Experimental study of oil displacement from a porous medium using nanosuspension

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Abstract. The paper presents the results of an experimental study of oil displacement by distilled water and an aqueous suspension of aluminum oxide nanoparticles. The correlation of extracted oil volume on the flow rate of the displacing fluid is obtained, and the pressure drop during the pumping of the displacing fluid through the rock sample is measured. It has been revealed that the suspension of nanoparticles can significantly improve the extraction of oil from sandstone.

1. Introduction
The efficiency of oil recovery from oil-bearing reservoirs by modern industrially developed methods in all oil-producing countries is considered unsatisfactory. The average final oil recovery rate for different countries and regions varies from 25 to 40%. Residual oil or reserves non-recoverable by commercially developed methods reach on average 55-75% of the initial geological reserves of oil in the subsurface. Therefore, increasing oil recovery is, certainly, extremely important. Even today, several technologies allow doing this (at least partially). However, contemporary methods of enhanced oil recovery are much more complex, expensive, and environmentally harmful than traditional technologies.

In recent years, studies showing that the use of nanoscale emulsions and suspensions can significantly increase the volume of oil recovery from the reservoir have appeared abroad [1-3]. A change in the wettability of the rock, which contributes to the leaching of film and capillary- retained oil from the rock, is one of the reasons why surfactants are used in methods of increasing oil recovery. A fairly large number of laboratory experiments have confirmed the high efficiency of nanoparticles in reducing the contact angle on the surface of various materials. Environmental problems that arise when using highly toxic surfactants can be solved by replacing such surfactants with nanoparticle-based suspensions [4-5].

The purpose of the present research is to study experimentally the displacement of oil from rock samples of sandstone using a suspension of aluminum oxide nanoparticles.

2. Problem statement
Cylindrical samples of sandstone rock (30 mm in diameter and 35 mm in length) were prepared for the oil displacement study. The sandstone was taken from the Berea sandstone deposit. This sandstone is characterized by uniform permeability and porosity. Samples were pre-dried, numbered, and then weighted.
The porosity of the samples was determined by the gas saturation method based on the Boyle-Marriott law. The average measured porosity of the samples was 22%. The gas permeability of these samples corresponded to a value of 230 millidarcies (mD). After determining the porosity and permeability, the samples were placed in a saturator, where they were saturated with oil for a long time. Figure 1 shows a photo of saturated cores.

Distilled water and water-based nanosuspension with aluminum oxide nanoparticles (produced by Powder Technologies, Tomsk) with a size of 50 nm and a mass concentration of 0.5% were used as the displacing fluid. The nanosuspension preparation principle was based on a two-stage method. In the beginning, the nanoparticle powder was put into distilled water, and then mixed using a high-speed agitator. After mixing, the solution was subjected to ultrasonic impact by the “Volna” disperser for 30 minutes [6-7].

The displacement experiments were conducted as follows. A core sample saturated with oil was weighed to determine the volume of oil in the pore space. Then it was placed into the test cell of the multiphase filtration unit. A geostatic pressure corresponding to the reservoir pressure and excluding the possibility of displacing fluid flow through the side surface of the sample was created in the test cell. The displacing fluid (water or nanosuspension) was fed into the test cell at a constant flow rate, and penetrated the core sample, thereby displacing the oil from the pore space of the rock. Then the displaced oil and the displacing fluid were collected in test tubes to measure their volume. The dynamics of displaced oil volume changes were recorded over time, as well as pressure dynamics at the inlet and outlet of the cell.

Figure 1. Samples of the saturated core.

3. Results and discussion
A study was conducted to reveal the effect of the displacing fluid flow rate on the displaced oil. Three flow rates of 0.5, 1.0, and 2.5 ml/min were considered. As a result of the research, the correlation of the extracted oil volume depending on the flow rate of the pumped displacing fluid was obtained (figure 2). It can be seen that with an increase in the flow rate of the displacing fluid, the volume of oil extracted from rock samples decreases, both for distilled water and nanosuspension. This is because at low flow rate the front of the displacing fluid moves more evenly within the porous medium, in contrast to the occasions with a large flow rate where the front of the displacing fluid breaks through the front of oil in the form of so-called fingers.

