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STUDIES OF HYDGOCARBON-BASED MUDS FOR DRILLING-IN PRODUCTIVE FORMATIONS

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ИССЛЕДОВАНИЯ БУРОВЫХ РАСТВОРОВ НА УГЛЕВОДОРОДНОЙ ОСНОВЕ ДЛЯ ПЕРВИЧНОГО ВСКРЫТИЯ ПРОДУКТИВНЫХ ПЛАСТОВ

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well drilling, flushing, complications, laboratory studies, rheology, plastic viscosity, assumed viscosity, synthetic asphalt, gilsonite, hydrocarbon-based muds, emulsion muds, structure formation, productive formation, filtration, density.

Purpose of the work is to increase effectiveness of drilling-in productive formations while using hydrocarbon-based muds. Several studies were performed within the work: evaluation of aqueous phase contents on alteration of rheological parameters of muds; evaluation of kind of gilsonite in hydrocarbon-based muds on its structure rheological and filtration properties.

Well completion using hydrocarbon-based muds is most efficient for purpose of preserving filtration and capacity properties of productive formation, but such muds are expensive enough. With purpose to reduce cost of such systems emulsion muds were developed, becoming more used during drilling-in, but for their efficient usage it is necessary to select components composition with reason, as even slight variations in quantity of reagents responsible for system stability, may lead to emulsion coalescence and phase separation.

Drilling-in productive formation using emulsion mud may lead to many complications, lessening reservoir to well connectivity or reducing reservoir permeability. One of such complications is loss of circulation. Mud used to drill-in formation should be made so that to practically avoid decline natural permeability of productive zones, provide for excellent hole cleaning and be easily conditioned.

Various materials exist, such as gilsonite (natural asphalt) or bitumen and amine-treated lignin, and also polymeric fillers used to prevent thieving due to reducing filtration and formation of impermeable mud cake.

Studies made within the work have demonstrated effectiveness of application of natural and synthetic asphalts in hydrocarbon-based muds, and also opened new directions for further studies with purpose to expose regularities appearing with change of components composition.

Ключевые слова:
бурение скважин, промывка, осложнения, лабораторные исследования, реология, пластическая вязкость, условная вязкость, синтетический асфальт, гильсонит, растворы на углеводородной основе, эмульсионные растворы, структурообразование, продуктивный пласт, фильтрация, плотность.

Целью работы является повышение эффективности вскрытия продуктивных пластов при использовании буровых растворов на углеводородной основе. В работе проведено несколько исследований: оценка влияния содержания водной фазы на изменение реологических параметров растворов; оценка влияния вида гильсонита в растворах на углеводородной основе на его структурно-реологические и фильтрационные параметры.

Заканчивание скважин с применением растворов на углеводородной основе наиболее целесообразно с целью сохранения фильтрационно-емкостных свойств продуктивного пласта, однако такие растворы достаточно дорогостоящие. С целью снижения стоимости таких систем были разработаны эмульсионные растворы, которые находят все большее применение при первичном вскрытии, но для эффективного их использования необходимо обоснованно проводить выбор компонентного состава, поскольку даже небольшие колебания количества реагентов, отвечающих за стабильность системы, могут приводить к коалесценции эмульсии и разделению фаз.

Вскрытие продуктивных пластов с эмульсионным раствором может привести к множеству осложнений, которые уменьшают связь коллектора со стволом скважины или уменьшают проницаемость пласта. Одним из таких осложнений является потеря циркуляции бурового раствора. Раствор, применяемый для вскрытия пласта, должен быть предназначен для того, чтобы практически не ухудшать естественную проницаемость продуктивных зон, обеспечивать превосходную промывку ствола и легко очищаться.

Существуют различные материалы, такие как гильсонит (природный асфальт) или битум и обработанный амином лигнин, а также полимерные наполнители, применяемые для профилактики поглощений за счет снижения фильтрации и образования непроницаемой фильтрационной корки.

