



Developments Made in the Field of Drilling Fluids by Saint Petersburg Mining University

M. V. Dvoynikov, M. V. Nutskova*, P. A. Blinov

Well Drilling Department, Oil and Gas Faculty, Saint Petersburg Mining University, Saint Petersburg, Russia

PAPER INFO

Paper history:

Received 10 July 2019

Received in revised form 08 November 2019

Accepted 16 January 2020

Keywords:

Completion

Complicated Conditions

Drilling

Fluid

ABSTRACT

The article discusses researches performed in the Well Drilling Department of the St. Petersburg Mining University. The directions of development of the department are shown. Special attention in this article is paid to research in the field of developing drilling fluids for drilling wells in various mining and geological conditions. It is shown that the gas-liquid mixtures studied by the department will be effective for under balanced drilling under conditions of abnormally low reservoir pressures when using a binary mixture of sodium lauryl sulfate 0.5% + linear sodium alkyl benzene sulfate 0.5% as a surfactant and polyacrylamide FP complex 107 (0.05%) as a forming and stabilizing additive + carboxymethyl starch BUR-2 (1%). Studies in the field of development of inhibitory fluids have shown that an increase in the concentration of polar compounds in the drilling fluid compared to their concentration in the rock $C_p > C_n$ by 0.25 mol/L makes it possible to increase the stability of the rocks around the wellbore compared to the initial conditions. Studies of lubricating additives showed that introducing 1.5–2.0% of FRW additive reduces the friction coefficient of the metal–metal pair in a clay solution by 70–75% and in an aqueous solution up to 65%. The findings suggest that drilling fluids developed at the Well Drilling Department of the St. Petersburg Mining University have a high potential for their application in oil and gas fields in order to improve the efficiency of drilling and completion of wells. It is also noted that the scientific and technical potential of the department allows for input control of reagents in drilling fluids, as well as the development and research of various compositions not only for drilling and completion of wells, but also for development and repair, which are applicable in real field conditions.

doi: 10.5829/ije.2020.33.04a.22

NOMENCLATURE

Q_L	Flow rate of liquid (m ³ /s)	D_s	Dispersion coefficient
Q_g	Flow rate of gas (m ³ /s)	D	Molecular diffusion coefficient
Q_{gm}	Gas flow rate providing the required downhole pressure considering the differential pressure (m ³ /s)	Gel	Gel strength (Pa)
Q_{gb}	Gas flow rate ensuring mud removal (m ³ /s)	E	Expansion rate
S_{AO}	Area of the annular space in the open hole (m ²)	K_r	Rupture coefficient
g	Avitational acceleration (m/s ²)	S_f	Foam stability (s/sm ³)
d_m	Average diameter of mud particle (m)	$R_{w(50\%)}$	50% water release rate (sm ³ /s)
P_R	Reservoir pressure (Pa)	Greek Symbols	
P_{atm}	Atmospheric pressure (Pa)	ΔP	Allowable differential pressure (Pa)
P_F	Hydrostatic pressure of the foam mud (Pa)	ρ_m	Mud density (kg/m ³)
P_r	Rock pressure (Pa)		Gas density at standard pressure and temperature (kg/m ³)
C_s	Concentrations of polar compounds in the solution (mol/l)	ρ_{stp}	Density of liquid (kg/m ³)
C_r	Concentrations of polar compounds in the rock (mol/l)	ρ_L	Density of liquid (kg/m ³)
k'	Dielectric constant of the pore fluid (F/m)	β	Estimated gas content to provide the necessary "downhole" pressure
		η_{600}	Viscosity at a speed of 600 rpm (mPa·s)

*Corresponding Author Email: turitsyna_maria@mail.ru (M. V. Nutskova)

T	Absolute temperature (K)	τ_{100}	Shear stress at a speed of 100 rpm (mPa·s)
C_c	Concentration of ions (mol/l)	τ_{600}	Shear stress at a speed of 600 rpm (mPa·s)
K	Coefficient of permeability of the rock	ϑ	Thickness of the double diffuse layer
M_v	Coefficient of change in the volume of the rock	ν	Valence of the ions of the pore fluid
\emptyset	Porosity of the rock	Φ	Water potential of the rock in Pa
K_w	Volumetric modulus of elasticity of water	θ_w	Volumetric water content
K_r	Volumetric modulus of elasticity of the rock	α_t	Coefficient of the filtration of the solution through the membrane
G_r	Shear modulus (Pa)	Subscripts	
C	Concentration of pore fluid in the solution (mol/l)	PVP	Polyvinylpyrrolidone
q	Density of the water flow	PHPA	Partially-hydrolyzed polyacrylamide
t	Time (s)	PAC LV + HV	Polyanionic cellulose low viscosity + high viscosity

1. INTRODUCTION

The construction of wells is a complex multi-criteria process. The quality of the process is paramount since the fulfilment of the purpose of construction is dependent on it. The set of measures for well drilling should ensure that risks are minimized at all stages of the drilling process as well as during subsequent well operation.

It is possible to provide an integrated approach for the construction of wells by combining research from experts in various fields, including but not limited to, the field of drilling fluids, cement slurries, directional drilling, equipment and tool development. The Mining University is a platform that provides such cooperation. The scientific potential of the employees and the laboratory and instrument base of the well drilling department currently provide not only training for the exploration and oil and gas industries but also conducts scientific research in the field of developing drilling fluids, drilling and completion techniques and technologies in complex mining and geological fields conditions within the framework of state tasks and research and development work for oil and gas companies of the Russian Federation.

The Scientific School of the Well Drilling Department of the St. Petersburg Mining University is developing technologies [1–4] and technical tools for drilling wells and their development [5, 6] in difficult conditions. Research has been focused on the development of drilling fluid compositions [7–18] and well cementing [19–26] in various geological conditions; development of technological solutions for drilling directional, multilateral wells with extended reach [27–32], development of technology and techniques for drilling in ice and drilling into the relict Lake Vostok in the Antarctica [33–39].

When drilling wells a significant proportion of the complications can be prevented by using drilling fluid systems that ensure maximum preservation of the nominal diameter of the wellbore due to various mechanisms of interaction between drilling fluids, formation fluids and rocks. For example, when drilling

wells under conditions of abnormally low reservoir pressures with low permeability, various researchers propose the use of low-density solutions, for example, aerated liquids [40–45], aphron-based solutions [46, 47] and oil-based solutions [48, 49], as well as the technology of drilling under balanced wells [44, 45, 50]. In addition, when drilling into formations with low permeability like shale the drilling process is prone to problems. Such formations must be drilled using special inhibitors [51–54]. This will increase stability and maintain the nominal diameter of the wellbore and reduce pay zone contamination. Currently, more and more horizontal wells are being drilled. In addition to the previous points, much attention is also paid to improving the lubricating properties of the drilling fluid which can be achieved through the use of oil-based fluids [48, 55] or through the introduction of special additives [56].

