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Research of the influence of polymeric drilling mud on the filtration-capacitive properties of polymictic sandstones

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Abstract. One of the main problems of the oil and gas industry, despite the high level of development of science and technology, is an effective primary and secondary opening of reservoirs, ensuring the preservation of the initial filtration and capacitance characteristics of the bottomhole zone. Even more important is the qualitative implementation of these operations with the introduction of low-permeability polymictic sandstones, since the productivity of producing wells can be significantly reduced as a result of the colmatation of the bottomhole formation zone. The example of the sample of the core of the Vyngapurovsky deposit shows the degree of change in permeability after exposure to it with drilling mud on a polymer basis. It was also established that it is possible to form a polymer membrane from the drilling mud at high reservoir temperatures.

Key words. Polymer drilling mud, polymictic sandstone, permeability, microcracks, Dnieper-Donets basin, polymer membrane, hydrochloric acid.

1. Introduction

One of the ways to preserve productive layers, which is widely used recently, is the opening of oil and gas reservoirs using polymer mud. The advantage of this drilling mud is that during the drilling process, the polymer is partially filtered out at the well-layer boundary, forming an almost impermeable crust that protects the formation and reduces the possibility of deep penetration of the mud filtrate into it. After drilling the well, the crust is easily removed by performing the hydrochloric acid treatment of the reservoir. In this article, we consider the results of laboratory experiments on the filtration-capacitance properties of four samples of polymictic sandstones from one of the gas condensate deposits located in the Dnieper–Donets Basin, drilling wells within which are carried out using polymer drilling mud (at the request of the subsoil user, we do not indicate the name of this deposit). In terms

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of the permeability, the studied samples correspond to the IV–V classes of collectors (0.001–0.1 μm^2) according to the A. A. Khanin classification [1–3]. It has been established that within the Dnieper–Donets Basin there is also a third-class collector (permeability 0.1–0.5 μm^2). Samples with such permeability in the field could not be selected, therefore, to take up this class of reservoirs and compare the results of the experiments, the core of the Vyngapurovskoye oil and gas condensate field, located in Western Siberia, was taken for research. It should be noted that polymeric and polymer-clay drilling muds are also widely used in drilling the wells in this region, and the purpose of the experiments is to study the influence of xanthan polymeric drilling mud on the filtration-capacitive properties of polymictic sandstones of various permeability, which are often found in different regions, including the Dnieper–Donets Basin and Western Siberia. The core taken from Vyngapurovskoye oil and gas condensate field has an absolute permeability of 123.52 $\times 10^{-3}$ μm^2 and is a polymictic sandstone with carbonate-clay cement (sample 417-1-4). Polymer drilling mud used for performing dynamic tests on the FDES-645 unit, is a mixture of the following components in %: biopolymer thickener (xanthan)–0.5, starch polysacharide–2, potassium chloride–5, sodium chloride–20, carbonate filler (marble chips)–10, water–the rest.

The technology of preparation of this drilling mud does not require special equipment; for this purpose, any mixing unit (clay mixer, hydromesh mixer, solution preparation unit) is capable of creating intensive mixing and continuously maintain it for at least 4 hours. An important point is the uniformity of mixing the entire volume and the absence of stagnant zones in the cooking vessel. This solution is used in the most difficult geological conditions and is recommended for drilling at great depths. The solution provides effective suppression of hydration and swelling of clay rocks, is characterized by low water loss, and also has a heat resistance up to 140–150 °C. All of the listed properties of the mud are very important, since the opening of productive deposits occurs at a depth of about 5000 m, and the temperature in the investigated depth interval of the gas condensate field of the Dnieper–Donets basin is 130 °C.

