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Increase in Permeability of the Terrigenous Reservoir after Exposure to Polymer-Based Drilling Mud

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Abstract

The paper describes the results of the experimental determination of the influence of a filtrate of a polymer solution on the permeability of productive formations of various permeability. As a model of the bottomhole formation zone, the restored-state core was used for conducting the research procedures. Damage to the core was simulated by pumping the drilling mud into the model. Measurement of the permeability of the core damaged by the drilling mud was carried out on kerosene, similar to the measurement of the basic permeability. As a result of the studies carried out on the influence of the filtrate of the polymer solution on the bottomhole zone model, it was found that the permeability recovery coefficient after the exposure to the filtrate of the polymer solution is inversely proportional to the base permeability of the productive formation.

Keywords: permeability, productive formation, polymer-based drilling mud, terrigenous reservoir.

INTRODUCTION

The goal of constructing oil and gas wells is production of hydrocarbons with maximum production rates. Currently, the applied completion techniques with overbalance on the reservoir imply inevitable penetration of liquid and solid phases of drilling muds and cement slurries into the pore space of oil and gas-saturated reservoirs, which leads to a decrease in the natural permeability of the formation in the bottomhole zone of the well, which leads to a decrease in hydrocarbon production rates. At the same time, the main negative impact on subsequent hydrocarbon production rates is primary penetration into the productive formation during drilling of the well. The negative effect on the quality of productive formation penetration is determined by the content in the drilling mud of the solid phase penetrating deep into the formation and creating a low-permeability colmatant layer, and a filtrate penetrating to a greater depth, which together causes an increase in hydraulic resistances during filtration through these zones of formation hydrocarbons.

To date, there are many ways to improve the quality of reservoir penetration, which are described by the decision of three consecutive stages of choosing optimal properties of the drilling mud and technology of well completion [1]:

- preliminary analysis of the effect of various technological factors and properties of the drilling mud on the nature and rate of change in permeability of the bottomhole formation zone;

- identifying technologically feasible solutions;

- determination of the properties and composition of the solution ensuring maximum hydrocarbon production rates.

The main geological and technological factor influencing the choice of properties of the drilling mud is the geological section, as well as the type of the well (vertical, directional or horizontal). This factor determines the necessity of compatibility of the properties of the drilling mud for productive formation penetration and main hole drilling. This problem is solved by selecting the drilling mud composition with the required physical and mechanical properties, and recently washing fluids using polymers have been widely used, which allows to increase the drilling speed and the stability of the walls of the well [2].

However, the use of polymer-based solutions degrades the filtration characteristic of the reservoir by blocking the pore space of the bottomhole formation zone by the formed polymer film [3].

MATERIALS AND METHODS

The authors analyzed the effect of the filtrate of a polymer solution on the permeability of reservoirs of different permeabilities. As a model of the bottomhole formation zone, the core of the restored state was used for research. Damage to the core was modeled by pumping the mud into the model (Table 1). Measurement of permeability of the core damaged by the drilling mud was carried out for kerosene, similar to measurement of base permeability. In parallel, kerosene permeability was measured of the whole model and differentially at two points at different distances from the "wellbore". Filtration was carried out in the direction "formation-well". Measurement of kerosene permeability was carried out at three kerosene filtration rates. As a result of

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studying the effect of the filtrate of the polymer solution on the bottomhole zone model, it was found that the coefficient of permeability recovery after exposure to DMF is inversely proportional to basic permeability of the productive formation (Fig. 1, Table 2). Analysis of Table 2 shows a significant reduction in permeability in a high-permeability formation, even in the remote part of the bottomhole zone of the formation, which indicates the formation of a polymer film in the depth of the productive formation, thereby creating additional filtering resistances when the fluid moves from the formation to the bottom of the well.