According to the results of the survey in the field of well completion it is clear that the development of drilling fluid compositions for drilling into the pay zones is an urgent task for specific geological conditions. The paper shows the research of the well drilling department aimed at developing aerated fluids, inhibited drilling fluids and solutions with improved lubricating properties for deviated and horizontal wells as well.

When drilling wells, a significant proportion of problems can be prevented using drilling mud systems that ensure maximum preservation of the nominal diameter of the well bore by means of providing various interaction mechanisms of drilling fluids, formation fluids and rocks.

2. RESEARCH METHODOLOGY

Methods for solving problems in scientific research involve a complex of theoretical, experimental and analytical work using standard and developed research methods.

Measurement of technological parameters of drilling liquids was carried out using standard instruments: density (ρ , kg/m³) – mud balance TrueWate; fluid loss –

filter press; rheological properties (gel strength (Gel, Pa), viscosity (η , mPa·s) and shear stress (τ , mPa·s) – rotational viscometers Fann 35SA and Rheotest RN 4.1; expansion rate (E), rupture coefficient (K_r), foam stability (S_f , s/sm³), 50% water release rate ($R_{w(50\%)}$, sm³/s)– measured glass cylinder; surface tension coefficient - tensiometer. EasyDrop drop shape analysis system; friction coefficient - Fann EP / Lubricity Tester. a device for determining the coefficient of clay cake KTK-2; acidity of the medium - pH meter Crison GLP 21; conditional viscosity - Marsh funnel; inhibitory ability - PNP-1 device. The preparation of solutions was carried out in a mixer at a speed of 2000-3000 rpm.

For the use of gas-liquid mixtures in practice a methodology was developed for calculating the flow of liquid and gas to ensure under balanced drilling.

Hydraulic calculations of well cleaning with foam muds are complicated by the compressibility of the gas phase. Safety regulations in the oil and gas industry allow drilling operations with differential pressure regulation in the well-reservoir system, provided that, the allowable differential pressure (ΔP) on the borehole walls during drilling does not exceed 10–15% of effective skeletal stresses [57].

The flow rate of liquid (Q_L) and gas (Q_g) was calculated based on the following conditions [58]:

$$Q_{gm} \leq Q_{gb}, \quad (1)$$

where Q_{gm} is the gas flow rate providing the required downhole pressure considering the differential pressure and Q_{gb} is the gas flow rate ensuring mud removal [58]:

$$Q_{gm} = 1,3 \cdot S_{AO} \cdot A \cdot B, \quad (2)$$

where [59]:

$$A = \sqrt{\frac{g \cdot d_m \cdot \rho_m \cdot P_R}{\rho_{stp} \cdot P_{atm}}}, \quad (3)$$

$$B = \sqrt{\left(\frac{0,011 \cdot S_{AO}^2 \cdot d_m \cdot \rho_R \cdot g}{Q_L^2 \cdot \rho_L + 0,008 \cdot S_{AO}^2 \cdot d_m \cdot \rho_m \cdot g} - 0,008 \right)}, \quad (4)$$

where S_{AO} is the area of the annular space in the open hole in m²; g – gravitational acceleration in m/s²; d_m – average diameter of mud particle in m; ρ_m – mud density in kg/m³; P_R – reservoir pressure; ρ_{stp} – gas density at standard pressure and temperature in kg/m³; P_{atm} – atmospheric pressure in Pa; ρ_L – density of liquid in kg/m³.

Gas flow rate ensuring mud removal is obtained as [58]:

$$Q_{gb} = \frac{\beta \cdot Q_L}{1 - \beta}, \quad (5)$$

where β is the estimated gas content to provide the necessary "downhole" pressure:

$$\beta = 1 - \frac{P_R - 0,5 \cdot \Delta P}{P_F}, \quad (6)$$

where P_F is the hydrostatic pressure of the foam mud in Pa.

Allowable differential pressure is calculated as [57]:

$$\Delta P = 0,1 \cdot (P_r - P_R), \quad (7)$$

where P_r is rock pressure in Pa;

An algorithm for hydrodynamic calculation of foam well cleaning is proposed, in which the initial conditional value of fluid flow Q_L is set, and the optimal value of Q_L is selected by increasing it by ΔQ_L until the condition $Q_{gm} = Q_{gb}$ is met. The developed method incorporates other various inert gases used for the foam mud aeration, and it is not only for air, as suggested in the methods that existed previously [59, 60].

According to the Le Chatelier principle, water will move from areas with high activity to areas with low activity in order to minimize imbalance, i.e. the flow will be observed from the region with lower salinity to the region of higher salinity. The penetration of water into the pore space of shale affects the thickness of the double diffuse layer according to the theory of Gouy Chatelier [61]:

$$\vartheta \propto \sqrt{\frac{k'T}{C_c \nu^2}}, \quad (8)$$

where k' is dielectric constant of the pore fluid in F/m, T – the absolute temperature in K, C_c – concentration of ions in mol/l, ν – valence of the ions of the pore fluid.

If the thickness of the double dielectric layer varies to a large extent, the volume of bound water in a clay rock changes, which in turn affects its physical and mechanical properties.

The main effect of dissolved ions is their effect on the osmotic pressure. Certain values of the osmotic pressure are achieved by changing the concentration of ions, according to the expression [61]:

$$\frac{\partial \Phi}{\partial t} = C_c [\nabla(K \cdot \nabla \Phi)], \quad (9)$$

where Φ – water potential of the rock in Pa, t – time in s, K – coefficient of permeability of the rock.

$$C_c = \frac{\partial \Phi}{\partial \theta_w} = \frac{1}{(M_v + \theta/K_w)}, \quad (10)$$

$$M_v = \frac{1}{(K_r + 4/3 G_r)}, \quad (11)$$

where θ_w – volumetric water content, M_v – coefficient of change in the volume of the rock, θ – porosity of the rock, K_w – volumetric modulus of elasticity of water, K_r – volumetric modulus of elasticity of the rock, G_r – shear modulus in Pa.

The influence of osmotic pressure on the flow of the pore fluid 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 flow of the pore fluid.

The interaction between the drilling fluid and the pore fluid, including material transfer, dispersion and diffusion can be described by the following equation [61]:

$$\frac{\partial \phi C}{\partial t} = -\nabla(Cq - \theta_w D_s \nabla C - \theta_w D \nabla C)(1 - \alpha_t), \quad (12)$$

where C – concentration of pore fluid in the solution in mol/l, q – density of the water flow, D_s –dispersion coefficient, D –molecular diffusion coefficient, α_t – coefficient of the filtration of the solution through the membrane.

The interaction of the drilling fluid and shale has a significant effect on the stability of the wellbore and leads to a change in pore pressure and stress-strain state of the rock around the well as a result of the redistribution of polar compounds due to the difference in their concentration in the drilling fluid and the rock [61].