Исследования, проведенные в работе, показали эффективность применения природных и синтетических асфальтов в растворах на углеводородной основе, а также открыли новые направления для дальнейших исследований с целью выявления закономерностей, возникающих при изменении компонентного состава.

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Introduction

World practice of well construction shows that further operation depends on effectiveness of drilling and well completion. Well drilling quality to great extent is determined not only by tools used, but also by technology, including washing processes inseparably related to type and quality of muds [1–11]. With purpose to maintain reservoir properties of near-wellbore formation zone at drilling-in productive horizon hydrodynamic pressure at well bottom should be kept at level of formation pressure or a bit lower, but in latter case probability of gas, oil and water inflows exists, to control which drilling site should be equipped with sealed circulation system, with rotating preventer installed at wellhead. While drilling with hydrodynamic pressure exceeding formation pressure, possibility of damage to formation near-well zone increases, especially when using muds with insoluble micro-fine solids, which could penetrate deep into formation.

During well operation productive formation could restore its permeability due to cleaning near-wellbore zone, but this is applicable only to highly permeable reservoirs. During development of deposits with medium or low permeability this phenomenon is not observed when traditional methods are used. Consequently, in avoidance of damage to formation near-well zone the most important role will belong to selection of mud for drilling-in productive horizon, which would prevent possibility of deep penetration of its filtrate into formation at moment of overbalance appearance, especially at well cementing stage [12–20].

At present a number of muds is used for drilling-in productive formations with different permeability return coefficients [14, 15, 18, 21–25]. The lowest coefficient value is with clay muds with weighting materials (for drilling in conditions of abnormally high formation pressure) – not more than 0,05–0,1; for aluminate muds – 0,2–0,4; salt water based clayless polymer muds – for them the value is 0,2–0,4. Permeability return coefficient for biopolymer muds is about 0,3–0,45; for aqueous muds with different mineralization – 0,45–0,85; at foam drilling-in productive formations – about 0,5. The highest values are with hydrocarbon-based muds (OBM). For them value of the coefficient is about 0,6–0,9.

During evaluation of quality of muds of this or that type contacting with reservoir and used to drill-in productive horizons, attention should be paid to the following aspects [26]:

– presence of emulsified water phase in hydrocarbon-based mud and its mineralization degree (characterizing possible swelling of clay particles in intrapore space during its interaction with water phase of hydrophobic emulsion mud in case of phase inversion);

– correspondence of solid phase of mud to pore structure with purpose to minimize deep colmatation of productive formation;

– minimal filtrate invasion parameters of process fluids used for well completion.

Drilling-in at overbalance leads to the greatest damage of low permeable formations during drilling, especially when using water-based muds with micro-fine solids, that is why for medium permeable and low permeable reservoirs it is reasonable to use muds with low content of solids, foam systems and hydrogen-based muds [20, 27–32].

Except that, during drilling directional wells including those with horizontal tailing-in, and also during branching, there is a great issue of wellbore stability, bringing weight to drilling tool, and also reduction of rod friction [1, 2, 33–36]. One of means aiding in trouble-free drilling of inclined and horizontal sections – application of mud systems with minimal friction coefficient [37, 38]. Meanwhile in this hydrocarbon-based muds are most effective.

Materials for mixing hydrocarbon-based muds

As dispersion medium for OBM may be used such nonpolar fluids as oil and petroleum products, synthetic hydrocarbons. Suitability of this or that material is evaluated both by its physical and chemical properties, and by process properties of OBM made on their base [29, 39–48].

While selecting hydrocarbon phase it is necessary to check its flash point first of all. According to Oil and Gas Industry Safety Regulations flash point of prepared hydrocarbon-based mud should by 50 °C exceed maximal expected mud temperature at wellhead [49]. OBM flash point is significantly higher than that of initial hydrocarbon medium, but during its selection it is also necessary to consider fire safety during initial stage of its preparation. Serious attention should be paid also to hydrocarbons toxicity, and their vapors maximal permissible concentration at workplace should not exceed the established norm.