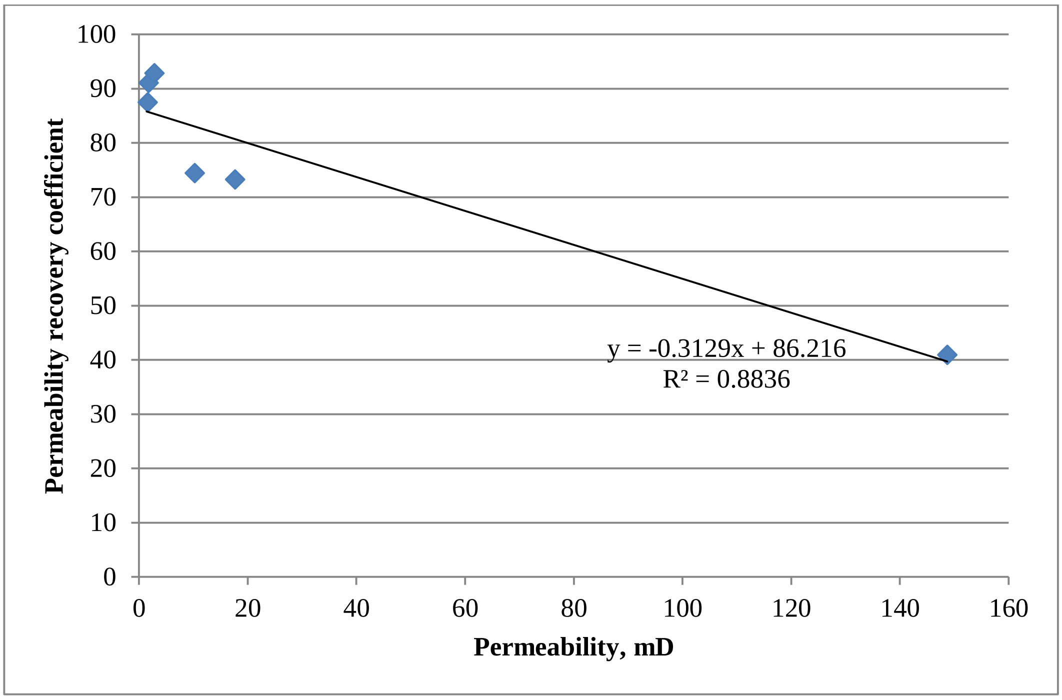

Figure 1. Comparison of the permeability recovery coefficient for kerosene after the action of the filtrate of the polymer solution with the baseline permeability of the reservoir.

Table 1. Rheological parameters of the drilling mud

Process fluid	Temperature, ^0C	Density, ρ, g/cm^3	Relative viscosity, T, s	Water loss, WL, $cm^3/30min$	Cake, C, mm	pH	Viscosity at 100 vol., φ_{100}, mPa·s	Viscosity at 200 rev, φ200, mPa ·c	Viscosity at 300 rev, φ300, mPa · s	Viscosity at 600 rev, φ600, mPa · s
1	2	3	4	5	6	7	8	9	10	11
Drilling mud with a specific gravity of 1.02 g/cm^3	18.8	1.10	126.0	8.2	0.7	9.6	53.9	73.4	89.1	117.1
	19.9	1.11	124.0	8.5	1.0	9.6	53.2	72.2	86.3	115.9
	19.3	1.105	125	8.35	0.85	9.605	53.55	72.8	87.7	116.5

Static shear stress (SSS)', mPa*s		Plastic viscosity, η_{PL}, mPa·c	Dynamic shear stress (DSS), dPa	Static shear stress (SSS), dPa		Effective viscosity, η_{EF}, mPa·s	Solids content, Vs,%	Content of sand, C_S,%	MBT
10s/	10min			10s	10min				
12	13	14	15	16	17	18	19	20	21
5.4	5.6	28.0	292.1	25.8	26.8	58.6	-	-	-
5.2	5.3	29.6	271.0	24.9	25.3	58.0	-	-	-
5.3	5.45	28.8	281.542	25.33	26.051	58.25	-	-	-

Table 2. Results of the study of the drilling mud effect on a column of core material

