CHANGE IN THE PERMEABILITY COEFFICIENT OF A MEDIUM AS A FUNCTION OF THE ELECTRIC CURRENT DENSITY PASSING THROUGH IT

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The possibility of irreversible change in the permeability of a porous saturated medium during passage of an electrical current through it was demonstrated theoretically and experimentally in [1-4]. These changes, as shown in [1, 5], are connected to the effect of the reorganization of the spatial structure of the medium. This comes about as a result of the localization of energy-release density in fine capillaries, which limit the conductivity of the medium. The method for studying the void space structure in the medium is described in [5]. The results of an experimental study of the change in permeability of a medium when a varying electric current passes through it is cited in [6]. In this work, we present the results of a comparative study of the change in permeability of argillaceous-arenaceous rock while variable and pulsed electric currents of various densities are passed through it.

A diagram of the experimental setup is shown in Fig. 1. A $CaCl_2$ solution from vessel 1 is fed into column 2 which is filled with the sample rock 3, and is collected in vessel 4. The capillary 5 makes it possible to maintain a constant pressure gradient between the ends of the column. The voltage on the column is supplied by the electrodes 6, in the form of a fine strainless steel mesh which entirely covers the ends of the column. For improved contact, the electrodes were driven into the rock. The height of the percolating layer or rock, equal to the electrode separation, was 8 cm and the column diameter 1.8 cm. The hydraulic head was 5 cm. The filling of the glass tube with sandy loam was done from above, through the open upper end, and a weak solution (0.01 N) of $CaCl_2$ was fed in from below through a filter. Such a method of filling was used to remove the air from the rock. The solution was used as the saturating fluid in order to eliminate processes related to ion exchange in the rock. The fractional composition (minus the clay mass) of the argillaceous-arenaceous rock used in the experiments in given in Table 1.

Table 2 gives the average grain size d, the variance of grain size D, the portion of clay in the total mass σ, the initial permeability K_0, and porosity m.

After the column is filled with rock, the $CaCl_2$ solution was passed through it for 5-15 days, until the fluid discharge through the rock became stable. Then electroprocessing of the first and second columns was carried out, while the third column remained a control. After electroprocessing, the change in the fluid discharge q through the column was measured. Then the cycle was repeated for different electric-action parameters.

In the first series of experiments, we studied the change in the permeability coefficient as a function of the voltage applied to the column for fixed values of energy release density in the medium. The results of measuring q/q_0 (the relative change in the fluid discharge through the column as a function of the applied electric field strength) is shown in Fig. 2. The starting value is $q_0 \sim 0.2$ ml/h. For a field strength $E < 10$ V/cm in the medium and for fixed energy release density in the rock of $A = 3.6 \cdot 10^4$ J/kg, no change in the permeability coefficient was observed in the medium. This confirms the threshold nature of the process of permeability change of the medium when it is electroprocessed [2]. As is evident from Fig. 2, increasing the voltage at the tube ends leads to significant growth in the irreversible change in the permeability coefficient. For $E > 60$ V/cm, there is a sharp degradation in the permeability of the medium during passage of the electric current. This is evidently related to the release of the gas phase in the capillaries when high-density currents are moving along the capillaries, and correspondingly to gaseous colmatage of the rock. This effect can occur as a result of the localization of high-density energy release in the fine capillaries [3]. As a result, the fluid temperature

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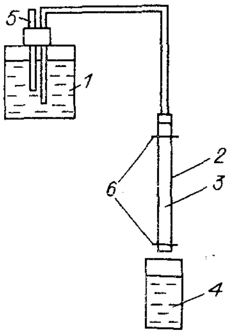

Fig. 1

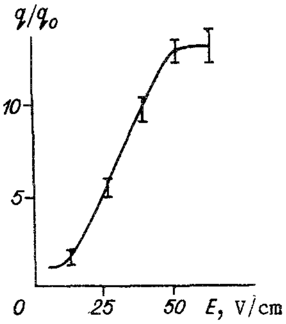

Fig. 2

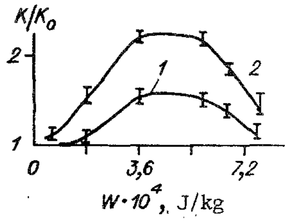

Fig. 3

TABLE 1

d, mm	σ, %
2,5	0,04
1,25	0,13
0,63	1,85
0,315	31,8
0,18	44,3
<0,16	21,8

TABLE 2

d, μm	D, μm^2	σ, %	K_0, μm^2	m, %
303	$39 \cdot 10^3$	11,1	$12 \cdot 10^{-4}$	18

in the fine capillaries can significantly exceed the average temperature of the medium, which for $A = 7.2 \cdot 10^4$ J/kg is considerably below the boiling point of the liquid.