Oil is the most available and cheap variant for OBM dispersion medium. At present oil is of limited use in gelled form as process fluid for different processes (killing, perforation) in shallow low temperature wells.

Diesel fuel – petroleum product having received the widest application as OBM hydrocarbon phase. Condition of colloid components of OBM, their association degree is determined by content of aromatic and paraffin hydrocarbons in dispersion medium. Though all diesel fuel brands have approximately same physical and chemical characteristics: resin amount is within 40–50 mg per 100 cm^3 of fuel; density – 0,83–0,85 g/cm^3; viscosity – 4,0–6,0 cPs, which permits to maintain developed OBM recipes in different regions.

Mineral oil are united into petroleum products with low content of aromatic hydrocarbons, being of greater environmental danger. Positive quality of mineral oils is their best withdrawal from surface of drilled rock particles (residual quantity 5–6 % against 16–17 % for diesel fuel).

Synthetic hydrocarbons – new generation dispersion medium for low toxic non-water based muds, being an ecological alternative to OBM, permitting to implement their advantages in regions with increased environment protection requirements.

Organophilic clays form as result of modification of clay materials by ammonium organic salts and find wide usage as effective additives to oils, paints and lubricants, as active fillers for plastics and rubbers, and also for preparing OBM.

Highly oxidized asphalt – product of oil tars air oxidation. Advantage of tar as structure-forming agent is that being organophilic naturally it does not require processing with wetting and hydrophobisating agents.

Water phase is main component of hydrophobic emulsion muds (HEM) determining their viscosity, structural and filtration properties. Not less important for HEM properties is also qualitative composition of water phase.

Fine dispersion fillers are intended mainly to stabilize suspension and emulsion OBM and to control filtration.

Calcium oxide – quicklime received during burning low shake limestones. It is used in majority of OBM recipes as source product to obtain active filler $Ca(OH)_2$, forming at calcium oxide reaction with water.

Calcium carbonate (chalk, marble chips, calcite) – is used as active filler and to weight OBM to density 1,22–1,24 g/cm^3. Dry finely dispersed calcium carbonate is a good adsorbent of superficially active substances (SAS) and hydrophobizing components of hydrocarbon medium, it obtains oleophilic properties providing for its function as stabilizer and filtration reducer. Calcium carbonate is used in number of HEM recipes during drilling-in, completion of productive formations and well killing to increase permeability return coefficient in near-wellbore zone.

For OBM weighting in general same materials are used as those in aqueous systems: barite weighting materials (density 4,3–4,7 g/cm^3), carbonate weighting materials (limestone – 2,7 g/cm^3; dolomite – 2,8–2,9 g/cm^3; siderite – 3,8–3,9 g/cm^3). To increase mud density in range of productive horizons application of carbonate weighting materials is appropriate, as they are acid-soluble, so harmful influence of productive formation colmatation by mud solid phase could be partially eliminated by acid treatments.

To achieve different process tasks OBM may contain various special fillers exerting substantial influence on their process properties. To such additives belong materials for OBM density reduction and mud loss prevention.

Usage of OBM in drilling-in highly permeable strongly drained fractured productive formations or killing wells in similar conditions with abnormally low formation pressures may lead to mud loss. It is not possible to obtain quality OBM with density lower than 0,86–0,87 g/cm^3 without usage of special lighting additives. Increase of lighting additives quantity leads to increase of OBM viscosity and structural parameters [27, 47, 48].

To superficially active substances relate those organic compounds molecule of which simultaneously contain polar group and nonpolar hydrocarbon chain. SAS play huge role in OBM composition. Even small additions of special agents (0,25–0,50 %) are able fully change OBM properties. It is SAS complex being used in OBM recipes that determine mud aggregative and sedimentative stability, stability against action of aggressive factors, controls mud disperse phase solvation processes.

In composition of OBM SAS perform the following functions [39, 41, 42, 44, 46]:

– Emulsifiers (main and additional). These are oil soluble metallic soaps of organic acids, oil soluble ethoxylated derivatives from organic acids, compound ethers, amines, amides, imidazolines, oligomeric polyamides, compound ethers of fatty acids, amino alcohols, and so on.

