Influence of drilling fluids on the filtration properties of reservoirs

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Abstract. Currently, during the opening and testing of productive formations, as well as during repair work in wells, specialized water- or oil-based technical fluids are used. All of them are characterized by compatibility to varying degrees with the lithological and physical properties of reservoirs in Western Siberia and have different effects on the filtration properties of the porous reservoir of productive formations. It is known that when using fresh water-based drilling fluids, due to the interaction of the fresh water filtrate with rock cement and some rock-forming minerals, the permeability of the bottom-hole zone changes. The paper presents the results of an experimental study of the effect of drilling fluids on terrigenous rocks of one of the fields. The impact of drilling fluids on the core, with the exception of FLO-PRO and NaCl, led to a decrease in the oil-permeability of core samples. In the core of the terrigenous reservoir, filtering FLO-PRO does not cause a negative result. The curves of permeability changes with increasing filtration pressure before and after FLO-PRO flow are identical in dynamics. According to the results of the study, it can be concluded that technical fluids FLO-PRO and IES (invert emulsion solutions) can be recommended for use as they do not violate the structure of the pore space of the reservoir and do not lead to a significant decrease in oil-permeability of all core layers.

1. Introduction

Currently, during the opening and testing of productive formations, as well as during repair work in wells, specialized water- or oil-based technical fluids are used. The chemical composition of fluids used for working in wells of multilayer fields is diverse: from simple salt solutions (NaCl and CaCl₂) to multicomponent polymer-containing compositions, such as FLO-PRO [1, 13]. Common for these liquids is their low viscosity and relatively high specific gravity with almost complete absence of weighting agents in the form of a solid phase (bentonite, barite, etc.). All of them are characterized by compatibility to varying degrees with the lithological and physical properties of reservoirs in Western Siberia and have different effects on the filtration properties of the porous reservoir of productive formations [2]. Especially during the opening of potentially unstable rocks of the Bazhenov and Georgievskaya Formations together with the productive formation JV1, which has a low reservoir pressure anomaly coefficient (0.85–0.9), inhomogeneous permeability across the section (from 1–2 to 15–20 md) and high fractured porosity imposes a number of serious restrictions on the choice of the type of drilling flushing fluid [3].
2. Literature review

In general terms, the reasons affecting the reservoir filtration and capacitive properties of the bottom-hole zone (BHZ) of porous reservoirs when exposed to industrial fluids can be divided into two groups: technological and geological [4]. Technological reasons, caused mainly by the mudding of the bottom-hole zone by solid particles of drilling fluids, are not considered in this work, since there is no solid phase in all tested fluids.

The geological reasons for the change in reservoir properties of reservoir rocks during their interaction with drilling fluids include [9, 10]:

- swelling of the clay phase of the reservoir due to the water-based drilling fluid filtrate penetrating into it;
- insoluble precipitation in the pores of the formation during the chemical interaction of the formation water with the filtrate of the technical/drilling fluid;
- a change in phase oil-permeability after the drilling fluid penetration into the reservoir;
- the formation of oil-water emulsions that reduce the relative permeability of the BHZ.

Being inherently a heterogeneous mineral system, reservoir rocks are differently resistant to various drilling fluids. The chemical reagents in their composition cause physicochemical reactions in the reservoir rocks, the final result of which is a change in the properties of the pore-fissure space [7, 8]. To prevent screens and collapses of the borehole walls, taking into account the possibility of other types of complications and ensuring high rates of penetration of the hole, it is necessary to comprehensively approach to the choice of the optimal density [14].

It was established that when using fresh water-based drilling fluids, due to the interaction of the fresh water filtrate with rock cement and some rock-forming minerals, the permeability of the bottom-hole zone changes. Using water-based salt drilling fluids, such as NaCl and CaCl₂, causes crystallization and formation of salt crystals in a porous medium due to the high degree of filtration of water-based drilling fluids into the formation. The effect of multicomponent drilling fluids, including oil-based invert-emulsion solutions (hydrocarbon-based solutions), for instance BARADRIL-N/XP-07 solution, when drilling a horizontal section of a well in a producing reservoir JV1, enables minimal repression on the formation and minimal risk of absorption which prevents pollution of the reservoir [5].