3. EXPERIMENTAL

3.1. Foam Mud According to the requirements for cleaning agents, they must be chemically inert to the rocks being drilled and reservoir fluids in order to prevent the destruction of the walls of the wellbore, contamination of productive formations. An example of such a composition is a foam mud, which facilitates underbalanced drilling into the reservoir and thus preserves the natural permeability of the bottom zone.

At the Well Drilling Department the foaming ability of surfactants was studied and the dependences (Figure 1) of the multiplicity of the concentration of the component in the range from 0.05 to 0.2% were determined. The graphs show the experimental data and the trend lines constructed from them (approximation and smoothing R^2 –R-squared value). In the given interval the dependence of the multiplicity on the surfactant

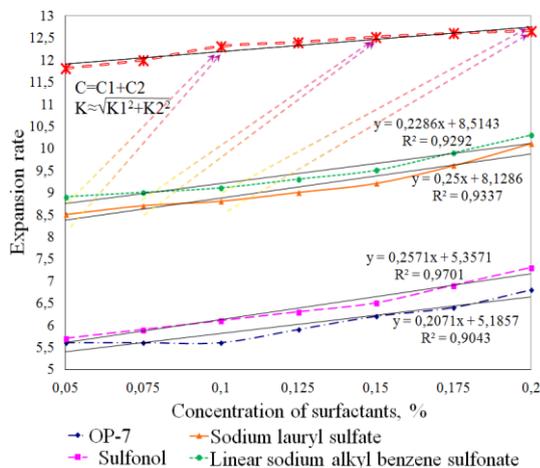


Figure 1. The dependence between the foaming ability of solutions and surfactant concentration.

concentration is traced as linear. For the binary composition of surfactants (in a total concentration of 0.1%) the resulting multiplicity is significantly higher than the sum of the multiplicities of the individual components (concentrations of 0.05%).

Further experimental studies were carried out with gas-liquid mixtures based on: sodium lauryl sulfate 0.05% + linear sodium alkyl benzene sulfate 0.05%, glycerol 1%, caustic soda 0.5%, fused potassium acetate 0.05%, organosilicon liquid gas condensate liquid-11 0.5%. The composition (sodium carboxy methyl cellulose, carboxymethyl starch-BUR-2, K.K. Robus. polyacrylamide Praestol, polyacrylamide FP-107) and the concentration (from 0.1 to 2%) of stabilizing and structure-forming components was varied. Tables 1 and 2 show the properties of 10 formulations that showed the best results.

The experimental data and the results of their processing prove that the flow of the studied gas-liquid

TABLE 1. Properties of gas-liquid mixtures obtained in laboratory conditions

№	ρ , kg/m ³	E	K_r	β	S_f , s/sm ³	$R_{w(50\%)}^*$, sm ³ /s
1	276	6.37	0.74	0.73	8.14	0.12
2	252	7.03	0.76	0.75	8.66	0.12
3	192	9.60	0.66	0.81	4.42	0.23
4	250	7.17	0.79	0.76	11.14	0.09
5	207	8.87	0.75	0.80	10.12	0.10
6	194	9.43	0.69	0.81	5.14	0.19
7	196	9.43	0.64	0.81	5.14	0.19
8	237	7.60	0.80	0.77	15.86	0.06
9	202	9.10	0.76	0.80	8.50	0.12
10	226	8.05	0.85	0.78	7.20	0.14

TABLE 2. Rheological properties of gas-liquid mixtures

№	η_{100} , mPa·S	η_{600} , mPa·S	τ_{100} , Pa	τ_{600} , Pa	Gel, Pa
1	123.10	56.58	12.86	34.12	22.95
2	134.70	53.96	14.11	32.54	62.55
3	72.59	32.65	7.48	19.69	74.25
4	165.20	68.51	17.33	41.35	74.25
5	148.60	53.94	15.54	32.56	91.35
6	151.90	52.10	15.92	31.44	83.70
7	113.90	42.62	11.84	25.62	56.25
8	251.40	90.06	26.45	54.41	26.10
9	197.90	69.18	20.77	41.78	29.70
10	250.40	90.13	26.39	54.44	59.85

mixtures in the range of shear rates from 100 to 600 s⁻¹ can be described by the Ostwald-de Waale rheological equation with a degree of certainty of $\sigma = 0.96 \dots 1.00$.

3. 2. Inhibiting Drilling Muds

One of the mechanisms of interaction of the drilling mud and borehole walls is the inhibition of chemically active rocks, especially folded plastic and cracked clays [14, 16–18]. In plastic clay intervals, conditions leading to pack off may arise, especially if the drilling technology, including drilling mud, does not comply with the mining and geological conditions. Strong packing in soft shale is due to two factors: pressure drop, which, according to Garnier and Van Lingen, increases due to hydration forces acting in compacted shale, and very high adhesion forces resulting from the plastic deformation of shale forming tight contact with bit surfaces [62, 63]. The forces of attraction acting at very small distances begin to manifest themselves as solids entering the tight contact. In addition, soft clays (or shale, which get softer when they come in contact with water-based drilling fluids) are characterized by small internal adhesion forces, and sticking depends on the difference between adhesive and cohesive forces. To prevent pack offs, reagents (detergents), which form a thin film on the surface of metals and reduce the forces of surface tension at the interface of the metal- drilled rock are designed to be utilized. On the basis of theoretical and experimental studies conducted at the Well Drilling Department, it can be concluded that to drill in clay deposits biopolymer-based drilling muds with small additions of surfactants, such as sulfanol can be put to use [14, 16, 17].

The degree of the wellbore stability is influenced by such factors as the ratio between the angle of inclination of the well and the angle of bedding, as well as the difference in strength properties along the bedding surface and along the normal to it [62–65]. Partial wall collapse is encountered in vertical wells drilled in argillaceous rocks with a large angle of incidence or in inclined wells that intersect the planes of shale beddings at small angles. The planes of bedding represent the weakening surface, along which the rock is destroyed under the action of the tangential stresses on them. The anisotropy of the properties can be neglected if the clay is in the early stage of lithogenesis and has a texture with a dimly pronounced bedding [64, 65]. In other cases, neglecting the anisotropy of the properties can lead to incorrect data when modeling the stability of the wellbore. The interaction of the drilling fluid and shale rock has a significant effect on the stability of the wellbore and leads to changes in pore pressure and the stress-strain state of the rock around the well, as a result of the redistribution of polar compounds due to the difference in their concentration in the drilling fluid and rock.

Figures 2 and 3 present the results of a calculation aimed at determining the effect of the interaction of drilling mud and rock, as a result of the difference in the concentration of polar reagents, on the stability of the rocks around the wellbore.

The graphs show that if the initial concentrations of polar compounds in the solution (C_s) and in the rock (C_r) are not balanced, then with an increase in the interaction time between them, the pore pressure changes and as a result, the stability of the rocks composing the borehole walls decreases.