– Structure-forming agents. To this group of SAS relate compounds able to intensify coagulative structure forming when introduced into stable invert emulsion of the following substances: water soluble ethoxylated alkyl phenols type OP-10 and neonol 6-90, disolvan-4411, sulfonol NP-3 and other.

– Hydrophobisating agents. These SAS increase degree of affinity of OBM disperse phase to hydrocarbon disperse medium, protecting it against hydrophilic flocculation. In HEM composition these SAS often add to action of main emulsifiers, playing role of emulsion stabilizers.

– Viscosity reducers. They, due to adsorptive blocking of disperse phase particles, permit to substantially increase volumetric filling of its system not hindering process properties.

Study of properties of hydrocarbon-based muds

Hydrocarbon-based muds used in drilling majority of wells, are expensive systems, as a rule made abroad. In this work studies were performed using home-made agents with purpose to evaluate influence of component composition on process properties of muds prepared. Experimental studies were performed in laboratories of well drilling chair of National Mineral Resources University (University of Mines). Following agents are included into mud component composition:

– mineral oil – dispersion medium;

– SAS-emulsifier, hydrophobizing agent for solid phase surface, providing for interboundary tension reduction at border «oil – water», also acting as a coagulative structure forming agent. In capacity of hydrophobizing agent it improves temperature and rheological stability of emulsion [44];

– calcium oxide – to regulate alkalinity and as source of calcium to neutralize carbon dioxide and hydrogen sulfide;

– SAS-wetter – to increase coagulative structure forming when added to hydrocarbon-based muds [44];

– organophilic bentonite – for structure forming and to provide for necessary viscosity, high thermal stability, electrical stability, and also to reduce filtrate formation;

– calcium barite and carbonate with different fractional composition барит in capacity of colmatant and weighting agent;

– calcium chloride – to increase hole wall stability in clay sediments;

– gilsonite – as filtration reducer.

Table 1

Basic components composition

Agent	Purpose in mud	Rate, g(ml*)/l of mud
Mineral oil	Mineral oil	700*
CaO	Neutralizer CO_2, CO_3	35
Water	Water phase	583*
$CaCl_2$	Inhibitor	82
SAS-emulsifier	Emulsifier, hydrophobizing agent	29
SAS-wetter	Wetter, structure forming agent	12
Gilsonite	Water loss reducer	6
Barite	Weighter	350
$CaCO_3$	Colmatant	117
Bentonite	Structure forming agent	12

Mud recipe taken as basic during studies is given in table 1.

To evaluate influence of hydrocarbons/water ratio on mud process properties seven muds were studied, having hydrocarbons/water ratio from 55/45 to 85/15. Muds were prepared at laboratory mixer HamiltonBeach at mixing speed 12 000 – 14 000 rev/min. Temperature of rheological parameters measurement – 50±2 °C. Results of laboratory measurements of mud properties are given in table 2.

Analysis of results of laboratory studies showed that along with reduction of water quantity assigned viscosity, plastic viscosity, dynamic shear stress, static shear stress increase to certain value being demonstrated by an evident maximum (hydrocarbons/water ratio = 70/30), along with further ratio growth reduction of these parameters is observed. This may be explained by chemical nature of muds obtained – it is supposed that at great amount of water (ratios from 55/45 to 65/35) it is possible to note lack of SAS for free water emulsifying and wetting solid phase; with reduction of water amount (to ratio 70/30) at constant amount of other components the system comes to the optimum condition – emulsion is stabilized due to activity of SAS in quantity enough both for retaining solids in suspended state and for preserving emulsion. Further water amount reduction leads to reduction of rheological characteristics of the system, as main influence on rheology is made by hydrocarbon medium, being less and less «thickened» by water. Except that, same tendency is observed with mud density, but this may be related to air intake during mixing. Nevertheless, to obtain decisive confirmation of the hypothesis it is necessary to perform additional rheological studies aimed to evaluate influence of hydrocarbons/water ratio on system properties with other components.

