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INFLUENCE OF DIFFERENCE IN SPECIFIC ELECTRICAL CONDUCTIVITIES OF LIQUIDS ON THE PROCESS OF DISPLACEMENT IN A POROUS MEDIUM

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The results of experimental investigation of the influence of the specific electrical conductivity of liquids on the process of displacement in a porous medium have been given. It has been established that, for cofiltered aqueous electrolyte solutions of virtually the same viscosity, an increase in the ratio of the electrical conductivities of the displacing and displaced liquids leads to a decrease in the displacement coefficient before the breakthrough of the displacing liquid. It has been found that, in displacement of a nonpolar liquid by aqueous systems close in viscosity, an increase in the specific electrical conductivity of the displacing liquid causes a reduction in the displacement efficiency.

The ratio of the viscosities of liquids is known to be the main factor determining the character of the process of displacement in a porous medium [1, 2]. At the same time, filtered liquids may have nearly the same viscosity ratio but different electrical-conductivity ratios because of the different composition of the substances dissolved in them. As a consequence counterflows or flows accompanying confined ones can appear; they are related to both kinetic and electrokinetic phenomena caused by the concentration gradient of neutral molecules, ions, and electric charge along the liquid flow [3–6]. In this connection, it is of interest to investigate the influence of the specific electrical conductivities of liquids on the process of displacement in a porous medium on the condition that the viscosity ratio is invariable.

In the first step, we investigated experimentally the mutual displacement of seawater with different concentrations of the electrolyte (sodium chloride NaCl) through a porous medium (quartz sand placed in a glass tube with a diameter of 0.016 m and a length of 0.44 m, arranged horizontally). The displacement was carried out at a constant pressure difference of $0.004 \cdot 10^6$ Pa. The water permeability of the porous medium was $8 \cdot 10^{-12}$ m^2. The appearance of the displacing liquid in the fluid taken was recorded by periodic determination of the specific electrical conductivity of the liquid at the porous-medium inlet with a multipurpose LCRE 7-11 meter.

We note that the viscosity relation of the liquids participating in cofiltration was virtually equal to unity. Then, at T = 296 K, the values of the specific electrical conductivity were 1.10, 1.88, 2.79, 3.56, and 4.30 S/m for an NaCl concentration of 0, 1, 2, 3, and 4 mass % respectively.

Figure 1 gives the displacement coefficient $\eta_{b.br}$ equal to the ratio of the volume of the displaced liquid before the breakthrough of the displacing liquid to the pore volume of the model as a function of the relation of the specific electrical conductivities κ_1 of the displacing and κ_2 displaced liquids.

As is seen in the figure, an increase in the ratio of the electrical conductivities of the liquids κ_1/κ_2 is accompanied by a decrease in the displacement coefficient. The result obtained is most likely associated with the phenomenon of anomalous (capillary) osmosis underlying in the motion of a liquid toward a lower concentration (electrical conductivity) of the solution [3, 4]; the larger the difference of the solutions used in concentration (electrical conductivity), the more intense the flow. When the capillary-osmotic flow, whose effect according to [4] is more pronounced than that of diffusion transfer for solutions containing ionic components, is in opposition to the confined flow ($\kappa_1/\kappa_2 < 1$), equalization of the displacement front occurs; otherwise ($\kappa_1/\kappa_2 > 1$) this flow is coincident with the confined one and, conversely, contributes to the breakthrough of the displacing liquid, which is expressed as a decrease in the displacement coefficient $\eta_{b.br}$.

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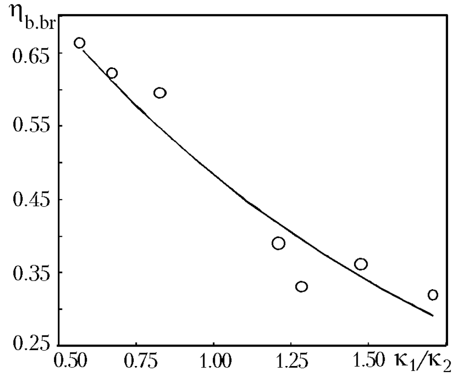

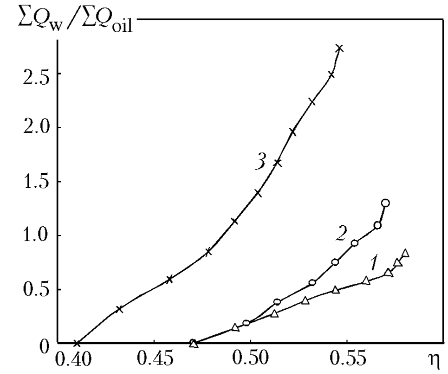

Fig. 1. Displacement coefficient $\eta_{b.br}$ before the breakthrough of the displacing liquid vs. the ratio of the specific electrical conductivities κ_1 of the displacing and κ_2 displaced aqueous solutions of NaCl.

