conducted a study of lubricants for drilling fluids:
- **Lubristeel** is a lubricant with dark brown and a specific odor. It interacts well with water, the solution acquires a dark brown hue. Over time, an oily skin forms on the surface with 8.83 pH of the solution filtrate.
- **FRW A, FRW B, FRW** are lubricants with homogeneous dark brown liquid, specific odor. Satisfactory dispersibility, precipitation is observed on the walls of the equipment, sometimes large particles are formed. A skin appears on the surface of the water. They have 9.06; 9.75; 9.61 pH of the solution filtrate.
- **Lubrital** is a lubricant with homogeneous dark brown liquid, specific odor. It dissolves well, uniform mass, remains stable over time, almost without precipitation. It has 9.3 pH of the solution filtrate.
- **PolyMudLiquid & ASP 820** are white turbid homogeneous liquids. They interact well with water, the solution acquires a viscous (like jelly) structure with a white hue. They have 9.57 pH of the solution filtrate.

A study of aqueous and clay (based on PBMA bentonite with a density of 1.03 g/cm³) solutions with an additive concentration of 1% (PolyMudLiquid and ASP 820 - with a concentration of 0.1%, since viscoelastic compounds are formed at an additive concentration of 1%, determine the friction coefficient and rheological properties of which are not possible). The above are the characteristics of the resulting aqueous solutions and the pH of the filtrate of clay solutions (at a pH of the filtrate of a pure clay solution of 9.46).

Figure 1 shows the results of a study of lubricity, based on the determination of the coefficient of friction of a metal-metal pair in a liquid medium characterizing the rotation of the drill pipe string in the cased section of the wellbore, and of the metal-clay cake pair characterizing the “sticking” of the drill pipe string to clay peel on the wall of the well.
Based on the practice of drilling wells, it is most rational to use additives to drilling fluids to maintain the coefficient of friction of the metal-metal pair in the range of 0.18–0.20 [8,9]. From fig. 1 shows that the lubricity of the FRW reagent of various modifications is within the same limits as the lubricity of other currently used additives. Clay muds with additives of 0.1% PolyMudLiquid and ASP 820 cause increased values of the friction coefficient of the metal-metal pair due to the higher viscosity of the resulting composition, since these additives are complex and affect not only the lubricating properties, but also the viscosity of the solution.

Figures 2–4 present the results of a study of the rheological properties of clay solutions. Figures 2 a, b shows the dependences of normal viscosity at the time of preparation (a) and after 2 hours on the rotor speed (b). The solution with the addition of ASP 820 reagent is characterized by significant viscosity at a low rotational speed of the viscometer rotor (at a rotation speed of 3 min$^{-1}$, the viscosity during preparation is 800 mPa.s, after 2 hours - 900 mPa.s, after 1 day - 2000 mPa.s), which can improve the removal of cuttings in the annular space, and on the other, increase the static shear stress, pressure loss on the bit and reduce the efficiency of washing the well as a whole. In this regard, the ASP 820 reagent is impractical to use as part of a clay mud even at low concentrations [10,11]. The FRW reagent, like other lubricating additives, slightly affects the rheological properties of drilling fluids.

Figure 3 shows that all solutions are characterized by an increase in viscosity with time. PolyMudLiquid and ASP 820 additives significantly increase viscosity. In addition, the latter increases dynamic shear stress. An increase in these indicators leads to an increase in hydraulic resistance, which negatively affects the hydrodynamics of the well drilling process.
Figure 3. The dependence of the viscosity of clay solutions with lubricants on the time since the preparation of the solution.

From this figure it can be seen that these additives can reduce the viscosity to 0.12 at a concentration in the range of 1.5–2%, which corresponds to a relative decrease in the viscosity compared to untreated clay solution by 75%.

Further, during the drilling process, when switching to a hydrocarbon-based drilling mud, it is necessary to find out to what extent the rate of mixing of the mud affects the electrical stability index. The obtained laboratory results of measuring the breakdown voltage depending on the speed of mixing the solution during preparation are presented in Figure 5.

Figure 4. The dependence of the friction coefficient a pair of metal - metal in a clay solution on the concentration of the additive FRW.

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Further, during the drilling process, when switching to a hydrocarbon-based drilling mud, it is necessary to find out to what extent the rate of mixing of the mud affects the electrical stability index. The obtained laboratory results of measuring the breakdown voltage depending on the speed of mixing the solution during preparation are presented in Figure 5.
As you can see on the graph, the breakdown voltage increases with time and with an increase in the speed of rotation of the mixer spindle. This suggests that, at a rotation speed of 17 000 rpm, the solution quickly gains its stability and reaches an almost peak value of the breakdown voltage after 30 minutes of mixing. The solution stood for 24 hours and was stirred for 10 minutes, then a decrease in the electrical stability index was recorded. A decrease in electrical stability was noted in all solutions by 6-14% to a value of the order of 1180 V, which indicates the alignment of indicators over time.

4. Results and discussion

According to the results of the research, the coefficient of friction of the peel of the treated clay solution varies from 0.1 to 0.06, while the relative decrease in the coefficient of friction reaches 37%. With an increase in the concentration of the lubricating additive of more than 2%, the decrease in the coefficient of friction of the crust slows down, which is characterized by a decrease in the angle of inclination of the curve.

As a result of studies of the electrical stability of the drilling fluid on a hydrocarbon basis, we can conclude that increasing the frequency of mixing the fluid for every 3000 rpm gives an increase in the electrical stability of the emulsion by 4-16%, an increase in time for every 15 minutes by 7-24%, up to reaching its ultimate value. Moreover, the marked alignment of the indicators of electrical breakdown in a day can be used in production: if there is no need for quick preparation of an emulsion drilling fluid with a given electrical stability, then it is sufficient to prepare a solution at lower rotation speeds.

5. Conclusion

As a result of the study, the FRW lubricant additive of various modifications showed results comparable with the results obtained with the currently used reagents: the decrease in the friction coefficient of the metal – metal pair in a clay solution was 70–75%, in a water-based solution - up to 65%. The preparation of the solution does not cause difficulties, foaming is not observed, the reagents practically do not change the pH of the solution, the introduction of a lubricating additive practically does not cause a change in the rheological properties of the clay solution. According to the results of the study of reducing the coefficient of friction in different environments, the optimal concentration of the lubricating additive FRW was approximately 1.5–2%. Thus, FRW additives of various modifications can be successfully used as lubricants, however, a more detailed study of them in the composition of drilling fluids, as well as a field study, is necessary.

In complex and emergency situations when drilling wells, the preparation time of a hydrocarbon-based drilling fluid can be significantly reduced due to the high-quality selection of components and the use of synthetic low-viscosity oil for the preparation of high-quality hydrocarbon-based drilling fluids. Researches have shown that the regulation of the mixing speed of the solution provides emulsion solutions with specified indicators of electrical stability.
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