№	Permeability, 10^{-3} μm^2			Drilling mud filtration parameters *			Permeability after mud impact, 10^{-3} μm^2		
	of the entire column	at a 15 mm distance from the BHZ	at a 45 mm distance from the BHZ	T of the impact, h	fluctuation of P, MPa	Amount of filtrate, Vpore	of the entire column	at a 15 mm distance from the BHZ	at a 45 mm distance from the BHZ
1	1.372	1.649	1.730	4	2.21	1.99	0.939	1.408	1.576
2	15.87	16.762	17.676	4	2.07	2.04	8.383	11.928	12.953
3	8.383	11.928	12.953	8	1.24	2.04	8.743	8.002	9.145
4	1.086	1.229	1.546	4	1.93	2.13	0.69	0.974	1.353
5	104.2	125.59	148.68	4	2.07	1.96	27.328	39.642	60.868
6	9.013	9.681	10.250	4	2.9	1.83	3.998	5.919	7.63
7	1.717	2.362	2.802	4	2.96	2	1.303	2.059	2.602
8	0.808	1.023	1.421	4	2.69	2.44	0.421	0.588	0.95

To intensify the inflow of hydrocarbons from the reservoir that was tapped with polymeric drilling mud, investigations were carried out on the compatibility of the drilling mud filtrate (DMF) with conventional reagents used to intensify inflows that showed a negative result (Table 3) [3].

Table 3. Characteristics of DMF compatibility with reagents used to intensify the inflow

Reagents	Sediment characteristic
SAS, 0,02 %	Amorphous, brown, plentiful
HCl, 6% (weight)	Amorphous, brown, plentiful
$CaCl_2$, 5 % (weight)	Amorphous, brown, plentiful
NaOH, 5% (weight)	Not plentiful, brown
condensate	No reaction
Methanol	The sediment is plentiful, amorphous, light-brown in color

A large amount of sediment indicates the incompatibility of the filtrate with the reagents (hydrochloric acid, synthetic grape acid, alkali, etc.), on the basis of which an aqueous solution of calcium hypochloride $Ca(ClO)_2$, which is a strong oxidant, is proposed to recover permeability of the productive formation exposed with a polymer or polymer-clay solution.

To determine the effectiveness of the proposed composition, laboratory tests were performed in comparison with the most common acid formulations (Table 4).

Table 4. Information on the tested acid compositions

№	Acid composition
1	HCl – 15 %
2	HCl – 15 % + acetic acid – 9 %
3	HCl – 15 % + formic acid – 9 %
4	HCl – 15 % + HF – 10 %
5	HCl – 15 % + HF – 10 % + formic acid – 9 %
6	HCl – 15 % + HF – 10 % + acetic acid – 9 %

As a result of the tests performed from the solutions presented (Table 4), it was determined that the maximum weight loss was recorded after treatment with a mixture of hydrochloric acid and hydrofluoric acid. A slightly smaller loss was obtained after exposure to a three-component formulation - HCl + HF + formic acid. The minimal effect was achieved with a mixture of hydrochloric and formic acids. To confirm the maximum efficiency of the selected acid composition (HCl + HF), two collections of sample cylinders were processed with two acid formulations: a mixture of HCl 15% + HF 10% and 15% hydrochloric acid. The coefficient of increase in permeability was 1.5-16 after treatment with a mixture of hydrochloric and hydrofluoric acids and 1.2-5.7 after treatment with hydrochloric acid. The greatest effect was obtained for low-permeability samples - with an initial Kpr <1 mD, the lowest in high-permeability samples. Thus, the conducted studies on the average rock samples of the studied objects have shown the necessity of carrying out laboratory studies on the impact of the damaged core with a mixture of hydrochloric and hydrofluoric acids.

To determine permeability of the liquid, an apolar liquid, kerosene, was used, due to its viscosity. At reservoir temperature, the viscosity of kerosene coincides in numerical value with the viscosity of oil under reservoir conditions, and also kerosene is identical with the reservoir oil in the surface tension at the boundary with water. In addition, in determining permeability for oil, oil to some extent reduces the core permeability, due to deposition of oil components in the pores of the core.