2. Methodology

In the laboratory of Enhanced Oil Recovery of the Mining University, the density of the drilling mud was measured, the thermal stability of the drilling mud was studied at a temperature of 130 °C, the static shear stress was determined and an index characterizing the thixotropic properties of the solution was calculated. Also, the conditional viscosity was measured, the fluid loss and the thickness of the filter cake of the solution were determined, and rheological studies of the mud were carried out on the Rheotest RN 4.1 universal rotary viscometer. The density of the drilling mud was measured using a DE 40 density meter from Mettler Toledo at 20 °C. To determine the thermostability of the investigated mud under reservoir conditions, a temperature cabinet with a set temperature of 130 °C was used, in which the polymer solution was kept for 24 hours. Two samples were placed in the thermostat: a pure drilling mud in a volume of 40 ml and a mud (40 ml) in which 4 ml (10 %

of the total volume) of kerosene was added to simulate the process of condensate precipitation in the reservoir.

Further, the conditional viscosity of the drilling mud on the Marsh funnel was measured. Viscosity of drilling fluids should be minimal, but sufficient to hold suspended particles of drill cuttings and weighting agent at a given mud density. The water loss of the fluid was determined on the filter press FLR-1, which is designed to determine this index in solutions used in drilling oil and gas wells. Then, in the laboratory, the porosity and absolute permeability of the samples of the core of the gas condensate field of the Dnieper–Donets Basin and Vyngapurovsky oil and gas condensate field were analyzed. The porosity of the core was measured on a helium porosimeter TPI-219. Determination of the absolute permeabilities of samples by gas (air) was carried out on a TBP-804 unit. After the necessary core preparation, dynamic and static filtration experiments were performed on rock samples of the gas condensate field of the Dnieper–Donetsk basin and the Vyngapurovskoye oil and gas condensate field to simulate the influence of the drilling mud on the reservoir filtration an capacitive properties using a FDES-645 filtration unit.

3. Results

Based on the results of the measurement, the density of the tested drilling mud was $1164\,\mathrm{kg/m^3}$.

The pure drilling mud and solution with kerosene proved to be stable during the entire experiment (24 hours) at a temperature of $130\,^{\circ}\mathrm{C}$.

The values of the static shear stress of the investigated mud, measured after 1 and 10 minutes, are equal, respectively: $\theta_1 = 9.952\,\mathrm{Pa}$ $\theta_{10} = 13.684\,\mathrm{Pa}$.

The thixotropy coefficient, reflecting the rheological properties of the fluid, as a result of the calculations, is $\kappa_{\mathrm{T}} = 1.375$. The obtained value of the exponent κ_{T} enters the required interval (1–1.5).

The conventional viscosity for mud on which the sand strata are exposed should be within an interval of 45–65 seconds. $t_1 = 47$, $t_2 = 46$, $t_3 = 45$ ($t_{\mathrm{average}} = 46$).

As can be seen for the investigated mud, the obtained value of conditional viscosity corresponds to the required value. During the experiment, it was found that the investigated mud has a water loss of $14.4\,\mathrm{cm^3}/30\,\mathrm{min}$ and forms a filter cake with a thickness of 0.4 mm. The results of studying the rheological properties of fluid on the Rheotest RN 4.1 are shown in Figs. 1 and 2.

As can be seen from the graphs presented in the figures, the polymer drilling mud has non-Newtonian properties and is a pseudo-plastic fluid, the effective viscosity of the solution decreases with increasing shear rate. It can also be seen on the graphs that the shear stress and the effective viscosity decrease significantly with increasing temperature, and consequently with increasing depth of the well, the viscosity of the mud will decrease and the hydraulic resistance in the circulation system decrease. The change in the viscosity of the mud at high temperatures will help to reduce the amplitude of pressure fluctuations during the start-up and shutdown of drilling pumps and perform downhole operations, as well as reduce the probability of formation of stagnant zones in the wellbore with the accumulation of

