produce large deformations which destroy the material [10]. High local stresses can also appear at inhomogeneities in the material upon heating [11].

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CHARACTER OF FRACTURE AND FILTRATION PROPERTIES OF A FLUID-SATURATED POROUS MEDIUM IN AN UNDERGROUND EXPLOSION

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It is well known that the mechanical action of an explosion in low-porosity media (such as granite) leads to an improvement in the filtration properties of the medium throughout the region affected by the explosion. In high-porosity media saturated with gas, however, explosions lead to a sharp deterioration in the medium's filtration properties [1]. An explosion in a high-porosity cemented medium saturated with a liquid is accompanied by a nonmonotonic change in its filtration parameters near the explosion. Here, while a locally deteriorated zone is formed, permeability overall is improved compared to the original value [2]. The size of the zone in which the filtration characteristics of the medium change turns out to be greater than in the case of the action of an explosion of the same power in a monolithic medium such as granite.

In the present study, we discuss the results of experimental and theoretical investigations of features of the mechanical effect of an underground explosion on porous liquid-saturated media. We examine the reasons for the qualitative difference between the radial dependences of the permeability corresponding to an underground explosion in media having different porosities and levels of saturation.

1. Experimental Method. Tests were conducted under laboratory conditions with spherical explosive charges of TÉN weighing from 1 to 2 g. The charges were exploded in artificially

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created cemented porous media. We also conducted tests under field conditions in a water-saturated carbonate bed using explosive charges of TG-20/80 with a power ranging from 200 to 765 kg TNT.

The laboratory tests were conducted in media with an initial porosity m_0 = 25 and 18%. These media were placed in a cylindrical container with d = 300 and h = 350 mm.

The basic physicomechanical properties of the dry media with porosities of 25 and 18% were as follows, respectively: crushing strength 20 and 28 MPa; velocities of longitudinal elastic waves 3000 and 3500 m/sec; permeabilities 300 and 100 ppm. The consistency of the initial properties over the cross section of the prepared models was determined by sounding them over several radii from the center before the explosion and by measuring density on 4-5-cm-thick disks sawed from models that had not yet been exploded.

After such preparations, the pore space of the models was saturated to 90-95% with kerosine. In the tests, we studied the character of fracture of the medium and the change to filtration characteristics. The character of fracture was determined visually and by direct measurements of density and sonic velocity in the medium around the explosion cavity. To better study the filtration properties of the medium, in preparing the model we placed 8-9 3-mm diameter stainless steel tubes at different distances from the charge. We took $\Gamma = Q/\Delta p$ as the filtration characteristic, where Q and Δp are the steady-state rate of flow of kerosine between a pair of tubes and the corresponding pressure gradient. The change in the filtration properties of the medium as a result of the explosion was evaluated on the basis of the ratio Γ/Γ_0 (where Γ_0 are the pre-explosion properties).

The method of investigation was described in greater detail in [1, 2].

The field tests were conducted in a water-saturated carbonate bed lying at a depth of 37-74 m below the surface. The properties of the rock of the bed changed sharply in the vertical direction but were relatively constant in the horizontal direction. The bed was characterized by a developed system of natural cracks. High-porosity intercalations were located in the depth range 41-44 m, the porosity of these layers significantly exceeding the porosity of the remaining part of the bed. Most of the filtering fluid passed through these layers. The physicomechanical properties of the rock of the bed are represented without consideration of the high-porosity part: porosity 21.2%; density 2.2 g/cm^3; compressive strength 460 kg/cm^2; velocity of elastic waves 3800 m/sec.

We exploded concentrated charges with a power of 200 and 765 kg TNT at a depth of 46 m. Here, the charging density was 1.67 g/cm^3. We bored observation holes 55 m deep around each blast hole before the explosion. The observation holes were located 3, 5, 7, and 9 m from the blast hole. After the explosion, we drilled inspection holes 2, 4, and 6 m from the respective observation holes. Cores of the entire exposed portion of the bed were taken in both types of holes.

To study the mechanical effects of the explosion on the producing bed, we conducted hydrodynamic tests in the observation wells and studied the cores removed before and after the explosions from these wells and the inspection wells. The method of investigation basically amounted to conducting test pumpings before and after the explosion. We determined the unit yields of wells and cones of depression and established the law of filtration of the fluid in the bed. We performed an airlift pumping before the pre-explosion pumpings in order to remove drilling mud from the cracks. After the explosion, in addition to the air-lift pumping we operated the wells to remove fragments of rock from the borehole. The error of the measurements was no greater than 0.3% of the measured level.

