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ELECTRIC-CURRENT-INDUCED RESTRUCTURING OF THE POROUS SPACE IN A MEDIUM

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It was shown in [1-3] that the transmission of an electric current through a porous saturated medium can be reduced to a change in its permeability and electrical conductivity. These changes are due to the restructuring of the porous space in a medium as a result of localization of the density of energy release in thin capillaries, limiting the conductivity of the medium. The structure of the porous space in rocks can be described within the framework of the percolation model of an inhomogeneous medium [4], using the capillary probability density function (CPDF) with respect to effective capillary radius. Here we report the results of an experimental study of the changes that occur in the structure of the porous space and, hence, in the permeability of sandy-argillaceous rocks when an ac electric current is passed through them.

The principal complication in carrying out such an experiment is that methods that would not affect the structure of the porous space of the medium must be developed for determining the CPDF. Accordingly, we used the electroporosimetric method developed especially for these purposes [5]; the essence of this method is as follows. The sample of rock under study is placed in a vertical tube (Fig. 1), whose end is immersed in a vessel of liquid; the steady-state distribution of saturation established in the medium by the capillary forces decreases as the height h of the liquid increases. As a result the electrical resistivity $\rho_e(h)$ of the rock decreases as h rises. If we measure $\rho_e(h)$ by the method of [5] at low voltages that do not result in a change in the CPDF, therefore, we can determine the CPDF before and after the passage of an electric current through the porous saturated medium.

As the electrically conducting liquid we used a $CaCl_2$ solution, which does not enter into an intensive ion-salt exchange with the rocks studied. The concentration of the solution was 0.1 N in all the experiments. Each tube of diameter 3 cm and length 1 m was filled with portions of dry rock, gradually permeated with solution entering through the end of the tube from the communicating vessel so that its level varied simultaneously with the level of the rock. We applied voltage to the outside electrodes to measure $\rho_e(h)$ and then measured $\Delta\varphi(h)$, the difference between the bottom electrode and electrodes placed equidistantly along the height of the tube. Knowing $\Delta\varphi(h)$, the current flowing in the tube, the cross-sectional area of the tube, and the distance between neighboring electrodes, we can find $\rho_e(h)$, the resistivity of the segment of the rock at a height h.

The experiment on electric treatment of sandy-argillaceous rock consisted of two stages. In the first stage the solution was filtered in the tube for 5-15 days (depending on the rock) until steady-state filtration was established. On the basis of the results of measurements of the liquid flow rate at a constant pressure gradient in the tube we measured K, the permeability of the medium as well as $\rho_{e0}(h)$, the resistivity of segments of the rock when the sample is completely saturated with the liquid. In the second stage, the flow of liquid through the tube was stopped until a steady-state saturation distribution was established, $\rho_e(h)$, was measured, and the CPDF was determined. Liquid was then again passed through the tube and the stability of K was checked.

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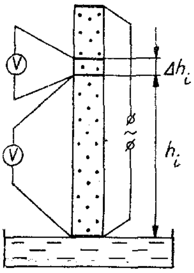

Fig. 1

TABLE 1

Type of rock	Grain size, mm					
	⩾2,5	1,5	0,63	0,315	0,16	<0,16
	fraction of total mass, %					
I	0,04	0,13	1,85	31,8	44,3	21,8
II	0,02	0,20	3,15	24,0	36,6	36,0

TABLE 2

Type of rock	d, μm	D, μm	G, %	K, μm²	m, %
I	203	117	11,1	0,313	23,1
II	186	122	14,5	0,119	22,3

For electrical treatment of the completely saturated rock we applied voltage to the outside electrodes made of fine stainless-steel mesh. After the electrical treatment we measured K and $\rho_{e0}(h)$ and reproduced the CPDF. During the entire experiment we measured K on a control tube, which was not electrically treated.