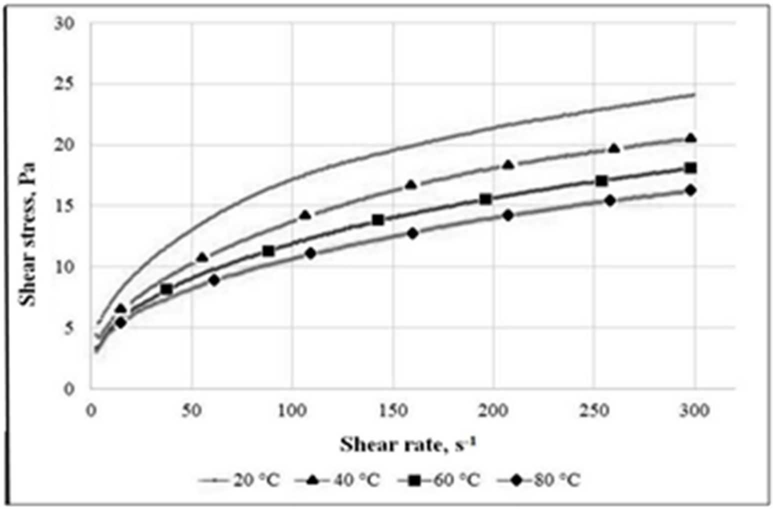

Fig. 1. Dependence of shear stress on the shear rate of shear

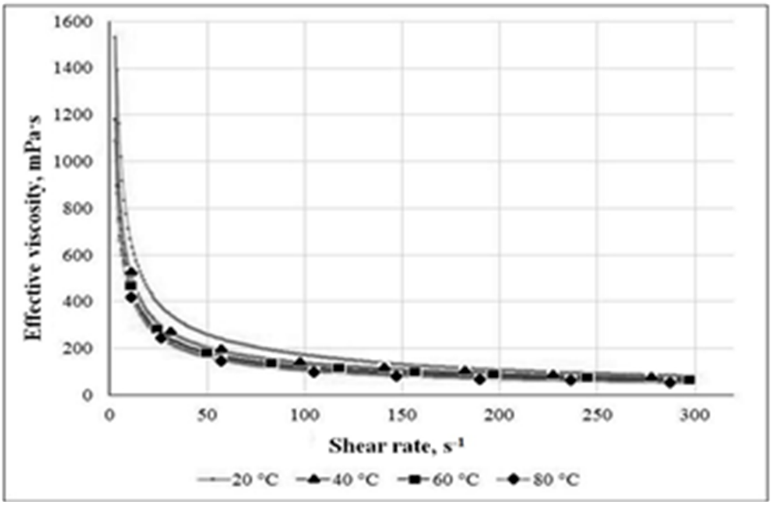

Fig. 2. Dependence of the effective viscosity on the shear rate

cuttings in them [4, 5].

Thus, as a result of laboratory studies, it was established that the polymeric drilling mud, used at the gas condensate field of the Dnieper–Donets Basin, meets all the necessary requirements for drilling fluids for drilling oil and gas wells. The results of extraction of 4 core samples of the gas condensate field of the Dnieper–Donets basin are shown in Table 1.

As can be seen from the presented table, sample 417-1-4 of Vyngapurovskoye oil and gas, the condensate field possesses the highest porosity and permeability. As for the gas condensate field of the Dnieper–Donets basin, here samples from the interval of depths of 4961.5–4961.6 m are characterized by higher filtration and capacitive properties as compared to samples from the interval 4959.5–4959.6 m, which indicates a significant layerwise inhomogeneity of the productive horizon in vicinity of well No. 59, from which the core was selected.

Table 1. Results of extraction of 4 core samples of the gas condensate field of the Dnipro–Donetsk basin

No. of core	No. 1 4959.5–4959.6		No. 2 4959.5–4959.6		No. 1 4961.5–4961.6		No. 2 4961.5–4961.6	
No. of core	water	P+I (50:50)	water	P+I (50:50)	water	P+I (50:50)	water	P+I (50:50)
$d \cdot 10^{-3}$ (m)	29.9		29.9		29.9		29.9	
$L \cdot 10^{-3}$ (m)	74.04		56.6		72.4		73.85	
$Q \cdot 10^{-9}$ (m^3/s)	8.3	8.3	1.7	2.5	16.7	16.7	16.7	16.7
ΔP (MPa)	4	1.8	5	2.5	0.65	0.41	0.46	0.28
μ	1	0.688	1	0.688	1	0.688	1	0.688
$k \cdot 10^{-3}$ (μkm^2)	0.223	0.342	0.027	0.057	2.689	2.897	3.848	4.325

The results of the porosity and absolute permeability measurements of the core samples are shown in Table 2.

