ON THE STABILITY OF THE WATER-OIL CONTACT IN LAYERED POROUS MEDIA

`![Fig. 1](image)`

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Fig. 1

Figure 1: Fig. 1

Abstract

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ON THE STABILITY OF THE WATER-OIL CONTACT IN LAYERED POROUS MEDIA

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In the present work the process of displacement of oil by water from layered porous media was investigated on transparent models of two-layer and three-layer strata. The experimental results show that in layered porous media, even with a substantial difference in the permeability of the layers, the shape of the water–oil contact surface becomes leveled. This leveling occurs owing to the crossflow of water into the low-permeability layer in a small zone near the displacement front.

Fig. 1. Leveling of the displacement front in a two-layer porous medium. *a*—maximum length of the bypass zone; *b*—crossflow of water from the more permeable layer into the less permeable one. 1—displaced phase; 2—displacing phase

In turn, a considerable part of the displaced phase flows from the less permeable layer into the more permeable one and through it approaches the outlet section of the reservoir model.

The model of the porous medium was ground glass with a hydrophilic surface; the model of oil was nonpolar kerosene with viscosity 1.3 cP; the model of the displacing phase was distilled water with viscosity 1 cP. The ratio of the permeabilities of the layers was varied within the range from 2 to 16. Transparency was achieved by adding immersion liquids to the displaced phase. Before the experiments, the models were completely saturated with the displaced liquid. The experiments were carried out at displacement velocities of 0.01–0.02 cm/sec.

On all 15 models of two-layer porous media, during the displacement process, some advance of the water front in the more permeable layer was observed from time to time. However, this advance is relatively small and is of short duration. Usually the length of the bypass zones of the water–oil contact does not exceed one or two heights of the porous-medium model for all permeability ratios of the layers considered. After reaching a certain maximum length, the bypass zone

Fig. 2

Figure 2: Fig. 2

rapidly disappears because of intensive vertical penetration of water from the more permeable layer into the less permeable one.* This shows that in layered porous media the surface

* Special experiments with liquids of equal density showed that, at the indicated displacement velocities, the influence of gravity forces on the phenomenon of crossflow is practically imperceptible. In addition, crossflow of water into the less permeable layer was observed visually on transparent models in which the more permeable layer was located below the less permeable one.

the water-oil contact constantly tends to assume a stable position. In this stable state the water-oil contact moves uniformly over the height of the reservoir model, at approximately the same velocity at all points.

Fig. 2. Equalization of the displacement front in a three-layer porous medium. *a* —maximum length of the tongue zone; *b* —flow of water from the more permeable layer into the less permeable one; *v* —position of the displacement front after vertical flow of water. 1 —displaced phase; 2 —displacing phase

In Fig. 1 are shown photographs obtained during displacement of the oil model by water from a two-layer porous medium with a permeability ratio of the layers $k_1/k_2 = 6.2$ ($k_1 = 6.2$ darcies, $k_2 = 1$ darcy). Photograph 1*a* corresponds to the moment when the tongue zone reached its maximum length, after which rapid invasion of water from the more permeable layer into the less permeable one begins (1*b*).

A tendency toward equalization of the displacement front was also observed on a model of a three-layer porous medium, in which the permeabilities of the upper and lower layers are identical and equal to $k_2 = k_3 = 0.55$ darcy, while the permeability of the middle layer is $k_1 = 6.85$ darcies ($k_1/k_2 = 12.45$). In this model, despite the high value of k_1/k_2, the water-oil contact moves practically uniformly. In three-layer porous media, as in two-layer media, slight deviations of the water-oil contact from the stable state are observed (Fig. 2*a*). However, in this case as well the maximum tongue length is small in comparison with the model length. The growth of the tongue zone is hindered by the phenomenon of fluid crossflow from the more permeable layer into the less permeable one (Fig. 2*b*). As can be seen from Fig. 2*v*, in three-layer porous media, as in two-layer ones, the displacement front practically approaches the outlet section of the model simultaneously.

It may be regarded as experimentally established that, at the indicated displacement velocities, the position of the water-oil contact in layered porous media is stable. Even after being disturbed it is rapidly restored (these disturbances may be caused by various accidental reasons, in particular by local changes in

Fig. 3

Figure 3: Fig. 3

the structure of the porous medium). Fig. 3*a* records a very illustrative case, when the form of the surface of the water-oil contact near the inlet of the model of a three-layer porous medium, owing to an accidental circumstance, had an unusual shape, i.e., was disturbed. By this time a volume of liquid corresponding to 5% of the pore volume had been pumped through the model. In the next photograph (Fig. 3*b*) the form of the displacement front had already approached its stable state. The photograph corresponds to the moment when the volume of liq-

porosity pumped through the model amounted to only 0.15 pore volume. Thereafter (Fig. 3c), the water-oil contact moved uniformly.

The uniform and stable advance of the water-oil contact in layered porous media is apparently due to the action of capillary forces near the displacement front.

In homogeneous porous media, capillary forces affect only the completeness of recovery of the displaced phase, i.e., they influence the quantitative characteristics of the process as a whole; in heterogeneous porous media, however, they fundamentally alter the qualitative aspect of the process as well.

Fig. 3. Formation of a stable displacement front after disturbance. *a* —the displacement front is disturbed; *b* —the displacement front has approached a stable position; *c* —stable position of the displacement front. 1 —displaced phase; 2 —displacing phase

The predominant role of capillary forces in the formation of a uniformly advancing water-oil contact is demonstrated by the results of our experiments with miscible phases (kerosene—gasoline), in which the oil model is displaced layer by layer without any noticeable crossflow of phases between layers.

The role of capillary forces in forming a stable, uniform displacement front is revealed by direct observation of the movement of the water-oil contact in transparent models. In particular, the phenomenon of capillary displacement is clearly visible in Figs. 1b, 2b, and 3. We emphasize that capillary displacement of the oil model from the low-permeability layer occurs through imbibition of water from the more permeable layer at the points of disturbance of the displacement front, i.e., where the gradient of water saturation is especially large.

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Note: Figure translations are in progress. See original paper for figures.