2. Experimental Results. Laboratory Tests. The explosion cavity and fracture zone were visible on the opened model in the horizontal plane where the charge had been placed; no cracks were seen to traverse the entire fracture zone. The cavity was spherical and had been burned by detonation products. A lighter zone in which the medium was compressed loosely bound was located around the cavity. At a certain distance from this zone (and with no change in color) the medium became less strong. However, the boundaries of the weakened region could not be determined visually. Table 1 shows the deformation zones found in the tests.

The distribution of the density of the medium after the explosion is shown in Fig. 1. The change in the density of the medium from the center of the explosion to the periphery was determined as the minimum value for 4-6 radii in three different models. Each point represents the average of several density values measured at different distances from the center of the explosion (clear points correspond to m_0 = 25%, dark points to m_0 = 18%). Two

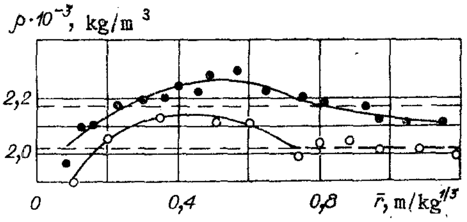

Fig. 1

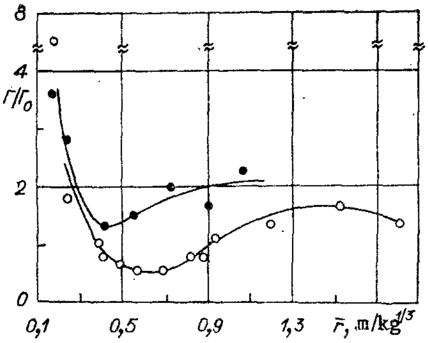

Fig. 2

TABLE 1

Initial porosity m_0, %	Dimensions of zones, m/kg$^{1/3}$				
	radius of cavity r_c	radius of zone with changed color $\bar{r}_r$	radius of loosened region $\bar{r}_{\ell r}$	compaction interval r_c	fracture radius $\bar{r}_f$
25	0,1	0,3	0,2	0,2—0,7	1,0
18	0,09	0,3	0,2	0,2—0,8	1,3

zones — a loosened zone and a compacted zone — were seen in succession around each cavity. The loosened zone reached $\bar{r} \approx 0.2$ m/kg$^{1/3}$ in both cases, with the maximum loosening near the cavity having been approximately 10%. The size of the compacted zone increased with a decrease in the initial porosity of the medium and the degree of compaction reached 5-6%. It is evident from the table that a reduced elastic-wave velocity is seen in the medium after the explosion up to $r_f \approx 1.0$ ($m_0 = 25\%$) and $\bar{r}_f \approx 1.3$ m/kg$^{1/3}$ ($m_0 = 18\%$). A rapid reduction in the velocities of the elastic waves is seen up to distances $\bar{r} \approx 0.5$-0.6 m/kg$^{1/3}$, with the minimum values (60% of the initial values) being found at the boundaries of the explosion cavity. The reduced wave velocities are evidence of the presence of residual deformations in the medium. Thus, the outer boundary of the reduced-velocity region can be taken as the boundary of the fracture zone.

Figure 2 shows changes in the permeability of the medium after the explosion under conditions of its initial saturation with kerosine. The data shows the nonmonotonic nature of the change in permeability. Three different zones with characteristic changes in permeability can be distinguished. In the first zone going away from the cavity (up to $\bar{r} \approx 0.4$ m/kg$^{1/3}$), permeability increases severalfold in the center and reaches a minimum at the external boundary of the zone; in the second zone, permeability is minimal; in the third zone, permeability at first undergoes a moderate increase and then decreases. Extrapolation of the tests data yields the value $\bar{r} \geqslant 2$ m/kg$^{1/3}$ as the external boundary of the zone where permeability assumes a background value.

Of particular interest is the second permeability zone. In a high-porosity reservoir with $m_0 = 25\%$, the permeability of the medium in this zone decreases in the interval of distances (from the charge) roughly from 0.4 to 1.0 m/kg$^{1/3}$. The minimum post-explosion permeability is 0.5 of the background level. With a reduction in the initial porosity of the medium to 18%, permeability in the second zone becomes higher than the initial values.

The permeability minimum in the second zone coincides with the maximum compaction of of the medium and the maximum residual compressive stresses in the radial and azimuthal directions [1-3]. It should also be noted that the external boundary of the third zone of permeability variation is significantly farther from the charge than is the boundary of the fracture zone $\bar{r}_f$ (with the latter having been determined from the change in the velocity of the longitudinal elastic waves). This is the zone of so-called prelimiting strains of the pore space [1].