Table 2. Results of measuring the porosity and absolute permeability in all 5 core samples

No. of core	No. 1 4959.5–4959.6	No. 2 4959.5–4959.6	No. 1 4961.5–4961.6	No. 2 4961.5–4961.6	417-1-4
$V_{core} \cdot 10^{-6}$ (m^3)	51.99	39.74	50.84	51.85	44.90
$V_{porous} \cdot 10^{-6}$ (m^3)	2.36	1.72	4.67	5.68	9.55
M_{sample} (%)	4.54	4.33	9.18	10.96	21.28
$k \cdot 10^{-3}$ (μkm^2)	1.02	0.32	7.09	14.69	123.52

For the core number 1 (4959.5–4959.6) of the gas condensate field of the Dnieper–Donetsk basin, a primary formation penetration was simulated, under conditions as close to the reservoir as possible, in a dynamic filtration regime, i.e. in the mode of washing the end of the core with drilling fluid, on the installation of FDES-645 (modification of the installation for working with the option Mud). The Mud option makes it possible to simulate the circulation of the drilling fluid in the device as well as in the well when the productive horizon is opened. The static filtration regime for the core No. 1 of the gas condensate field of the Dnieper–Donets basin was not modeled, the core has a very low permeability ($k_{air} = 1.02\,\mu m$).

Consequently, in the process of drilling, there occurs often absorption of drilling mud, associated with the opening of microcracks in the formation due to high repression. To confirm this conclusion, during the experiment, the pressure difference in the FDES-645 circulating system and the core pressure decreased periodically below the recommended value of 500 psi (3.5 MPa). This pressure difference ultimately led to the destruction of the sample at the end. Thus, during the dynamic experiment, it was established that technogenic cracks formed at the end of the core sample (Fig. 3), while the total porosity of the sandstone, following the scanning of the core on the SkyScan computer microtomograph, increased after the impact of the drilling mud by the calculations from 4.54 % to 12 %. This applies only to that part of the core sample where man-caused cracks were formed, the rest of the porosity remains unchanged. This experiment confirmed the presence of microcracks in the productive strata of the gas condensate field of the Dnieper-Donets Basin and the possibility of their disclosure due to differences in pressure and absorption of the drilling mud during the drilling process.

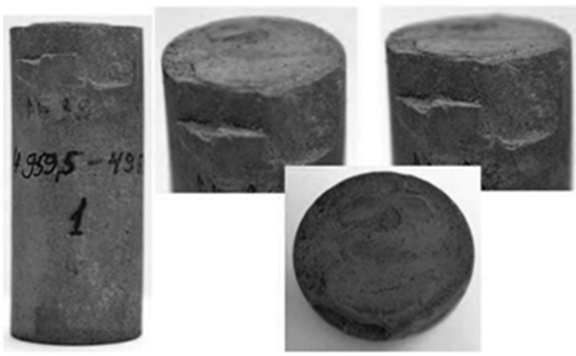

Fig. 3. Appearance of Core No. 1 (4959.5–4959.6) gas condensate field of the Dnieper–Donets Basin after simulation of the dynamic filtration regime

Further, dynamic and static experiments were carried out on the core of Vyngapurovskoye oil and gas condensate field. In the process of studying this core, the reservoir conditions of the gas condensate field of the Dnieper–Donets Basin were modeled ($T_{\text{formation}} = 130\,°\text{C}$, $P_{\text{formation}} = 48.7\,\text{MPa}$). The purpose of this experiment was to evaluate the change in the filtration and capacitive properties of polymictic sandstones after the polymer drilling mud was exposed to them. Simulation was carried out in 2 stages:

Dynamic mode of filtration of the mud, at which the solution was circulated along the end of the core with a constant flow rate; Static filtration regime at a constant effective pressure, which is equal to the difference in pressure of the drilling mud column at a depth of 4960 m and hydrostatic pressure. The constant effective pressure was 1157 psi (7.98 MPa). In the dynamic filtration regime, the polymer drilling mud was pumped at a flow rate of 1 ml/min for 4 hours, then the same time the sample was maintained in a static mode at a constant pressure of 7.98 MPa and a variable flow rate. The graph obtained in the course of the experiment is shown in Fig. 4.