To further study the inhibition mechanism, studies were conducted to determine the stability of shale. Selection of reagents was carried out based on the analysis of the work of researchers and the experience of commercial use of inhibitors of clay swelling rocks. The combinations were selected on the basis of their assumption that compounds with different molecular

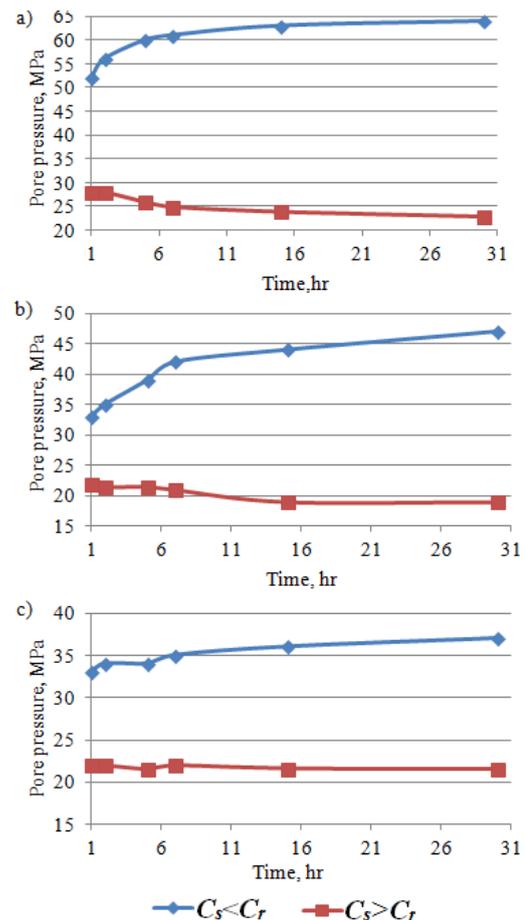


Figure 2. Graphs of pore pressure distribution in the rock around the wellbore over time: a) is on the contour of the well; b) is at a distance of 1.5r from the well axis; c) is at a distance of 2r from the axis of the well, where r is the radius of the well in m.

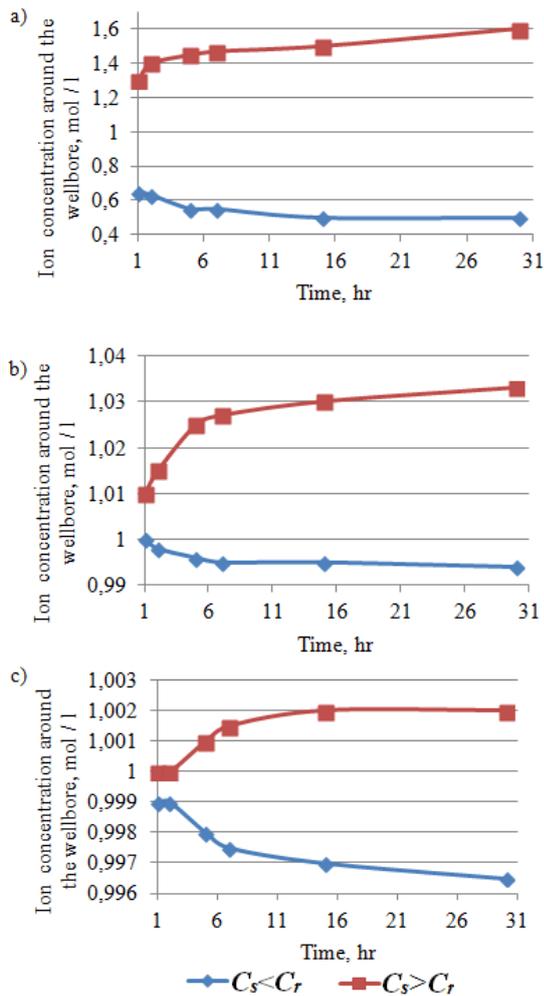


Figure 3. Graphs of the distribution of the concentration of dissolved ions in the rock around the wellbore over time: a) is on the contour of the well; b) is at a distance of $1.5r$ from the well axis; c) is at a distance of $2r$ from the axis of the well, where r is the radius of the well in m.

weights can form a structure with more dense packing in water. High-molecular compounds like polyvinylpyrrolidone (PVP), triethanolamine, Barazan, PHPA, PAC LV + HV in combination with polar reagents such as NaCl, KCl, NaHCOO were used as reagents capable of forming interstitial solutions. The choice of polar compounds was made on the assumption that the filling of various types of water cavities with ions would affect the inhibition efficiency.

In Figure 4 samples of clay rocks (obtained from bentonite clay powder by pressing under a load of 6 MPa and then dring to the required moisture indices) in aqueous solutions are presented.

Based on the results of the experiments presented in Figure 4, it can be concluded that the range of overlap of various types of water cavities does not have a significant effect on maintaining the stability of the sample.

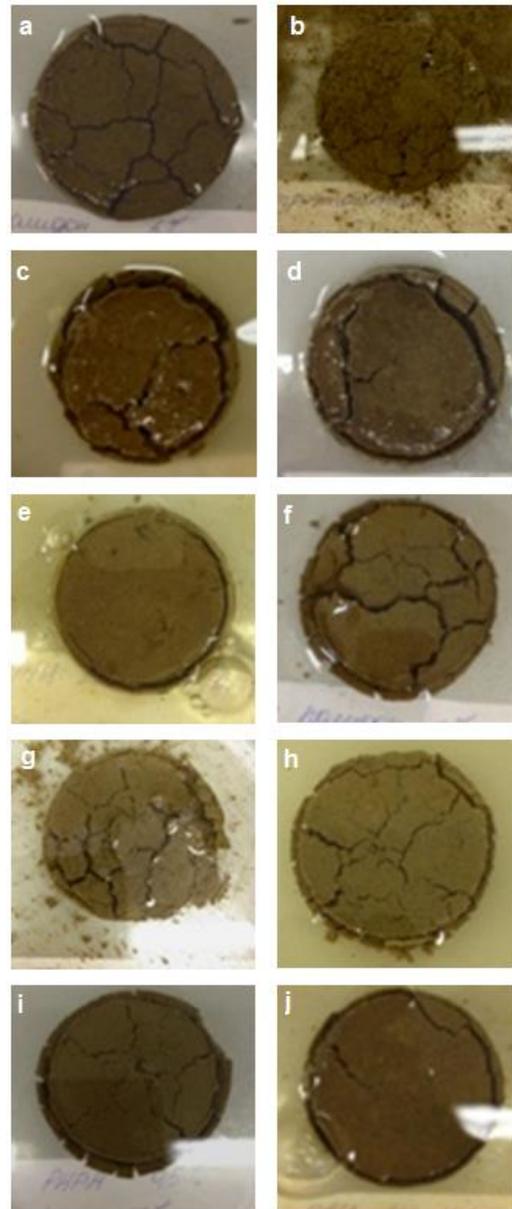


Figure 4. Samples of clay rocks in aqueous solutions of inhibitors

- a: 5% HCOONa + 5% PVP;
 - b: 5% HCOONa + 5% triethanolamine;
 - c: 5% HCOONa + 0.5% Barazan;
 - d: 5% HCOONa + 0.5% PHPA;
 - e: 5% HCOONa + 1% PAC LV + HV;
 - f: 3% NaCl + 2% KCl + 5% PVP;
 - g: 3% NaCl + 2% KCl + 5% triethanolamine;
 - h: 3% NaCl + 2% KCl + 0.5% Barazan;
 - i: 3% NaCl + 2% KCl + 0.5% PHPA;
 - j: 3% NaCl + 2% KCl + 1% PAC LV + HV;
- 120 hours after the beginning of the experiment.