However, as a result of research, it was shown that when nanoparticles were added to the displacing fluid, the volume of displaced oil increased significantly. At that, it was shown that with an increase in the flow rate of the displacing fluid, the increment in the volume of displaced oil when using nanosuspension increased in comparison with that when using distilled water. Thus, for example, at the flow rate of nanosuspension equal to 1 ml/min, the increment in the displaced oil
volume was by 33% higher than that for oil, displaced by pure water, while at the flow rate of 2.5 ml/min, this ratio amounted to 2.5 (figure 2).

To explain the results obtained, the contact angle was measured at the oil/sandstone/displacing fluid interface. Typical photos of oil droplets on sandstone for the studied fluids are shown in figure 3. As a result, it was revealed that the average values of the contact angle for a drop of oil in distilled water were within the limits of 125°-130°. It was shown that the addition of nanoparticles affected the oil wetting characteristics of sandstone. Analysis of the effect of nanoparticle additives on the contact angle has shown that when adding 0.5 wt.% of aluminum oxide nanoparticles, the internal contact angle increased from 130° to 155° (figure 3b). In our opinion, this is the main reason for the increased oil recovery factor when using nanosuspensions during core flooding.

Figure 2. Dependence of the displaced oil volume on the volumetric flow rate of the pumped displacing fluid.

Figure 3. Photo of an oil drop on sandstone in distilled water (a) and a nanosuspension of aluminum oxide (b).

Figure 4 shows data on the pressure drop during the displacement of oil from the oil-saturated core. Pressure drop curves have a characteristic appearance that is associated with the processes occurring during oil displacement. It can be seen that at the beginning of the displacement process, the pressure increases rapidly. At this time, the oil is replaced by a displacing fluid. At the core outlet, the pure oil flow is observed. Further, at some point in time, the displacing fluid breaks through to the core outlet, and the pressure decreases sharply. At this time, a mixture of oil and water flows out at the core outlet. This process is accompanied by a pressure drop. After the oil flow terminates, the pressure stabilizes.
After this, the displacement fluid is filtered. From the data obtained, it can be seen that when nanoparticles are added to the displacing fluid, the breakout time and the time interval during which the oil-water mixture flow is observed, increases significantly. This results in more oil being washed out of the porous medium.

\[ \text{Figure 4. Pressure drop over time during displacement at the displacement fluid flow rate of 2.5 ml/min.} \]

**Conclusion**

The experimental results have shown that the addition of nanoparticles allows for increasing the oil recovery factor. Thus, it is shown that the concentration of 0.5 wt.% of aluminum oxide nanoparticles with a size of 50 nm can increase the oil recovery factor by about 33% compared to that for distilled water (at a flow rate of 1 ml/min).

When studying the effect of the displacing fluid flow rate on the efficiency of oil recovery using nanosuspensions, it is shown that with increasing flow rate, the efficiency of using suspensions for oil displacement increases. The difference in the volume of displaced oil at high flow rates is especially noticeable. The ratio of the displaced oil volumes corresponding to nanosuspension and distilled water at a flow rate of 2.5 ml/min equals 2.5.

Based on the research results, it can be concluded that the use of nanosuspensions to increase the oil recovery factor is an urgent and promising task.

In the future, it is planned to conduct a series of experiments to study the increase in oil recovery factor depending on the material, size, and concentration of nanoparticles in the suspension. It is also planned to study the effect of the above parameters of nanosuspension on the contact angle, wettability, and interfacial tension. Based on the results obtained, it will be possible to conclude the effectiveness of using a particular type of nanosuspensions as a displacing fluid to increase the oil recovery factor.

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