Field Tests. According to data from visual study of the core material in the test wells and its comparison with the core material in the observation wells, the external boundary of the deformation zone in the water-saturated carbonate bed extended to distances of approximately 1.0 m/kg$^{1/3}$. In the immediate vicinity of the cavity, the rocks were intensively fractured up to the state of sandy limestone. The size of the core lumps subsequently increased to 5-10 cm or more.

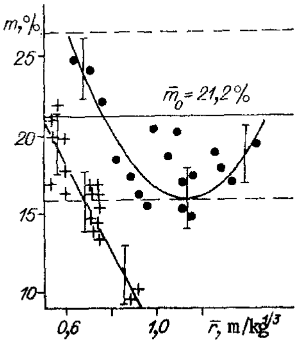

Fig. 3

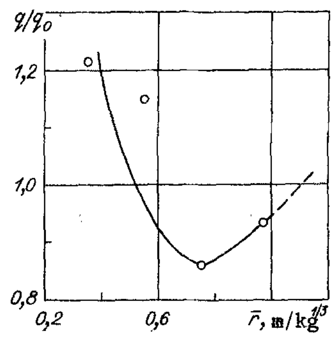

Fig. 4

Figure 3 shows the changes in the porosity of the matrix of the reservoir as determined from the core material. (The core extracted from the high-porosity intercalations was small and is thus not represented here.)

For the 200-kg charge, the extracted core (dots) completely characterizes the change in the porosity of the rock until the initial values are restored. For the 765-kg charge (plus signs), the farthest well in the test turned out to be closer than the external boundary of the porosity variation. It is evident from Fig. 3 that the matrix of the bed is loosened at distances that are closer in (roughly 0.6 m/kg$^{1/3}$) and is compacted within the distance range of approximately 0.6-1.3 m/kg$^{1/3}$ (the dashed lines show the scatter of the natural porosity of the rock mass). The range of variation of bed porosity is considerably narrower after the explosion. Thus, the standard deviation σ after an explosion with the 200-kg charge is 1.95, versus $\sigma = 5.3$ before the explosion, i.e., the porosity of the matrix undergoes "ordering" by the explosion.

The permeability of the cores for the tests conducted with charges of 200 and 765 kg decresaed by roughly one order after the explosion within the intervals in which the porosity reduction was seen. With an initial mean core permeability $\bar{K} = 12.6$ ppm and $\sigma = 7.1$, the post-explosion permeability was $\bar{K} = 1.9$ ppm ($\sigma = 2.1$) for the 200-kg charge and $\bar{K} = 0.9$ ppm ($\sigma = 1.3$) for the 765-kg charge.

Figure 4 shows data on the unit yields of the wells before and after explosion of the 765-kg charges. In the case of the charge corresponding to 200 kg of TNT, the absolute unit yields of the wells had been reduced for technical reasons prior to the explosion. Although the character of their change is similar to the pattern depicted in Fig. 4, due to the reduced pre-explosion yields the graph is shifted upward compared to the graph for the test conducted with the 765-kg charge. It is evident that the change in the filtration properties of the water-saturated carbonate reservoir – with a matrix having an initial porosity $m_0 = 21.2\%$ (the porosity of the intercalations being significantly higher) – as a result of the explosion is nonmonotonic in character going from the explosion cavity to the periphery. With allowance for the test data for the case of the 200-kg charge, the external boundary with the altered filtration properties extends $\bar{r} > 1.6$ m/kg$^{1/3}$ from the charge. The filtration properties of the reservoir decrease about 20% within the range $\bar{r} = 0.5$-1.0 m/kg$^{1/3}$, while they improve near the cavity up to $\bar{r} = 0.5$ m/kg$^{1/3}$. The changes which occur in the high-porosity intercalations naturally make the largest contribution to the observed pattern. Both porosity and permeability within these layers substantially exceed the analogous quantities for the rest of the bed.

The following facts should be emphasized from an examination of the empirical data. 1. The permeability of the reservoir after the explosion varies nonmonotonically from the cavity to the periphery. 2. The permeability minimum occurs where the matrix has been least compacted and is under the greatest stresses. 3. Inelastic deformations arise in the matrix of the fluid-saturated medium after the explosion. 4. When the initial porosity of the reservoir exceeds 18%, a zone is formed in which the post-explosion permeability decreases to below the background value. 5. Changes in the filtration properties of the resevoir are seen far beyond the limits of the fracture zone.

Presented below is an explanation for these facts.