3. 3. Fluids for Drilling of Inclined and Horizontal Wells

The problem of wellbore stability is particularly acute when drilling inclined and horizontal

wells. Practice shows that for a number of fields, when the angle of well inclination is at certain value, which may be different for different rocks, problems arise during drilling, hole caving [66]. When drilling a well in a rock mass, there is a redistribution of stresses associated with a decrease in pressure in the well in the surrounding areas. At the same time, shear stresses appear, which are responsible for the destruction [27].

During the simulation of the stress state of rocks around the well, critical points were determined. For small angles of well inclination, they are in the plane formed by its axis and vertical. With an increase in the angle of well inclination, the maximum tangential stresses increase and the points of the maxima shift in both directions around the circumference at a certain angle. It should be noted that with an increase in the angle of well inclination, not only the magnitude of the maximum of tangential stresses does increase, but also the size of the region in which high stresses act. This, of course, increases the likelihood of destruction. Based on the calculations, it can be concluded that the most dangerous from the point of view of the loss of stability of wells are the slopes within the range 40°–60° depending on the adhesion modulus and the angle of internal friction of the rock [7, 11–13].

In addition, when drilling directional and horizontal wells, the issue of improving the tribotechnical characteristics of the drilling fluid is very essential. One of the tools that promote problem-free drilling in directional and horizontal sections is the use of drilling fluid systems with minimal friction coefficients [67].

It is advisable to use hydrocarbon-based drilling fluids, as well as water-based ones with special lubricant additives. When drilling wells, in almost all cases, the intensity of rubbing of the casing strings depends on the application force and friction forces of the connecting locks of drill pipes to their inner surface, therefore, it is most expedient to use techniques based on the friction pair of the metal-to-metal or metal-to-rock to assess the lubricity of the additives [66–68]. In conjunction with the Perm National Research Polytechnic University, a study of lubricant additives in drilling fluids was conducted. Studies were conducted with Lubristeel, FRW A, FRW B, FRW reagents, Lubrital, PolyMudLiquid, ASP 820. FRW, FRW A and FRW B copyrighted by the Perm National Research Polytechnic University.

Figure 5 presents the results of a lubricity study based on the determination of the friction coefficient of a metal-metal pair in a liquid medium, which characterizes the rotation of the drill string in a cased section of the wellbore, and a metal-clay crust, which characterizes the sticking of the drill string to clay crust on the borehole wall.

Based on well drilling practices, the most rational is the use of such additives, which make it possible to maintain the value of the friction coefficient of the metal-

metal pair in the range of up to 0.18–0.20 in drilling fluids [74]. It can be seen that the lubricity of the FRW reagent in various modifications is in the same range as currently used additives. The behavior of clay solutions with additives of 0.1% PolyMudLiquid and ASP 820 is characterized by a higher value 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 lubricity, but also the viscosity of the solution.

According to the results of the research, the coefficient of friction of the peel of the treated mud varies from 0.1 to 0.06, while the relative decrease in the coefficient of friction reaches 37%. When the concentration of the lubricant is increased by more than 2%, the decrease in the coefficient of friction of the peel slows down, which is characterized by a decrease in the angle of inclination of the curve.

4. RESULTS AND DISCUSSION

Studies conducted at the well drilling department have shown that it is advisable to use binary surfactant mixtures to obtain foam muds, which makes it possible to obtain compositions with specified technological characteristics due to their synergistic effect. Foam muds are colloidal systems (the dispersion medium of which is a liquid, the dispersed phase is gas), in which thickening of the dispersion medium by means of introduction of clay or polymers results in providing stability. When drilling into productive horizons, the use of clays is limited in order to conserve reservoir properties, therefore, to increase the stability of the compositions, it is advisable to use polymer reagents [9, 10]. The composition which includes polyacrylamide FP 107

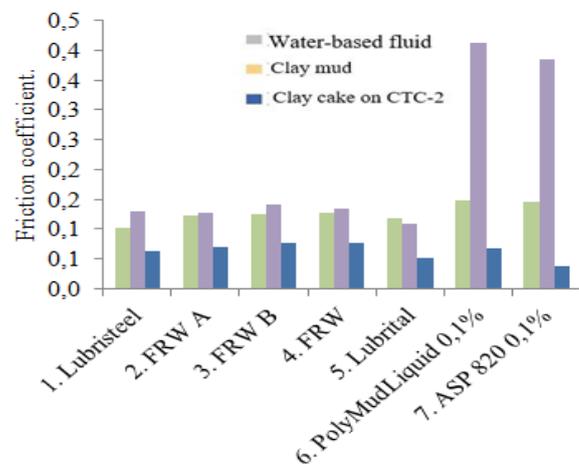


Figure 5. Coefficient of friction of solutions with lubricating additives

(0.05%) + carboxymethyl starch-BUR-2 (1%) as a structure-forming and stabilizing additive, is most expedient technologically and economically (does not lose technological parameters during subsequent circulation cycles).

Analysis of the graphs (Figures 2 and 3) shows that decrease in the concentration of polar compounds in the drilling fluid compared to their concentration in the rock $C_s > C_r$ by 0.25 mol/l (see Figures 1 and 2) contributes to a significant increase in pore pressure around the wellbore due to the transfer of unbound water into the space rock and leaching of dissolved ions from it. Ion transport in turn reduces the concentration of polar compounds in the rock around the wellbore. As a result of the described processes, there is a redistribution of stresses in the rock around the wellbore and a decrease in their stability compared to the initial conditions.

Increasing the concentration of polar compounds in the drilling fluid in comparison with their concentration in the rock $C_s > C_r$ 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 into the drilling mud. As a result, the stability of the rocks around the wellbore is increased in comparison with the initial conditions.

The results of study of the stability of shale (Figure 4) showed that treatment of water-based drilling fluids with reagents with different molecular weights helps to reduce the activity of the dispersion medium of the solution, restrain the growth of pore pressure in the rocks making up the borehole walls, and thereby increases the stability of the wellbore when drilling in clay rocks.