Experimental studies of influence of asphalt application in capacity of filtration reducer in OBM

To evaluate influence of kind of asphalt (appearance shown in fig. 1) on process characteristics of OBM basic mud was studied with kinds of asphalt:

Mud 1. TDM, natural asphalt.

Mud 2. Synthetic asphalt grade B (Synasphalt B).

Mud 3. Synthetis asphalt (Synasphalt).

Mud 4. Sulfonated asphalt.

Mud 5. Basic mud without asphalt.

This work gives results of laboratory studies (fig. 2) of rheological properties of hydrocarbon-based muds, measurements of rheological parameters were performed before heating (at temperature 25 ^{o}C) and after heating to 90 ^{o}C (synthetic asphalts melting point – 80–85 ^{o}C).

Input of gilsonite leads to increase of assigned and plastic viscosity, but after heating these nuds to 90 ^{o}C natural asphalts (natural and sulfonated) increase mud assigned viscosity (comparing to basic mud) as they start to create structure, and synthetis asphalts (synasphalt and synasphalt grade B) demonstrate viscosity reduction due to their melting.

Input of gilsonite leads to reduction in dynamic sheer stress. Meanwhile after heating to 90 ^{o}C in mud with natural asphalt grade TDM increase of dynamic sheer is observed comparing to tests at room temperature.

Input of asphalt does not make significant influence on static sheer stress.

Input of asphalt without heating leads to increase of filtrate volume, but after heating these muds to 90 °C filtrate volume reduces significantly, as physical connection with permeable rocks is formed, creating effective cake to prevent penetration of mud and its filtrate into formation.

Speed of filtrate formation often is the most important property of mud, especially when drilling permeable formations, where hydrostatic pressure exceeds formation pressure. Correct filtration control may prevent or minimize drill pipe sticking, and improve wellbore stability in certain intervals. As a rule, large filtrate volumes are related to thick filter cake, as cake is made by sedimentation of clay particles on wellbore walls during loss of filtrate into formation. So, the greater is filtrate volume, the thicker is filter cake and mud is less effective. Studies showed that at high temperatures and pressures OBM without asphalt have highest mud spurt comparing to other compositions. In general the studies performed have demonstrated that usage of synthetic asphalt as water loss reducer is worthwhile.

Table 2

Mud parameters obtained

Parameter measured	Mud serial number						
	1	2	3	4	5	6	7
Hydrocarbons/water, %	55/45	60/40	65/35	70/30	75/25	80/20	85/15
Assigned viscosity, sec	33,2	40	80	370	216	152	120
Plastic viscosity, mPa·sec	21	33,5	63	68	63	61,5	48,5
Dynamic shear stress, Pa	5	6,5	9,5	29	29	24,5	20,5
Static shear stress 10 sec, Pa	4	4	8	18	18	12	9
Static shear stress 10 min, Pa	4	4,5	7	17	18	13	10
Actual density, g/cm^3	1,17	1,22	1,25	1,28	1,27	1,29	1,29
Calculated density, g/cm^3	1,22	1,24	1,26	1,28	1,28	1,3	1,32