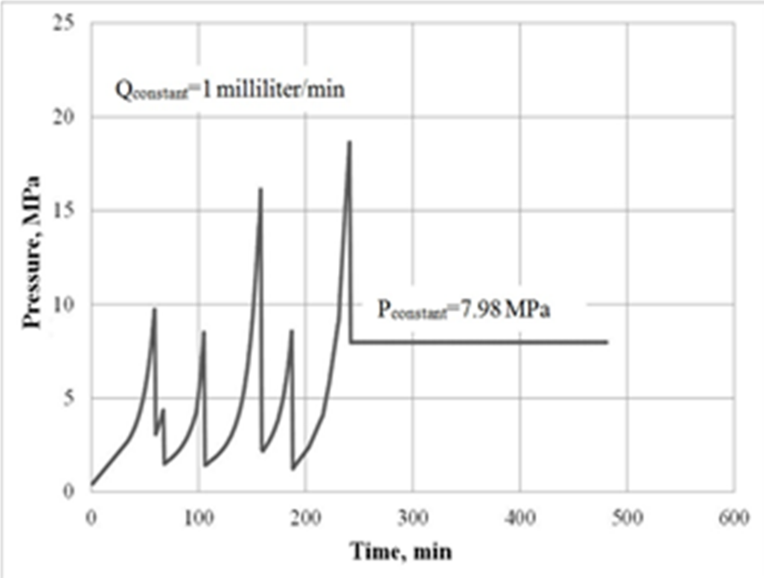

Fig. 4. Graph of pressure changes, obtained during simulation in dynamic and static modes

Under the dynamic regime of filtration of the polymer drilling mud along the core end, the same sharp changes in pressure were observed in the experiment as in the previous experiment on the core from Dnieper–Donets basin. After 4 hours, the installation was transferred to the static mode, i.e. in the regime of maintaining constant pressure at the end of the core. Figure 5 shows a sample of Vyngapurovskoye oil and gas condensate field core after dynamic and static tests on the FDES-645 unit.

Fig. 5. Appearance of the core sample from Vyngapurovskoye oil and gas condensate field after dynamic and static tests on the FDES-645 unit

Further, a mechanical removal of the filter cake from the end part of the core was carried out with the help of a metal scraper and the absolute permeability in gas was measured, in order to determine the change in the filtration characteristics of the test sample 417-1-4 after exposure to the drilling mud. The results of permeability measurements before and after exposure to the mud showed that the permeability of this sample decreased from $153.52\times10^{-3}\,\mu m^2$ to $64.31\times10^{-3}\,\mu m^2$. In the work

[2], the influence of the polymer component of drilling fluids on the permeability of polymictic sandstones was investigated and similar results were obtained. High-molecular polysaccharides were the polymer components: platogel, xanthan gum and sodium carboxymethyl cellulose technical (Kamzel-1000). The aqueous solutions of these polymers prepared at the concentration in which it was present in the drilling mud saturate the cores, then they were extracted with an alcohol-benzene mixture, dried and the gas permeability was measured. The results were obtained as follows: the presence of xanthan gum and Kamtsel-1000 in the pore space reduced the core permeability by 25–49 % relative to the values obtained before saturation of these samples with aqueous solutions of polymers [2].