Further studies are aimed at selecting the optimal concentrations of compounds and combinations of reagents that will ensure complete preservation of the sample with long-term interaction of the dispersion phase of the solution with rocks [23].

Based on the analysis of the obtained data, studies of the lubricity of the additive, the lubricating additive FRW in various modifications, showed comparable results to the results obtained using reagents currently used: the reduction of the friction coefficient of the metal-metal pair in the clay fluid was 70–75%, and in the water-based up to 65%. Problems are not encountered in the course of preparation of the fluid, no foaming is observed, the reagents practically do not change the pH of the solution, the introduction of a lubricating additive practically does not cause changes in the rheological properties of the mud. According to a study of the reduction of friction coefficient in different environments, the optimal concentration of the lubricant additive FRW was approximately 1.5–2%. Thus, FRW additives in various modifications can be successfully used as lubricants, however, more detailed study of them in the composition of drilling fluids, as well as research in field conditions is necessary [15].

5. CONCLUSION

Drilling fluids developed and being developed at the Well Drilling Department of the St. Petersburg Mining University have a high potential for their application in oil and gas fields in order to improve the efficiency of drilling and completion of wells. Further research is aimed at developing not only new compositions of fluids, but also technologies for their use in specific mining and geological conditions. Also, the scientific and technical potential of the department allows for input control of reagents in drilling fluids, as well as the development and research of various compositions not only for drilling and completion of wells, but also for development and repair, which are applicable in real field conditions.

6. REFERENCES

1. Lebedev, V.A., Leusheva, E.L. and Morenov, V. A., "Complex Power Supply at Well Drilling in Complicated Climate Conditions", *Journal of Mining Institute*, Vol. 213, (2015), 47–53.
2. Leusheva, E.L. and Morenov, V. A., "Combined oilfield power supplying system with petroleum gas utilization as an energy carrier", *Neftyanoe Khozyaystvo-Oil Industry*, Vol. 4, (2015), 96–100.
3. Leusheva, E.L. and Morenov, V. A., "Development of combined heat and power system with binary cycle for oil and gas enterprises power supply (Russian)", *Oil Industry Journal*, Vol. 2017, No. 7, (2017), 104–106.
4. Leusheva, E. and Morenov, V., "Energy delivery at oil and gas wells construction in regions with harsh climate", *International Journal of Engineering - Transactions B: Applications*, Vol. 29, No. 2, (2016), 274–279.
5. Kupavikh, K.S. and Nutskova, M. V., "Ecological features of oil well repair at low-permeability reservoir", *International Journal of Applied Engineering Research*, Vol. 11, No. 11, (2016), 7505–7508.
6. Kupavykh, K.S. and Shipulin, A. V., "Pulsed method of coalbed methane drainage", *Gornyi Zhurnal*, Vol. 5, (2018), 78–82.
7. Blinov, P.A. and Dvoynikov, M. V., "The process of hardening loose rock by Mud Filtrat", *International Journal of Applied Engineering Research*, Vol. 11, No. 9, (2016), 6630–6632.
8. Blinov, P.A. and Podoliak, A. V., "The method of determining the effects of drilling fluid on the stability of loose rocks", *International Journal of Applied Engineering Research*, Vol. 11, No. 9, (2016), 6627–6629.
9. Nutskova, M.V. and Kupavykh, K. S., "Improving the quality of well completion in deposits with abnormally low formation pressure", *International Journal of Applied Engineering Research*, Vol. 11, No. 11, (2016), 7298–7300.
10. Nutskova, M.V., Dvoynikov, M.V. and Kuchin, V. N., "Improving the quality of well completion in order to limit water inflows", *Journal of Engineering and Applied Sciences*, Vol. 12, No. 22, (2017), 5985–5989.
11. Blinov, P.A., Dvoynikov, M.V., Sergeevich, K.M. and Rustamovna, A. E., "Influence of mud filtrate on the stress distribution in the row zone of the well", *International Journal of Applied Engineering Research*, Vol. 12, No. 15, (2017), 5214–5217.
12. Blinov, P.A. and Dvoynikov, M. V., "Rheological and filtration parameters of the polymer salt drilling fluids based on xanthan