Natural asphalt TDM Synasphalt Synasphalt grade B Sulfonated asphalt

Fig. 1. Appearance of studied asphalts

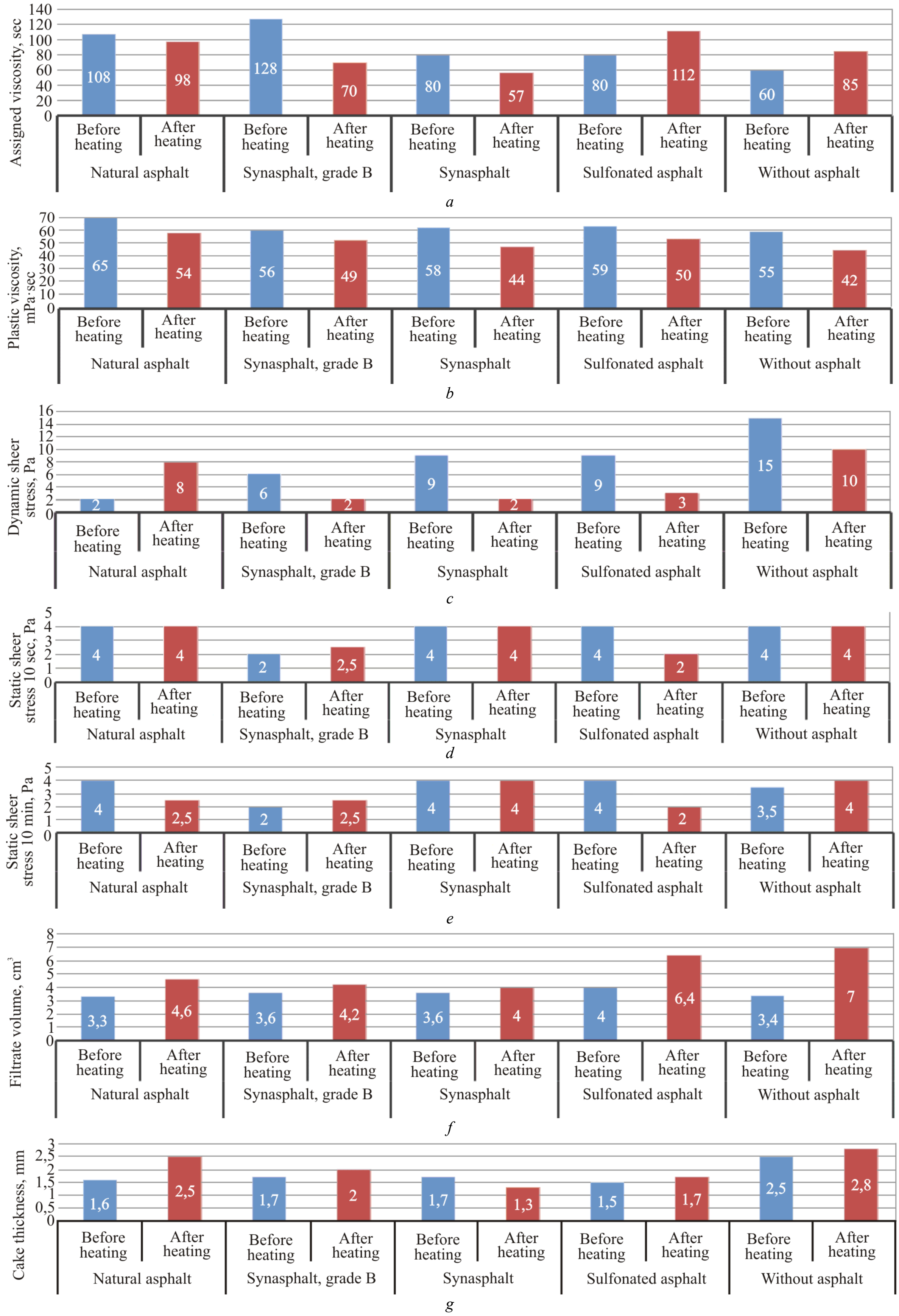

Fig. 2. Influence of kind of asphalt on: *a* – assigned viscosity; *b* – plastic viscosity; *c* – dynamic sheer stress; *d* – static sheer stress 10 sec; *e* – static sheer stress 10 min; *f* – filtrate volume; *g* – thickness of hydrocarbon-based mud cake thickness

Conclusions

Analysis of results of laboratory studies permitted to establish that hydrocarbons/water ratio exerts considerable influence on process properties of OBM, but in order to obtain regularities according to which it is possible to make an unambiguous decision on components composition, it is reasonably to perform a significant complex of experimental studies with different reagents.

Mud losses into formation while drilling with OBM happen in cavernous rocks and natural or artificial fractures in permeable and low permeable horizons. But this problem may be solved using such materials as asphalt, including synthetic, not widely used in drilling at present.

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