Thus, as a result of the experiment, almost a 2-fold decrease in the permeability was recorded, which is explained by the penetration of the mud filtrate and the carbonate particles of the solution weighting agent into the core. Also, in the laboratory experiment with the polymer filtrate produced by the filter press FLR-1, it was found that at high temperature (105 °C) water from it begins to evaporate and a solid polymer film is formed (Fig. 6). The formation of such a film can be explained by the fact that the composition of the drilling mud contains xanthan and various salts (KCl, NaCl), which can interact with rock-forming minerals. Thus, it was shown that at a high temperature a polymer film is formed from the filtrate, which can shield the hollow space of the matrix and cracks.

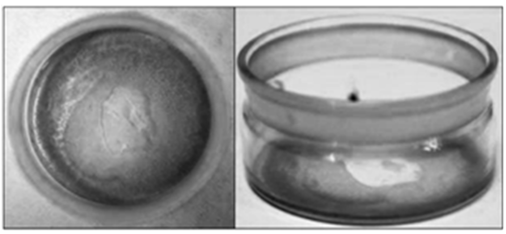

Fig. 6. Polymer film after evaporation of water from the filtrate

It is known that xanthanum and marble dissolve hydrochloric acid, the solutions of which are usually used to clean the productive formation after drilling wells using polymer drilling mud [1, 7]. To study the action of hydrochloric acid on the resulting polymer film in laboratory conditions, another experiment was carried out. In the course of which, an aqueous solution of 12 % hydrochloric acid was gradually added to the bottle with the polymer film formed from the filtrate, which completely dissolved it. This experiment showed the effectiveness of the use of aqueous solutions of hydrochloric acid for the purification of bottomhole formation zone after the use of polymer drilling mud. However, how deep into the fissure-porous collector can penetrate and react the acid compared to the of the drilling mud filtrate to be clarified in subsequent experiments.

In conclusion, it should be noted that in low-porosity sandstones of gas condensate fields of the Dnieper–Donets basin there are microcracks that can expand during drilling and form the so-called technogenic fracturing. As a result, significant absorption of the washing liquid and deep penetration of the drilling mud into the formation take place, while the filtration-capacitive properties changes both in the bottomhole formation zone and in its remote part. The polymer film, formed from the drilling mud filtrate, can also screen collector pores and microcracks.

4. Conclusion

1. The investigated samples of the core of the gas condensate field of the Dnieper–Donets basin allow attributing the productive sandstones of the V-21 formation in well No. 59 mainly to the fractured-pore type of the reservoir. As shown by laboratory experiments, in the process of opening such sandstones, the microcracks present in them can be opened at a pressure difference in the FDES-645 circulating system and the core pressure is below the recommended value of 500 psi (3.5 MPa). During the experiment, the pressure drop reached 200 psi. Based on the obtained results, it can be argued that in real conditions of drilling wells at the opening of productive strata for repression, fracture processes will occur on a larger scale than in the laboratory.

2. The carried out filtration experiment on the sample of the core of the Vyngapurovskoye field showed that the polymer drilling mud used in drilling wells significantly reduces filtration-capacitive properties of polymictic sandstones. In this case, the absolute permeability of sample No. 417-1-4, after exposure to the mud, decreased almost twofold from $123.52\times10^{-3}\,\mu m^2$ to $64.31\times10^{-3}\,\mu m^2$. This change in permeability can be explained by the deep penetration of the filtrate and particles of the carbonate weighting agent into the core, despite the presence of a protective filter cake at the end of the sample.

3. The laboratory experiment to study the effect of hydrochloric acid on a polymer film showed that a polymer film formed from a high-temperature (105 °C) filtrate of the mud can be effectively destroyed by a 12 % aqueous solution of hydrochloric acid, but in further laboratory experiments it is necessary to find out how deep it is capable to penetrate the fissured-pore sandstone and react with the contaminant.

4. The use of modern technologies of stimulation of the inflow during the development of wells, such as acid treatments and multi-stage hydraulic fracturing of the reservoir, as well as the correct selection of the acid composition and method of hydrochloric acid treatment bottomhole zone will significantly increase the productivity of low-porosity polymictic sandstones.

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