Fig. 2. Accumulated water factors $\Sigma Q_w/\Sigma Q_{oil}$ vs. running coefficient of displacement η of transformer oil for different specific electrical conductivities of the displacing aqueous system: 1) distilled water; 2) seawater; 3) seawater with addition of 12% NaCl.

It is noteworthy that the resulting curve is analogous to the dependence of the water-free coefficient of displacement of a hydrocarbon liquid by water on the liquid-viscosity ratio decreasing with increase in the viscosity of the liquid displaced [1, 2].

In the next step, we investigated the displacement, in a porous medium, of a model hydrocarbon liquid by aqueous systems close in viscosity but significantly different in specific electrical conductivity. The model hydrocarbon liquid was nonpolar transformer oil (referred to as oil in the subsequent discussion) with a specific electrical conductivity of $2 \cdot 10^{-8}$ S/m. Distilled water, seawater, and seawater with addition of 12% NaCl, whose specific electrical conductivities were 0.005, 1.1, and 10.2 S/m (T = 296 K) respectively were used as the displacing liquid. The ratio of viscosities of the oil and the aqueous systems remained approximately the same and equal to 25.

The displacement was carried out at a constant pressure difference of $0.018 \cdot 10^6$ Pa through a porous medium of quartz sand placed in a horizontal glass tube with a diameter of 0.015 m and a length of 0.52 m. The water permeability of the porous medium was $2 \cdot 10^{-12}$ m^2. The volume flow rate of the liquid displaced was measured at the porous-medium outlet.

Figure 2 gives the accumulated water factor characterizing the efficiency of the process of displacement and representing the ratio of the accumulated volume flow rate of water ΣQ_w to the accumulated volume flow rate of oil ΣQ_{oil} as a function of the running coefficient of displacement η of oil for different values of the specific electrical conductivity of the displacing aqueous system.

It is seen in the figure that the value of the accumulated water factor increases with electrical conductivity of the displacing liquid for the same displacement coefficients. Consequently, once water has appeared in the liquid extracted from the porous medium, the efficiency of displacement of oil is the lower the larger the difference in electrical conductivity of the displaced and displacing liquids. The probable reason is also the phenomenon of anomalous osmosis [6]. Capillary-osmotic flow coincident with the direction of displacement of oil develops because of the negative electrical-conductivity gradient of the liquids, with the result that the aqueous-system flow is enhanced. We note that the water-free coefficient of displacement of oil (points on the abscissa axis) by distilled and seawaters takes on the same values (η = 0.47) and decreases (η = 0.41) in displacement by seawater with addition of 12% NaCl. On this basis we may assume that, before the breakthrough of the displacing liquid from the porous medium, the character of the process of displacement is determined just by the difference in the liquid viscosities. In the case of displacement of oil by seawater with addition of 12% NaCl, i.e., when the difference in specific electrical conductivities is the largest, the anomalous-osmosis effect, together with viscosity instability, begins to be of considerable importance before the breakthrough of water, which finally leads to a reduction in the water-free coefficient of displacement of oil.

Thus, the experiments carried out have shown that the difference in the electrical conductivities of the displacing and displaced liquids for a constant viscosity relation exerts an influence on the characteristics of displacement in a porous medium. The results obtained may be used in developing the strategy of control of the pumping of aqueous systems into oil-bearing beds, which will make it possible to improve the efficiency of technological processes in oil production.

These investigations were inspired by Academician of the National Academy of Sciences of Azerbaijan A. Kh. Mirzadzhanzade.

NOTATION

Q, volume flow rate, m^3/sec; T, temperature, K; η, displacement coefficient; κ, specific electrical conductivity, S/m. Subscripts: b.br, before the breakdown of a displacing liquid; 1, displacing liquid; 2, displaced liquid; w, water; oil, transformer oil.

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