The use of hydrocarbon-based solutions to a lesser extent affects the change in reservoir properties of reservoir rocks, but can lead to hydrophobization of part of their pore space. The oil-permeability of the rocks after oil interaction with the drilling fluid used to work in the BHZ of the well will determines their applicability.

Methods for monitoring and controlling the filtration properties of drilling fluids, especially for deep wells, also require clarification. In this case, it is necessary to distinguish between the problems that arise when developing a drilling fluid as a coagulation-thixotropic system of a certain type (which is associated with the stability of the fluid and the nature of the interaction with drilled rocks) and the problems of choosing its formulation (fractional composition) for controlling the technological properties [15].

Salt solutions (brines) are technological fluids prepared on the basis of filtered fresh water and NaCl and CaCl₂ salts used to control the density of the solution. The specific gravity of solutions in the range of 1.1–1.25 g/cm³ is selected depending on the task. Mineralization of brines significantly exceeds the salinity of formation water.

Solutions (brines) are used as a working medium during repair and restoration work in wells and during the secondary opening of formations by perforation. The use of solid-phase perforation liquids based on NaCl and CaCl₂ salts significantly prevents an intensive decrease in the natural permeability of the formation during perforation, but does not exclude it, especially in low-permeability terrigenous reservoirs with small pore sizes and high clay content.

The main properties of highly saline solutions of salts are ease of preparation and low cost. Solutions do not cause swelling of clay minerals of the rock and penetrate no deeper than 5-10 meters into the reservoir.
An indifferent solution is a technical fluid used as a working medium during the secondary opening of formations by perforation and for killing wells during repair and insulation works. In its composition, the solution contains water; calcium chloride (1–40 wt. %); organic solvent (lower aliphatic alcohols, glycols, acetone; 10–50 wt. %), inhibitory salt (potassium or ammonium chloride; 1–10 wt. %).

The solution possesses improved drainage and inhibitory properties, increases the efficiency of opening productive formations by perforation, and facilitates the initiation of fluid flow after perforation. A positive effect is achieved by the fact that the composition of the kill fluid includes, in addition to the traditional calcium chloride (CaCl₂) used to regulate the solution, an organic solvent that promotes the dehydration of swelling clays, reduces interphase tension at the border with hydrocarbons, and destroys persistent emulsions in the bottom-hole zone. The presence of potassium chloride (or ammonium) in the solution prevents swelling and stabilizes clay minerals in the reservoirs. The density of the solution is controlled by the concentration of chemicals and can range from 1.01 to 1.28 g/cm³.

FLO-PRO solution is a water-free clay-free system with a minimum content of solid phase. The main components of the FLO-PRO solution are: fresh (or sea) water, calcium carbonate, polymer preparations FLO-VIZ and FLO-TROL, sodium or potassium salts, LUB lubricating additives. FLO-PRO is used to provide high quality opening of productive horizons with deviated and horizontal wells. The main properties that underlie the use of the FLO-PRO system are:

- high viscosity of the filtrate of the FLO-PRO solution at low stress and shear rate. FLO-PRO simultaneously has the properties of both a liquid (during flow) and a solid (at rest). The effective viscosity of the solution is minimal at high flow rates, which reduces pressure losses in bottom-hole hydraulic devices (downhole motors, bit nozzles, etc.). At the same time, the viscosity of the solution increases to anomalously high values at low shear rates (near the walls of the well, in pores and fractures of the rock), which significantly increases the holding and carrying capacity of this technical fluid;
- the absence of a finely divided solid phase, which prevents clogging of the pore channels of the reservoir rock;
- low fluid loss of the solution, which can significantly reduce the radius of the zone of penetration of the filtrate into the BHZ;
- high thermal stability of the solution.

The IES (invert emulsion solution) is a technical fluid that is used to limit water inflow (killing) of the filtrates of working solutions in the BHZ of a well during the secondary opening of reservoir formations.

The invert emulsion solution is based on a specially prepared drip-liquid mixture of diesel fuel and industrial water in the presence of chemical stabilizers, and sometimes surfactants.

The main properties that are indicators for the operational use of the solution of IES are:

- the minimum fluid loss of the solution, which can significantly reduce the radius of the zone of penetration of the filtrate into the BHZ;
- a relatively easy removal of the solution from the BHZ during depression;
- high thermal stability of the solution;
- the absence of a finely dispersed solid phase, which prevents the clogging of the pore channels of the reservoir rock.