In the second series of experiments, we conducted a comparative study of the change in permeability of the medium with passage of variable and pulsed currents through it. Towards this end, the first column was subjected to a variable electric current of industrial frequency, while the second, to a pulsed heteropolar current. The third column was kept as the control. The duration of the electroprocessing and the average density of the energy release in the first and second columns were set identically. The pulse duration was $\tau = 0.2$ sec, and the repeat pulse period was $T = 0.5$ sec. The irreversible change in the permeability coefficients of the medium was measured after 3-5 days of electroprocessing. Then the cycle was repeated for other values of the density of energy release in the medium. The dependence of the relative change in permeability coefficients on the energy-release density in the medium is shown in Fig. 3 (curve 1 corresponds to variable current electroprocessing of the medium; curve 2 to pulsed current processing). It is clear that the pulsed electroprocessing of the rock is significantly more effective when compared to the electroprocessing with a 50 Hz variable current. There is also a difference in the threshold value of the energy-release density at which the permeability coefficient begins to change. In the first and second cases it is equal to $1.8 \cdot 10^4$ and $0.9 \cdot 10^4$ J/kg, respectively. The pulsed electroprocessing of the rock with $A > 7.2 \cdot 104$ J/kg results in long-term reduction of the permeability of the medium, which evidently may be releated to the gaseous colmatage.

Thus, the results of the experimental investigation show that for fixed values of energy-release density, the effectiveness of the electroprocessing grows significantly with increasing field strength in the medium. Electroprocessing of the medium by means of passage of a pulsed electric current through it is signficantly more effective than when the medium is electroprocessed by means of an industrial-frequency variable current.

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IMPULSIVE HYDRAULIC RUPTURE OF A POROUS MEDIUM

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In recent years, the problem of impulsive hydraulic rupture of solids has acquired great practical significance, mainly in mining. This method of rupture is used in mining for directional change of rock permeability, which is done to raise the rate of geotechnical processes. To date, a number of theoretical [1-3] and experimental [4] studies have been done, which make it possible to predict the conditions for the appearance of cracks and their dimensions, for a given spatial configuration. This was done without accounting for porosity – one of the characteristic properties of natural and man-made geometricals. In addition, the earlier work gave too little attention to the influence of the strength properties of the rock (rupture strength) on the rate and dimensions of the cracks.

Here, we present the results of an experimental study of the effects of porosity and strength of the solid on crack development in the hydraulic rupture regime.

We used a man-made stone as a material which simulates a porous medium of the sulfur-containing limestone type. The stone was manufactured from a sand–cement mixture (the matrix) and crushed rosin (a low-strength filler component) with a grain size of no larger than 7 mm. The rosin content c_r was 10, 30, and 50%, which is in the range of elemental sulfur content in limestones from deposits in the western regions of the Ukrainian SSR. Samples of this mixture were held at room temperature for 28 days or more to reach the required strength, as determined by uniaxial compression tests to be 20-90 MPa. The porosity of the model material varied from 4-8%. These physicomechanical properties of the sample are characteristic of many natural and man-made geomaterials.

In this work, we used the experimental method described in detail in [4]. Just as in [4], we used two types of working fluids for hydraulic rupture of the models. Their kinematic viscosity coefficients are $2.2\cdot10^{-6}$ and $6.8\cdot10^{-4}$ m^2/sec. The amplitude–time regime of the pulsed pressure generated in the fluids was chosen so that the observational results could be applied to prediction of the operation of present-day borehole equipment and impulsive rupture technology. Thus, the pressure in the working fluids was up to 20-30 MPa, the pressure growth rate was 10^9-10^{10} Pa/sec, and the pulse duration time was 20-30 msec. The relation between the sample dimensions and the loading conditions was chosen so that the developing crack did not reach the free surface of the sample. The crack dimensions were determined by direct measurement after cutting the samples perpendicular to the plane of the crack. This was done according to traces of penetration of the tinted rupture fluid.

The experiments were designed according to the requirements of statistics, with a confidence level of 0.9. The number of parallel experiments with identical conditions was taken as no fewer than 5, and the results of these were averaged. The total number of experiments was 180. Based on analysis of these experiments, we were able to establish the following.

During impulsive hydraulic rupture of porous media, just as during rupture of a material as homogeneous as polymethyl methacrylate (PMMA) [4], the spatial orientation of the developing cracks depends on the presence of stress concentrators. It also depends on the symmetry of the load, which is determined by the relation between the height of the barefoot interval

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