3. Theoretical Model. The action of shock loads on a medium can produce both reversible and irreversible changes in its permeability. Inversible changes may occur as a result of restructuring of the pore space during the dynamic stage of the process, as well as a result

of the action of a residual-stress field. Various mechanisms can lead to restructuring of the pore space: contact fracture of the grains; flow of cement into pore channels, etc. These effects are manifest to the greatest extent when a charge is exploded in a high-porosity ($m_0 > 15\%$) medium saturated with gas, since the gas in the pores offers almost no resistance to the contact fracture of the grains. When the medium is saturated with a liquid whose compressibility is comparable to that of the skeleton, the effect of an explosion on such a medium during the dynamic stage of the explosion process is similar to the effect of an explosion on a monolithic medium. The passage of a shock wave (SW) through the former medium may result in the formation of cracks. The cracks may subsequently intersect one another and the fractured medium may shear, thus producing dilatational permeability. The presence of shear stresses leads to rotation of the blocks (lumps) formed by the cracks relative to each other and opening of the cracks between the blocks. The radial dependence of dilatational permeability in the fracture zone of the medium has the form [4]

$$K_g = 0.7\cdot 10^{-2} d_0^2 \left[1 - (1 - \xi^{\delta})^{\lambda}\right]^3 \exp\left[2\left(\frac{\xi^{\delta}-1}{\xi_*^{\delta}-1}\right)\frac{2\beta}{\delta}\ln\frac{d_m}{d_0}\right].$$

Here, d_0 and d_m are the minimum and maximum sizes of the blocks on the internal and external boundaries of the fracture zone; $\xi = r/a_m$; $\xi_* = R/a_m$ (R is the external radius of the fracture zone); β is the degree of decay of the stresses at the front of the SW ($\sigma(r) \sim r^{-\beta}$); $\delta = 3(1 + \lambda)$; λ is the dilatation coefficient; a_m is the radius of the cavity.

Estimates show that in the case of the passage of a SW, there is not sufficient time for the liquid to filter from the blocks into the cracks. Thus, the effective pressure in the medium (the difference between the pressure in the skeleton and the liquid) of the dynamic stage of the explosion remains nearly constant if the pores are completely filled with liquid. The presence of liquid in the pores prevents contact fracture of the grains and the flow of cement into the pore space. After completion of the dynamic stage of the explosion, filtration leads to a drop in the pore pressure of the liquid and an increase in the effective pressure. These events may in turn lead to a change in the permeability of the medium under the influence of the field of residual stresses [3]. If the change in effective pressure exceeds 100 MPa, then the change in permeability is determined from the formula [5] $K = K_0 \exp(-\alpha\Delta p_f)$ [K_0 is the permeability at the initial pressure, Δp_f is the change in effective pressure (MPa), and α is a coefficient dependent on the type and structure of the medium]. Thus, as a result of the effects described above, the permeability of the fractured medium will be composed of the dilatational permeability and the permeability of the blocks (matrix) – which changes under the influence of the residual-stress field.

It must be noted that saturation of the medium with liquid alters the effective pressure in the medium, reduces its strength, and leads to a significant reduction in SW decay compared to the case of a monolith. There is a substantial increase in the dimensions of the region affected mechanically by the explosion and the size of the radial cracking zone if the charge depth H is not too great: $H < (\sigma_1 - 2\sigma_0)/3\rho g$ (σ_1, σ_0 is the strength of the medium in shear and tension; ρ is the density of the medium; g is acceleration due to gravity).

If this condition is not satisfied, then no radial cracking zone can be formed. In this case, the fracture zone is immediately followed by a zone characterized by elastic displacements. In the latter zone, the radial component of the permeability tensor increases as a result of restructuring of the stress tensor. The phenomenon of a change in the permeability tensor was seen in laboratory tests in [6] for a specimen loaded by a non-uniaxial load.

Shown below are the results of calculation of the change in the radial component of the permeability tensor in the elastic-displacement zone with allowance for this phenomenon and the results obtained for the fracture zone. The relations for the radial permeability coefficients are given as functions of the corrected radius. In order to change over to absolute values, it is necessary to allow for the increase in the size of the fracture zone in a porous medium saturated by a liquid with a known hydrostatic pressure.

Figure 5a ($K_0^1 = 1$ D) shows the dependence of the corrected dilatational permeability on distance. Figure 5b shows the change in the permeability of the medium (blocks) under the influence of the residual stresses in the fracture zone (dashed line). Figure 5 also shows the relation for total permeability $(K_d + K_b)/K_0$. The calculations were performed for the case when $\ln(d_m/d_0) = 3$, $K_1 = 0.7\cdot 10^{-2} d_0^2 = 1.75\cdot 10^5$ D, $\lambda = 0.1$, $K_0 = 1$ D, $\beta = 2$, $\xi_* = 5$.