The method of measuring fluid permeability is based on measuring the hydraulic resistances that occur during fluid flow through porous media. Knowing the pressure drop across the measured core section at a given volumetric flow rate of the fluid, its viscosity and geometric dimensions of the filtration area allows us to calculate permeability by applying the Darcy law:

$$K = (Q \times \mu \times L)/(dP \times F), \quad (1)$$

where K – permeability for fluid, μm^2;

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Q – fluid flow rate, under experimental conditions, cm^3/s;

μ - fluid viscosity, mPa·c;

L – length of the sample at which the pressure drop is measured, cm;

dP – pressure drop at a given flow rate, 105 Pa;

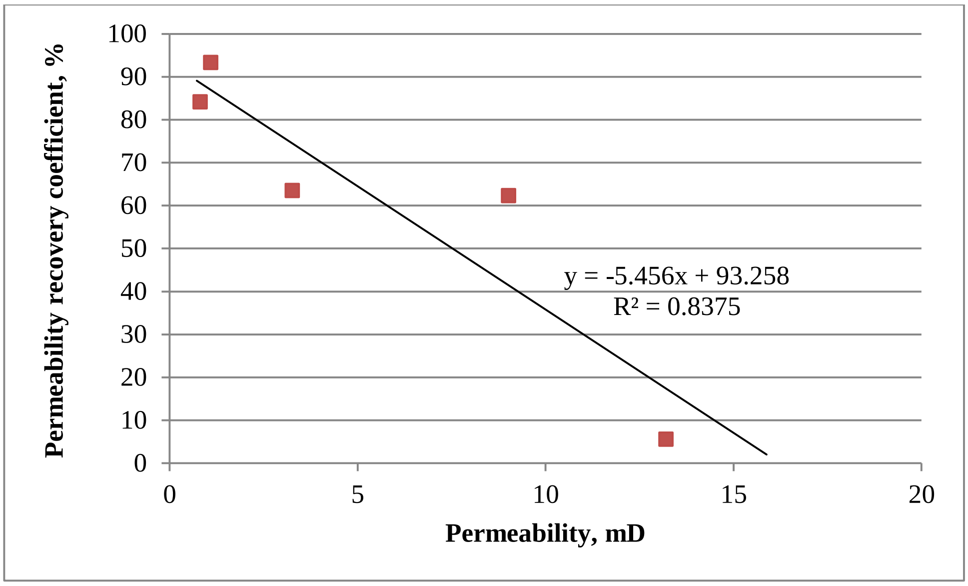
F – cross-sectional area of the sample, cm^2.

After measuring permeability of the damaged formation, the acid composition was pumped in the direction from the wellbore to the formation, while maintaining a constant flow rate. The pressure drop was determined at the beginning and at the end of the acid composition injection. After pumping up to 2 pore volumes of the acid composition, filtration stops for an exposure (time for the reaction of acid compositions with the rock) for 8 hours. After injection of the acid composition in the formation was completed, kerosene was back-filtered "from the formation to the well" and final kerosene permeability was measured for the entire model and differentially at two points at different distances from the "wellbore". The results of the study are presented in Table 5.

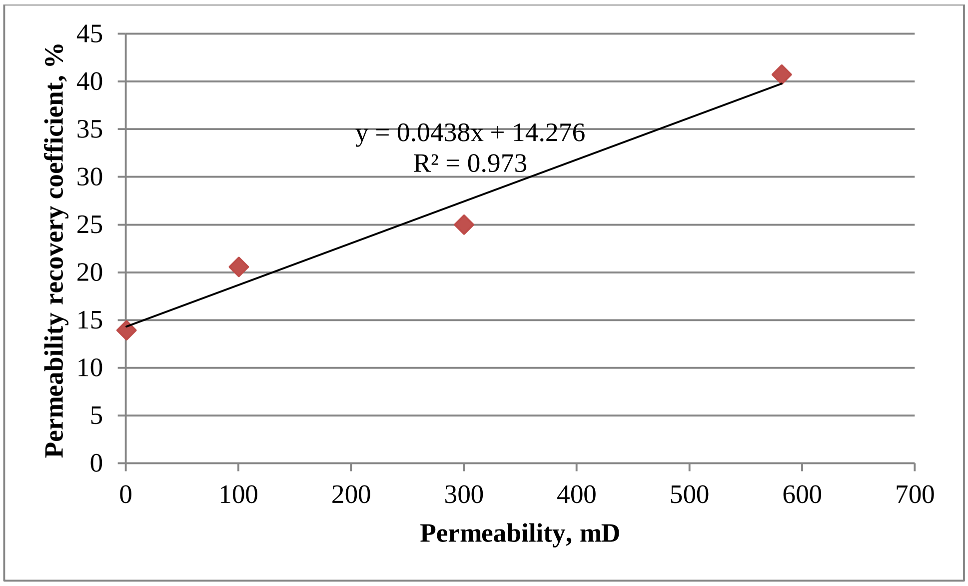
In the course of the research to study the effect of polymer-based mud filtrate on the quality of penetration into the productive formation it was revealed that a significant decrease in permeability occurs in the zone of a high-permeability reservoir (Kpr> 100 mD) - up to 25% relative to the initial one. For a low-permeability reservoir (Kpr <5 mD), permeability drops less significantly - up to 50-75% of the baseline. At the same time, the effect of acid composition and process fluid is also manifested in different ways in reservoirs of different permeability (Fig. 2).

