INFLUENCE OF A LOW-FREQUENCY ACOUSTIC FIELD ON THE CAPILLARY IMPREGNATION OF GAS-SATURATED POROUS SYSTEMS

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Experimental results on the influence of a low-frequency acoustic field on the capillary impregnation of gas-saturated artificially cemented and noncemented porous rock samples are given. It is found that the impregnation rate can be increased and gas can be displaced completely from the porous collector on account of the field action.

At present the ultrasound capillary effect, a substantial increase of the rate and efficiency of porous material impregnation by the action of an ultrasonic acoustic field, is widely used in industrial processes [1, 2]. The ultrasound effect on the capillary impregnation of porous materials has been adequately studied both for impregnation of gas-saturated porous media [3, 4] and for capillary displacement of liquid hydrocarbon from them [5]. The influence of a low-frequency acoustic field on the capillary impregnation has not been studied at all.

Moreover, it is the low-frequency field that is highly promising for the development of advanced methods of action on mineral deposits, particularly on natural hydrocarbons. Low-frequency action appears advantageous in these methods because it is associated with a much lower damping in the rocks compared to high-frequency action. Therefore, we studied capillary impregnation of gas-saturated porous materials in a low-frequency acoustic field.

The influence of low-frequency acoustic action on the parallel-flow impregnation of porous media was studied experimentally in artificially cemented and noncemented rock samples. The noncemented porous specimens were manufactured from quartz sand of various fractions, which allowed materials with different permeabilities from units to tens of square micrometers to be studied in the experiments. As cemented media we used cement–sand mixes with various sand and cement proportions. Media with different porosities (from 20 to 28%) and permeabilities (from 0.03 to 0.8 μm^2) were simulated by varying the sand and cement proportions and by using different sand fractions. The specimens were impregnated with distilled water at atmospheric conditions. In the experiments the action was applied at 0.4-6 W/m^2 and a frequency of 20-200 Hz.

The height and velocity of water rise in the specimen (the impregnation rate) and the average water saturation of the specimen in its moist part (water saturation of the specimen) were considered as parameters controlling the impregnation process. The capillary rise was measured directly from the water–gas interface position in the specimen. The impregnation rate was taken as the water rise increment per unit time. Water saturation of the specimen was estimated from the ratio of the water volume in the impregnated part of the specimen to the void volume in its watered part.

The influence of the acoustic action on the capillary impregnation process was studied in its different stages. In the first experimental series, the impregnation parameters found in two variants (with and without acoustic action throughout the impregnation process, from the beginning to the end) were compared. In the second experimental series, we studied the acoustic field effect on the impregnation process in the damping stage, that is, on additional impregnation. In the third experimental series, the impregnation parameters under acoustic action on the impregnation process with a variable oscillation frequency were followed.

The experiments revealed that under certain conditions a low-frequency acoustic action can influence the impregnation parameters. An acoustic field influences impregnation of both high-permeable and low-permeable porous materials. Impregnation of the high- and low-permeable specimens has practically no qualitative differences, but there are quantitative differences between these processes. We will therefore give, as an example, the experimental data in individual series, or for low-perme-

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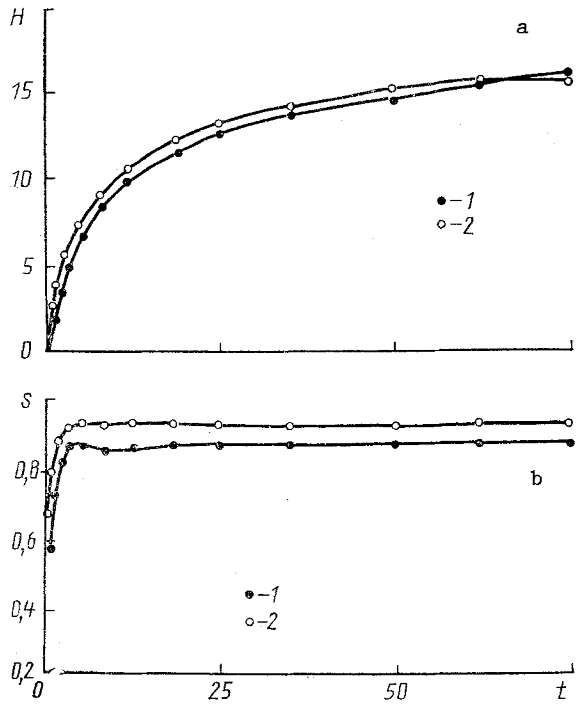