We studied sandy-argillaceous rocks, for which the fractional composition had previously been determined (Table 1, less the mass of clay, for two types of rock). In Table 2 the symbol d denotes the average grain diameter, D is the grain dispersion by size, G is the fraction of clay in the total mass, K_0 is the initial permeability, and m is the porosity.

Figures 2 and 3 show the measured values of $\rho_e(h)/\rho_{e0}(h)$, where $\rho_{e0}(h)$ is the resistivity of the same segments when the sample is completely saturated with liquid, for sandy-argillaceous rock of types I and II, which differ as to the form of the CPDF; the solid and dashed lines, respectively, represent the results before and after electrical treatment. The first type of rock was electrically treated for 2.5 h at a field strength E = 14.2 V/cm, current density j = 3.3 mA/cm². The electrical treatment increased the permeability 1.87 times. When the second type of rock was electrically treated for the same length of time at E = 6.5 V/cm and j = 0.7 mA/cm² the permeability increased by 13%. In both cases the temperature of the surface of the tubes varied only slightly during the electrical treatment.

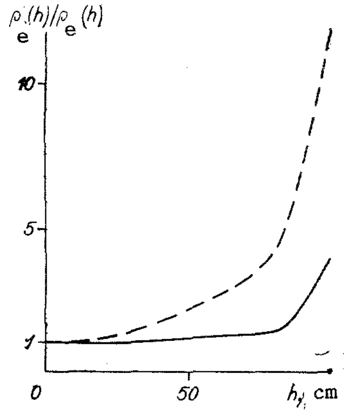

Fig. 2

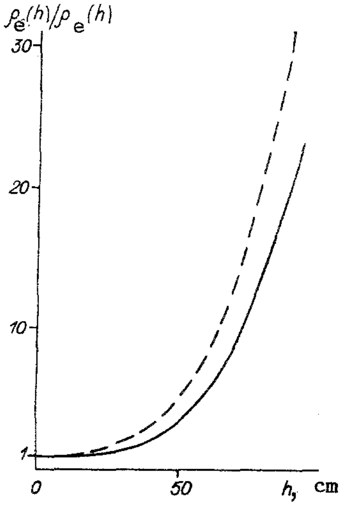

Fig. 3

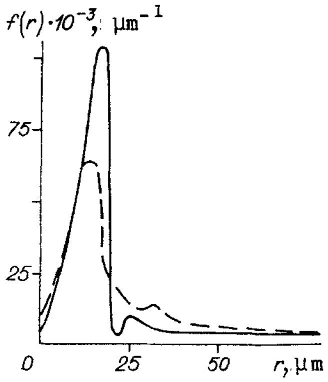

Fig. 4

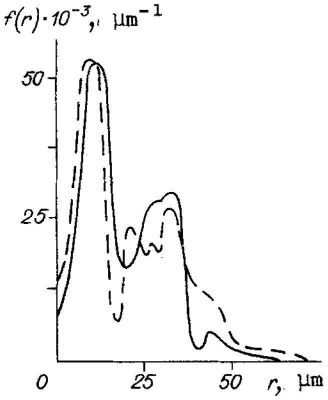

Fig. 5

Figure 4 shows the results of reproducing the CPDF for the first type of rock and Fig. 5, for the second type. The solid curve represents the CPDF before treatment and the dashed line, after electrical treatment. We see that electrical treatment causes the CPDF to change. The average radius of the capillaries grows and the fraction of relatively fine capillaries decreases. The average radius R increased from 18.0 to 19.7 μm in the first case and from 13.5 to 16.3 μm in the second. The value of $\sqrt{\langle (r - R)^2 \rangle}$ varied from 11.0 to 13.0 μm in the first case and from 5.8 to 12.0 μm in the second.

In summary, the experimental data show that electrical treatment causes a substantial change in the structure of the porous state of a medium and increases the conductivity of the medium. We must point out that the change in the conductivity of the capillaries is a quasivolume effect and differs substantially from the case when the conductivity of the medium changes as a result of electrical breakdown.

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