The results of field studies indicate that when wells are perforated using IES solutions, which prevent the development of negative colmatation and physicochemical processes in the BHZ, the permeability of productive formations remains up to 80% of the initial one.

To select the optimal properties of drilling drilling fluid, it is necessary to conduct standard petrophysical studies to study their filtration-capacitive properties and chemical composition.

This paper presents the results of an experimental study of the effect of drilling drilling fluids on terrigenous rocks of one of the fields. From the total amount of core samples studied in the laboratory, the samples were selected that are characterized by average (or close average) values of porosity and permeability (Table 1).
Table 1. Brief information on the physical properties of core samples

| Indicator                             | JV1  |
|---------------------------------------|------|
|                                       | 5    |
| Porosity                              | Min  | 3.11 |
|                                       | Max  | 20.76|
|                                       | Mean | 13.19|
| Klinkenberg-corrected permeability    | Min  | 0.007|
|                                       | Max  | >200 |
|                                       | Mean | 3.44 |
| Sample number                         | 37   |

3. Methods for study

The reservoir properties of the Jurassic horizon are low. The collectors are gray sandstones, dark gray with a brownish tint, fine-grained, silty. The texture is homogeneous, oblique, intermittently wavy, due to the distribution of clay and carbonaceous material. Clastic material makes up 85–90% of the rock, medium and poor sorting.

Cement (5–10%) of sandstones is film-pore in type, heterogeneous in composition. Open pores are frequent (up to 1%). A distinctive feature of the rocks of the JV1 horizon as a whole is finely dispersed crystalline pyrite (up to 15%), which often impregnates the rock mass, sometimes forms condensations, and also replaces the central parts of the radiolarians in the form of continuous masses.

Impermeable interlayers are represented by fine-grained sandstones and siltstones, clayey with basal cement, which includes kaolinite, hydromica, chlorite, and the formation of the montmorillonite series. Interlayers with carbonate cement are often encountered, the main component of which is calcite, often dolomitized. The mudstones from both parts of the reservoir and the lintels separating them are dark gray, clay material of a chlorite-hydromica composition.

The cover of the JV1 horizon is mudstones of the Bazhenov and Georgiev suites up to 30-meters thick with high shielding properties. The mudstones are black and dark gray, bituminous, tiled and finely elutriated with a large number of radiolarians. The texture is homogeneous, layered, sometimes micro-spotted, due to the uneven distribution of organic matter.

The considered reservoir JV1 (1) is represented by siltstone >70%, sandstone ~15%, clay minerals (10–15%), and is complicated by carbonates (Fig. 1). Clay cement (according to the XRD analysis) is mainly represented by kaolinite and the illite group; it is complicated by chlorite in terms of spar grains. Swelling minerals (smectite and montmorillonite) are practically absent.
The porosity of the rocks varies in a wide range from 2 to 22%; low porosity is due to the presence of carbonate cement. The average value of porosity is 13.2%. The gas-permeability of the formation varies over a very wide range, from hundredths of md to tens of md with an average permeability of 0.64 md. Oil saturation in the reservoir is episodic, with rare interlayers. In practice, the formation, if it is a reservoir, has a very low potential in terms of filtration and capacitive properties. Obviously, in this section of the field there were the most unfavorable conditions for the formation of the reservoir.

In terms of well 162, the JV1 (1) layer, according to well logging data, had more favorable conditions for the formation of the reservoir, but it was not possible to take out the core sample from the JV1 group. Only one sample with a porosity of 29% and good permeability of 300 md was selected from the productive part of the formation. This sample was used to study the effect of FLO-PRO drilling fluid on the reservoir properties.

The rocks of the JV1 formation (1) react to the drilling fluid differently than the rocks of the overlying layers. The permeability of core samples, through which NaCl drilling fluids (sample k-34712), CaCl$_2$ (sample k-34715), an indifferent solution (sample k-34742, Fig. 2), and the IES filtrate (sample k-34743, Fig. 3) were filtered, in the pressure drop ranging from 0.2 to 0.8 atm. decreased, and with a pressure drop of more than 1.0 atm. stabilized for almost all samples.