- gum”, *Journal of Engineering and Applied Sciences*, Vol. 13, No. 14, (2018), 5661–5664.
13. Blinov, P. A., “Determining the stability of the borehole walls at drilling intervals of loosely coupled rocks considering zenith angle”, *Journal of Mining Institute*, Vol. 236, (2019), 172–179.
 14. Leusheva, E. and Morenov, V., “Research of clayless drilling fluid influence on the rocks destruction efficiency”, *International Journal of Applied Engineering Research*, Vol. 12, No. 6, (2017), 945–949.
 15. Melekhin, A.A., Chernyshov, S.E., Blinov, P.A. and Nutskova, M. V., “Study of lubricant additives to the drilling fluid for reducing the friction coefficient during well construction with rotary steerable system (Russian)”, *Oil Industry Journal*, Vol. 2016, No. 10, (2016), 52–55.
 16. Morenov, V. and Leusheva, E., “Development of drilling mud solution for drilling in hard rocks”, *International Journal of Engineering -Transactions A: Basics*, Vol. 30, No. 4, (2017), 620–626.
 17. Martel, A., Leusheva, E. and Morenov, V., “Investigation of the fractional composition effect of the carbonate weighting agents on the rheology of the clayless drilling mud”, *International Journal of Engineering - Transaction A: Basics*, Vol. 31, No. 7, (2018), 1152–1158.
 18. Nikolaev, N.I. and Leusheva, E. L., “Increasing of hard rocks drilling efficiency (Russian)”, *Oil Industry Journal*, Vol. 2016, No. 3, (2016), 68–71.
 19. Kozhevnikov, E.V., Nikolaev, N.I., Melekhin, A.A. and Turbakov, M. S., “Studying the properties of cement slurries for cementing oil wells with long horizontal section drilled with rotary steerable system”, *Neftyanoe Khozyaystvo-Oil Industry*, Vol. 9, (2015), 58–60.
 20. Merzliakov, M.I. and Podoliak, A. V., “Terms of melting the permafrost when cementing of boreholes plugged with gas-liquid mixtures with hollow microspheres”, *International Journal of Applied Engineering Research*, Vol. 12, No. 9, (2017), 1874–1878.
 21. Merzliakov, M.Y. and Podoliak, A. V., “Improving the efficiency of well cementing in permafrost regions by using gas-liquid cement mixtures”, *International Journal of Applied Engineering Research*, Vol. 12, No. 9, (2017), 1879–1882.
 22. Tabatabaee Moradi, S.S. and Nikolaev, N. I., “Free fluid control of oil well cements using factorial design”, *Journal of Engineering Research*, Vol. 5, No. 1, (2017), 220–229.
 23. Tabatabaee Moradi, S.S., Nikolaev, N.I., Chudinova, I.V. and Martel, A. S., “Geomechanical study of well stability in high-pressure, high-temperature conditions”, *Geomechanics and Engineering*, Vol. 16, No. 3, (2018), 331–339.
 24. Leusheva, E., Nikolaev, N. and Tabatabaee Moradi, S. S., “Improvement of cement properties using a single multifunctional polymer”, *International Journal of Engineering - Transaction A: Basics*, Vol. 31, No. 1, (2018), 181–187.
 25. Tabatabaee Moradi, S.S. and Nikolaev, N. I., “Optimization of cement spacer rheology model using genetic algorithm (research note)”, *International Journal of Engineering - Transaction A: Basics*, Vol. 29, No. 1, (2016), 127–131.
 26. Tabatabaee Moradi, S.S. and Nikolaev, N. I., “Assessment of the cement failure probability using statistical characterization of the strength data”, *Journal of Petroleum Science and Engineering*, Vol. 164, (2018), 182–188.
 27. Dvoynikov, M.V. and Blinov, P. A., “Analysis of incident causes while directional and horizontal wells drilling”, *International Journal of Applied Engineering Research*, Vol. 11, No. 20, (2016), 10039–10042.
 28. Dvoynikov, M.V. and Blinov, P. A., “Survey results of series-produced downhole drilling motors and technical solutions in motor design improvement”, *International Journal of Applied Engineering Research*, Vol. 11, No. 10, (2016), 7034–7039.
 29. Dvoynikov, M., Syzrantsev, V. and Syzrantseva, K., “Designing a high resistant, high-torque downhole drilling motor”, *International Journal of Engineering -Transactions A: Basics*, Vol. 30, No. 10, (2017), 1615–1621.
 30. Oshibkov, A.V., Vodorezov, D.D., Syzrantseva, K.V., Frolov, S.A., Dvoynikov, M.V. and Bakirov, D. L., “Analysis of sidetracking characteristics influence on multilateral well construction reliability”, *Oil industry*, Vol. 11, (2015), 121–123.
 31. Oshibkov, A.V., Vodorezov, D.D., Syzrantseva, K.V., Frolov, S.A., Dvoynikov, M.V., Svetashov, V.N. and Bakirov, D. L., “The stress-strain condition estimation of construction of multilateral well junction”, *Oil industry*, Vol. 6, (2015), 83–85.
 32. Syzrantseva, K., Arishin, V. and Dvoynikov, M., “Optimization of the damping element of axial vibrations of the drilling string by computer simulation”, *Journal of Engineering and Applied Sciences*, Vol. 11, No. 10, (2016), 2312–2315.
 33. Dmitriev, A.N., Bolshunov, A.V. and Podoliak, A. V., “Assessment of ice borehole temperature conditions at interface with subglacial Lake Vostok (Antarctica)”, *International Journal of Applied Engineering Research*, Vol. 11, No. 11, (2016), 7230–7233.
 34. Dmitriev, A.N. and Ignatiev, S. A., “Forecast of Thermal Behaviour Dynamics at Interface of Borehole 5 and Subglacial Lake Vostok (Antarctica)”, *International Journal of Applied Engineering Research*, Vol. 12, No. 9, (2017), 1885–1887.
 35. Podoliak, A.V. and Blinov, P. A., “The technology of directional drilling in ice via drills on carrying cable”, *International Journal of Applied Engineering Research*, Vol. 11, No. 9, (2016), 6411–6417.
 36. Podoliak, A.V., Bolshunov, A.V. and Dmitriev, A. N., “Drilling of Deep Borehole 5G at the Antarctic station ‘Vostok’ in ice layers with the ice temperature close to the phase transition point”, *International Journal of Applied Engineering Research*, Vol. 11, No. 11, (2016), 7234–7237.
 37. Vasilev, N.I., Bolshunov, A.V., Dmitriev, A.N. and Podoliak, A. V., “Round-trip assembly for investigations of subglacial lake vostok”, *International Journal of Applied Engineering Research*, Vol. 11, No. 9, (2016), 6376–6380.
 38. Vasilev, N.I., Bolshunov, A.V. and Ignatiev, S. A., “Inertial Mechanical Reamer for Borehole 5G-3 Conditioning for Penetration into Subglacial Lake Vostok”, *International Journal of Applied Engineering Research*, Vol. 12, No. 5, (2017), 561–566.
 39. Vasilev, N.I., Dmitriev, A.N., Podoliak, A.V., Lukin, V.V. and Turkeev, A. V., “Maintaining differential pressure in boreholes drilled in ice and the effect of ice hydrofracturing”, *International Journal of Applied Engineering Research*, Vol. 11, No. 19, (2016), 9740–9747.
 40. Luo, Y.R., Chen, M., Liu, D.S., Jin, Y., Du, M.H. and Hou, J., “Technology and applications of foam drilling fluid in fractured and complex formations”, *Petroleum Science and Technology*, Vol. 30, No. 16, (2012), 1747–1754.
 41. Azimi, A. H., “Experimental investigations on the physical and rheological characteristics of sand-foam mixtures”, *Journal of Non-Newtonian Fluid Mechanics*, Vol. 221, (2015), 28–39.
 42. Saxena, A., Pathak, A.K. and Ojha, K., “Synergistic effects of ionic characteristics of surfactants on aqueous foam stability, gel strength, and rheology in the presence of neutral polymer”, *Industrial & Engineering Chemistry Research*, Vol. 53, No. 49, (2014), 19184–19191.
 43. Wei, N., Meng, Y., Li, G., Wan, L., Xu, Z., Xu, X. and Zhang, Y., “Cuttings transport models and experimental visualization of underbalanced horizontal drilling”, *Mathematical Problems in Engineering*, Vol. 2013, (2013), 1–6.
 44. Ismail, I., Mamat, N.S., Mamat, B., Ismail, A.S., Kamis, A. and Ikhsan, A., “Improving Gas Bubbles’ Half Life in Foam Drilling Fluid”, *Jurnal Teknologi*, Vol. 62, No. 1, (2013), 103–110.