The most effective is application of the composition of hydrochloric 10% + hydrofluoric acid 3% in the area of a low-permeability reservoir (Fig. 2a, Table 5).

№	Pre-treatment parameters				Treatment with DM+ $Ca(ClO)_2$		Treatment with DM +acid		
	Kpr gas, mD	Kp, %	Kos, %	Kpr kerosene, base, mD	Kpr. kerosene, mD	Krecov, %	Kpr. kerosene, mD	Krecov, %	Underbalanc, MPa
1	7.0	13.6	64.8	3.18	0.39	12.3			
2	95.3	19.6	31.1	78.8	48.2				
3	116.8	17.0	42.4	100.2	24.6	25.9			
4	3.1	17.7	50.6	0.74	0				
5	728.9	19.8	17.0	582	237	40.7			
6	4.6	18.6	47.4	0.79	0.11	13.9			
7	19.92	15.3	58.63	13.20			0.74	5.6	6
8	6.28	18.5	51.4	1.37			1.31	95.8	6
9	24.92	16.37	32.67	15.88			9.85		6
10	6.2	13.43	37.65	1.09			1.01	93.4	3
11	22.81	17.57	44.71	9.01			5.62		3
12	5.14	17.04	47.79	1.72			1.98	115.4	3
13	4.82	16.01	53.53	0.81			0.68	84.2	-
14	4.37	17.85	51.69	1.26			0.80		6
15	2.77	11.64	43.24	0.81			0.50		6
16	2.78	18.48	62.68	0.73			0.49		6



(a)



(b)

Figure 2. Dependence of the permeability coefficient of the productive formation after treating the core damaged by the drilling mud filtrate with acid compositions on permeability: a - after exposure to an acid composition of 10% hydrochloric + 3% hydrofluoric; b - calcium hypochloride Ca(ClO)

RESULTS AND DISCUSSION

Moreover, it is graphically determined that with an increase in permeability, the effect of the acid composition action is reduced, and with an underbalance of 6 MPa and higher, permeability deteriorates both in the entire column and at the distance. This fact indicates a shift and further blockage in the pore space by particles of the reaction of clay acid with the rock, the drilling mud filtrate and the solid component of the mud at the boundary of the colmatation screen. It should also be noted that the use of a mixture of highly concentrated acids - 15% HCl + 10% HF - has a negative effect. This confirms the fact that using clay acid as a solution for intensifying the influx of hydrocarbons from a productive formation penetrated by a polymer-based solution is ineffective. In this case, there is dissolution of the parent rock with the formation of new cracks or dissolution of the surface of natural cracks, and not by dissolving the products contaminating the BHZ. On the other hand, for a low-permeability reservoir, the use of an aqueous solution of hypochlorite does not lead to even a partial recovery of the core permeability after the impact of the drilling mud, permeability even falls. This is clearly shown in Figure 2 b., where the permeability recovery coefficient does not exceed 20%. However, with increasing permeability, effectiveness of the proposed solution increases and reaches 40-60%, which indicates the dissolution of products contaminating the BHZ.

The results obtained allow us to recommend for commercial use in recovering permeability of terrigenous reservoirs after the action of a polymer-based drilling mud:

1. When tapping a low-permeability reservoir, use the acid composition 10% HCl + 3% HF.
2. In the medium- and high-permeability reservoirs - an aqueous solution of calcium hypochlorite 10% + SAS 0.03%.

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