Fig. 1. Time variation of the water rise in sample 1P (a) and water saturation of the sample (b) without the action (1), with the action at 1 W/m^2 and frequency of 50 Hz (2). H, cm; t, min.

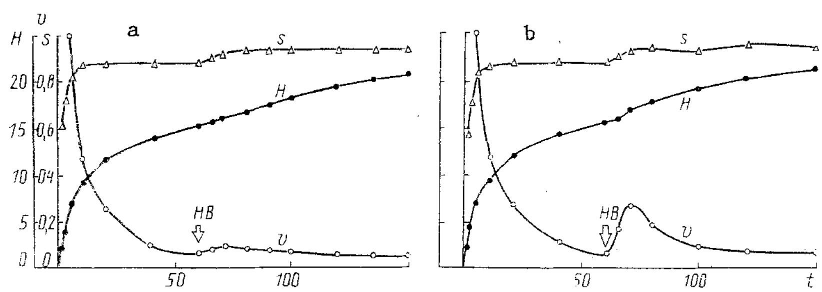

Fig. 2. Time variation of the water rise (H) in specimen 1P, impregnation rate (v), and water saturations of the specimen under acoustic action at 0.5 W/m^2 (a, b) and frequency 25 Hz (a) and 200 Hz (b). IA, initial action; v, cm/min.

able or high-permeable media. In most of the experiments the impregnation rate was found to increase at the initial moment under acoustic action. The rate increment on account of the acoustic field effect was 1.1-1.4 times on the average, both for low- and high-permeable media. The acoustic action increased water saturation and, correspondingly, decreased the entrapped gas volume in the sample. The water saturation in the acoustic experiments was 7-12% and 8-15% higher than that in the experiments without acoustic action for high- and low-permeable media, respectively.

It was found that the impregnation rate and water saturation of the specimens tended to increase as the oscillation frequency and intensity rose.

As an example, Fig. 1 shows the data for impregnation of specimen 1P under the action of an acoustic field throughout the impregnation process and without the action. The sample was made of noncemented sand with 100-μm grain diameter, 38-μm^2 permeability, and 39% porosity. One can see from the figure that 1 W/m^2 low-frequency sonication of the specimen at a frequency of 50 Hz resulted in a 1.1-1.3 times higher initial impregnation rate than the impregnation without sonication.

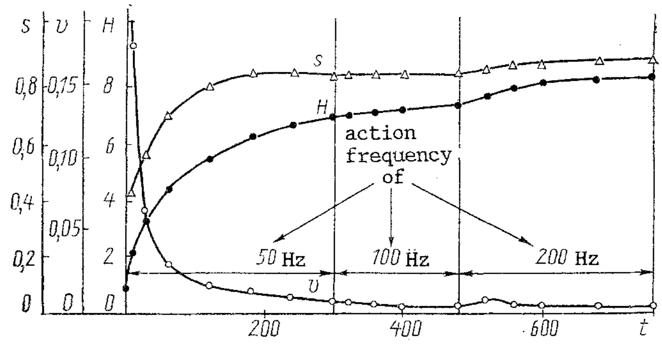

Fig. 3. Time variation of water rise (H) in specimen 3C, impregnation rate (v), and water saturation (s) of the specimen under 1 W/m^2 acoustic action.