Otherwise, there was a change in the permeability of the core sample through which the process water was filtered (sample k-34744, Fig. 4). Since the start of filtration (at a pressure drop of 1.8 atm.),

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**Figure 1.** Reservoir Particle Size Histogram

![Reservoir Particle Size Histogram](image-url)
the permeability of the sample naturally increased, and with repression more than 3.0 atm. showed a tendency to stabilization.

Studies of the FLO-PRO filtrate. In the sample (k-21796), characterized by high reservoir properties (Kp for gas is over 200 md, Kp for solution of NaCl is 79.6 md), the permeability of this drilling drilling fluid with an increase in pressure drop from 0.2 to 1.4 atm. increased by more than 5 times. At higher pressure drops (above 1.6 atm.), the permeability of the FLO-PRO filtrate is stabilized at 40 md. For the sample (k-34738), whose reservoir properties are close to average and in the reservoir (Kp for gas = 5.16 md, Kp for NaCl = 2.82), the permeability of the FLO-PRO filtrate at slight pressure drop (up to 1.0 atm.) slightly lowered, and with a pressure drop of more than 1.5 atm. stabilized at 0.1 md (Fig. 5).

Figure 2. Change in permeability during injection of an indifferent solution
Figure 3. Changes in permeability during injection of the IES filtrate
Figure 4. Change in permeability when injecting technological water

The impact of enumerated drilling fluids on the core, with the exception of FLO-PRO and NaCl, led to a decrease in the oil-permeability of core samples. Indeed, for the core samples through which an indifferent solution, IES, CaCl$_2$ and technological water were filtered, the core permeability during reverse oil filtration decreased by 1.5–3.0 times. In this case, the smallest decrease is observed for the samples through which CaCl$_2$ solutions and technological water were filtered.
Sample k-34748 (reservoir JV 1-1)

Dependence of relative oil-permeability on effective pressure during stationary filtration

Dependence of relative oil-permeability during reverse filtration with growing effective pressure

Dependence of relative permeability of indifferent solution on effective pressure during stationary filtration

Dependence of relative oil-permeability on effective pressure during filtration time at $P_{eff} = P_{stab} = 2.2$ atm (regime of permeability stabilization)

**Figure 5.** Changes in permeability during injection of the FLO-PRO filtrate

FLO-PRO drilling fluid (samples k-21796, k-34738) and highly mineralized NaCl solution (k-34712) practically did not cause changes in the oil-permeability of core samples. The oil-permeability of these samples was intensively and almost completely restored after filtration through the sample of the corresponding technical fluid.

The generalized results of the effect of drilling drilling fluids on the JV1 formation (1) are shown in Fig. 6.
Figure 6. The dependence of the relative oil-permeability of the samples on the effective pressure: a) before filtering technological fluids; b) after technological fluids. Filtration time is 60 min

4. Results
Photographs obtained using a scanning electron microscope do not give an unambiguous picture of the reasons for the decrease in the permeability of samples in oil after filtering technological water, CaCl$_2$ solution, and IES through them. On the one hand, it is clearly seen that the filtration of these liquids did
not cause swelling of the soaking clays, and on the other hand, the surface of the mineral grains was even somewhat cleansed of small crystals of the second and third generation.

Figure 7. Photos of cleaved rocks (a) before and (b) after FLO-PRO filtering: sample k-34738, layer JV1 (1) (50x, 500x, 2500x magnification)

The pore space is relatively clean. Pore channels are clearly visible. However, this did not lead to a complete restoration of the permeability of core samples during reverse oil filtration. At the same time, in the photographs of the samples (k-34738 and k-34712) (Figs. 7 and 8), through which the NaCl and
FLO-PRO solution were filtered, it can be seen that the surface of the large grains remained complicated with small crystals and scales of clay minerals. Changes in the pore space structure of these samples are not observed [6].

Figure 8. Photos of cleaved rocks (a) before and (b) after NaCl filtering: sample k-34712, layer JV1 (1) (50x, 500x, 1000x, 2500x magnification)
5. Conclusions
In the core of the JV1 (1) formation, the FLO-PRO filtering does not cause a negative result. The curves of permeability changes with increasing filtration pressure before and after FLO-PRO flow are identical in dynamics.

Technical fluids FLO-PRO and IES can be recommended for use, as they do not violate the structure of the pore space of the reservoir and do not lead to a significant decrease in the permeability of core of all layers in oil.

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