45. Graeme, R. and Melvin, D., "Bubbling under at Bunga Raya", *Offshore Engineer*, Vol. AOU, (2008), 59–60.
46. Heidari, M., Shahbazi, K. and Fattahi, M., "Experimental study of rheological properties of aphron based drilling fluids and their effects on formation damage", *Scientia Iranica*, Vol. 24, No. 3, (2017), 1241–1252.
47. Growcock, F.B., Belkin, A., Fosdick, M., Irving, M., O'Connor, B. and Brookey, T., "Recent advances in aphron drilling fluid technology", *SPE Drilling & Completion*, Vol. 22, No. 2, (2007), 74–80.
48. Bakirov, D.L., Podkuiko, P.P., Babushkin, E.V., Fattakhov, M.M., Akhmetshin, I. ., "Results of oil based drilling mud testing when sidetracking in the Nong-Eganskoye oil field", *Neftyanoe khozyaystvo - Oil Industry*, Vol. 11, (2012), 108–109.
49. Zhang, S., Jiang, G.-C., Wang, L., and Wang, Q., "Formation protection drilling and completion fluid in developing low permeability reservoirs", *International Journal of Earth Sciences and Engineering*, Vol. 6, No. 6, (2013), 1335–1341.
50. Khalil, M. and Mohamed Jan, B., "Viscoplastic modeling of a novel lightweight biopolymer drilling fluid for underbalanced drilling", *Industrial & Engineering Chemistry Research*, Vol. 51, No. 10, (2012), 4056–4068.
51. Jing, Z.X., Zheng, T., Sun, X. J., "Silicate based cationic drilling fluid system for horizontal wells Title", *Drilling Fluid and Completion*, Vol. 22, No. 5, (2005), 72–74.
52. Stawaisz, R., Taylor, S., Hemphill, T., Tare, U., Morton, K. and V., "Successfully replacing oil-based drilling fluids with water-based drilling fluids: Case study demonstrates value of extensive planning and execution in an extended-reach well", *SPE Drilling & Completion*, Vol. 18, No. 4, (2003), 332–338.
53. Jin, S.B., Niu, X., Dong, X. ., "Drilling fluid technology for Well TK431 in Tahe oilfield", *Drilling Fluid and Completion Fluid*, Vol. 19, No. 6, (2002), 71–73.
54. Yu, C., Yang, S., and Zhao, S., "Borehole Wall Strengthening with Drilling Fluids in Shale Gas Drilling", *Drilling Fluid and Completion Fluid*, Vol. 35, No. 6, (2018), 49–54.
55. Bakirov, D.L., Babushkin, E.V., Fattakhov, M.M. and Malyutin, D. V., "Improving the efficiency of multilateral wells construction by the use of oil-based drilling fluids (Russian)", *Oil Industry Journal*, Vol. 2016, No. 8, (2016), 28–30.
56. Jassim, L., and Yunus, R., "Simulation model of nano and conventional drilling fluids performance in horizontal well", *Advances and Applications in Fluid Mechanics*, Vol. 20, No. 2, (2017), 249–277.
57. Federal norms and rules in the field of industrial safety, "Safety rules in the oil and gas industry, Series 08", CJSC Scientific and Technical Center for Research on Industrial Safety Problems, (2013).
58. Petrakov D.G., Yakovlev A.A., and T. M. V., "Modeling the test studies of the exposing the producing horizon with liquid-gas mixtures process", *Territorija "NEFTEGAS" [Oil and Gas Territory]*, Vol. 11, (2015), 30–33.
59. Okpobiri, G.A. and Ikoku, C. U., "Volumetric requirements for foam and mist drilling operations", *SPE Drilling Engineering*, Vol. 1, No. 1, (1986), 71–88.
60. Olanson, M. T., "Application of foam cements in Alberta", *Journal of Canadian Petroleum Technology*, Vol. 24, No. 5, (1985), 49–57.
61. Ma, T. and Chen, P., "A wellbore stability analysis model with chemical-mechanical coupling for shale gas reservoirs", *Journal of Natural Gas Science and Engineering*, Vol. 26, (2015), 72–98.
62. Bradley, W. B., "Failure of inclined boreholes", *Journal of Energy Resources Technol.*, Vol. 101, No. 4, (1979), 232–239.
63. Zoback, M.D., Moos, D., Mastin, L. and Anderson, R. N., "Well bore breakouts and in situ stress", *Journal of Geophysical Research: Solid Earth*, Vol. 90, No. B7, (1985), 5523–5530.
64. Aadnoy, B.S. and Chenevert, M. E., "Stability of highly inclined boreholes (includes associated papers 18596 and 18736)", *SPE Drilling Engineering*, Vol. 2, No. 4, (1987), 364–374.
65. Aadnoy, B.S., and Ong, S., "Introduction to special issue on Borehole Stability", *Journal of Petroleum Science and Engineering*, Vol. 38, No. 3, (2003), 79–82.
66. Barmotin, K.S., Frolova, N.V. and Moysa, Y. N., "Application of the lubricant additive LUBRI-M with increased antisticking properties", *Neftyanoe Khozyaystvo*, Vol. 4, (2005), 30–31.
67. Litvinets, I.V., Prozorova, I.V., Yudina, N.V., Kazantsev, O.A. and Sivokhin, A. P., "Effect of ammonium-containing polyalkyl acrylate on the rheological properties of crude oils with different ratio of resins and waxes", *Journal of Petroleum Science and Engineering*, Vol. 146, (2016), 96–102.
68. Ivannikov, V.I., "Overpressure anomalies in deep and super-deep wells", *Construction of Oil and Gas Wells by Land and by Sea*, Vol. 5, (2012), 22–26.

Persian Abstract

چکیده

در این مقاله تحقیقات انجام شده توسط گروه حفاری چاه دانشگاه معدن سنت پترزبورگ مورد بحث قرار گرفته است. جهت‌های توسعه گروه بیان شده‌اند. توجه خاص این مقاله به تحقیقات در زمینه توسعه سیالات حفاری مناسب برای شرایط مختلف معدنی و زمین‌شناسی است. نشان داده شده است که، ترکیبات مخلوط گاز-مایع بررسی شده در گروه حفاری برای مخازن تحت فشار پایین مفید هستند. در این ترکیبات از سولفات لاریل سدیم نیم درصد و آلکیل بنزن خطی سولفات سدیم نیم درصد به عنوان مواد فعال سورفاکتانت و از پلی‌اکریل‌امید (۰/۰۵ درصد) و پلیمر CMC-BUR به عنوان پایدارکننده استفاده شده است. تحقیقات در زمینه سیالات بازدارنده نشان داد که افزایش غلظت ترکیبات قطبی در سیال حفاری به میزان ۰/۲۵ مول بر لیتر در مقایسه با غلظت آن‌ها در سنگ، منجر به افزایش پایداری لایه‌ها در اطراف دیواره چاه می‌گردد. تحقیقات افزودنی‌های روان‌کننده نشان داد که اضافه کردن ۱/۵ تا ۲ درصد از افزودنی FRW باعث کاهش ضریب اصطکاک بین فلز-فلز به میزان ۷۰ تا ۷۵ درصد در سیال رسی و تا ۶۵ درصد در آب می‌گردد. نتایج نشان می‌دهند که سیالات حفاری توسعه‌یافته در گروه حفاری پتانسیل بالایی برای کاربرد در میادین نفت و گاز برای بهبود عملکرد حفاری و تکمیل چاه دارند. همچنین اشاره شده است که پتانسیل علمی و فنی گروه امکان بررسی افزودنی‌ها در سیالات حفاری و همچنین توسعه و بررسی ترکیبات مختلف نه تنها برای حفاری و تکمیل چاه بلکه برای تعمیر چاه که در شرایط واقعی میدان کاربرد امکان‌پذیر است، را دارد.