Simultaneously with increasing the impregnation rate the water saturation increased by 6-7% in that experiment. The impregnation rates leveled with time, and 25 min after initial impregnation they remained practically equal. However, when sonication continued, the water saturations of the specimens were again 6-7% higher than that without acoustic action.

Low-frequency sonication influenced not only the initial impregnation but also its final stage when the acoustic action was applied just at that stage. This was indicated by experiments in which 20-200 Hz sonication was started at impregnation decrease. In most of the experiments, the acoustic field mainly influenced water saturation of the specimens and, to a smaller extent, the impregnation rate. It should be noted that in some experiments the impregnation rate did not increase or was not even stabilized. Meanwhile, water saturation was found to rise in nearly all the experiments. In experiments with both low- and high-permeable specimens a 6-14% increase of water saturation was observed. The same increase of water saturation was also found in the experiments in which the impregnation rate did not increase but continued to fall.

The typical variation of the process parameters in parallel impregnation in that experimental series is shown in Fig. 2 for specimen 1P. It can be seen that a 25-Hz acoustic field applied at 0.5 W/m^2 stabilized the impregnation rate. After starting the action (at t of 60 min in that experiment), the rate of increase of the impregnation rate dropped, and the impregnation rate was stabilized at 0.08-0.1 cm/min. That impregnation rate remained unchanged for about 40 min. After sonication had started, the water saturation of the porous medium also increased. The water saturation rose from 0.870-0.873 to 0.928-0.932 in the period between 60-80 min, remaining at the same level while sonication continued.

More substantial changes of the main impregnation parameters were observed in specimen 1P in a 200-Hz acoustic field. During the initial action some increase of the impregnation rate was observed. During the period between 60-70 min the impregnation rate increased from 0.07 to 0.15 cm/min. Subsequently, the impregnation rate diminished, but during the following 25 min it remained larger than that before the acoustic field was applied. Along with the rise of the impregnation rate, the water saturation of the specimen in the experiment was 9-13% higher.

The experiments have shown that an additional factor that influences the efficiency of capillary displacement of gas out of porous media may be a change of the action regime, i.e., as an increase of its intensity or oscillation frequency. This follows from the experiments in which the frequency or intensity was varied in the course of impregnation. The impregnation parameters changed especially noticeably as a result of a change of the action regime at the final stage when the impregnation rate was small and could not be increased by sonication with the same parameters. It is noteworthy that in this case an increase of the intensity or oscillation frequency might not raise the impregnation rate in a certain range of intensity or frequency. An increase in the efficiency and acceleration of capillary impregnation started upon definite intensities and oscillation frequencies.

Figure 3 shows the results of impregnation experiments with specimen 3C. The figure shows that an increase in the oscillation frequency during impregnation not only accelerated the impregnation but also increased the degree of gas replacement by water in the specimens. In the experiments, acoustic action with 1 W/m^2 intensity and 50 Hz frequency was applied to the specimens at the start of impregnation. As the impregnation faded out, the oscillation frequency rose, the other process parameters being unchanged. One can see from Fig. 3 that increasing the oscillation frequency from 50 to 100 Hz (at a time of 300 min) did not change the impregnation parameters. However, when the frequency was raised to 200 Hz, the impregnation rate was 3 times higher (from 0.025 to 0.075 cm/min). Simultaneously, the water saturation of the specimen increased by 5 or 6%.

In the experiments in which the oscillation frequency was increased in the course of impregnation, the results were similar. It should be noted that frequencies which caused substantial changes in the impregnation process were different, depending on the experimental conditions (oscillation frequency at the initial moment of impregnation, the time of regime change, etc.) and on collecting properties of specimens.

Thus, the present findings suggest that a low-frequency acoustic field may have a certain effect upon capillary impregnation of gas-saturated porous materials. Low-frequency action on porous specimens increases the capillary rise velocity of water and the degree of gas displacement from porous specimens. The impregnation indices depend, to a considerable extent, on the frequency and intensity of the action.

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