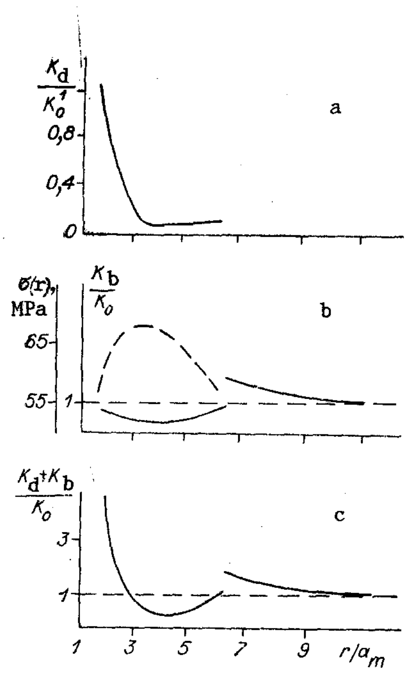

Fig. 5

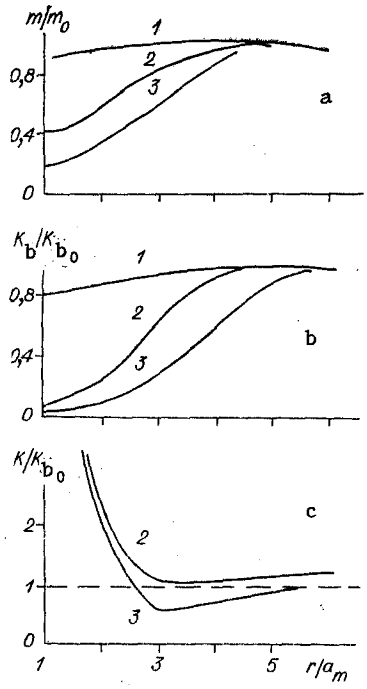

Fig. 6

It is evident from Fig. 5 that the dependence of total permeability on distance is nonmonotonic, which is connected with the competition between dilatational and block permeability. An increase in the distance from the charge is accompanied by a rapid decrease in dilatational permeability and an increase in block permeability. The latter can in turn be attributed to a decrease in the residual stresses present with an increase in the distance from the explosion cavity. The change in effective pressure in the medium is equal to zero in the elastic-displacement zone, and only a stress redistribution takes place: σ_r increases in absolute value while σ_φ decreases. This leads to an increase in the cross section of the capillaries oriented in the radial direction and, accordingly, to an increase in the radial component of the permeability tensor. This component can be found from the formula [7]

$$K_r/K_0 = \left[1 + \frac{3(1+\nu)\sigma}{m_{0t}E_f}\right]^3 \Big/ \left[1 + \frac{(1+\nu)\sigma}{E_f}\right].$$

Here, ν is the Poisson's ratio; σ is the change in the radial component of the stress tensor; E_f is the effective Young's modulus; m_{0t} is the initial value of crack porosity (model parameter). In the calculations, we took $\sigma/E_f = 5\cdot10^{-4}$, $m_{0t} = 10^{-2}$, $\nu = 0.33$. The above formula determines the maximum change in the radial component of the permeability tensor (on the internal boundary of the elastic-displacement zone). The change in this component subsequently decreases with a decrease in σ in accordance with the law $\sigma \sim r^{-2}$ as the distance from the charge increases.

Thus, it has been shown that there is satisfactory qualitative agreement between the theoretical and empirical relations for the change in permeability in the vicinity of an underground explosion in a porous medium saturated with liquid.

The irreversible change in the filtration properties of the medium in the case of an underground explosion can be explained within the framework of the model proposed in [8]. This model makes it possible to determine the change in the porosity of a medium under the influence of an SW for cases in which the medium is partially or completely saturated with a liquid or gas. The model also permits description of both elastic changes in the volume of the pores under a load and the plastic movement of the pores — when the load exceeds the yield point of the medium Y. Calculations of the change in the porosity of such a medium after an underground explosion were performed in [9]. Also presented in [9] was a method of solving equations that describe the dynamics of the propagation of a spherical SW. Similar calculations were performed for media saturated to different degrees by a liquid. The motion of the medium was described using hydrodynamic equations that took into account strength effects.

To write the equation of state of a porous saturated medium, Dunin and Surkov [8] assigned several parameters characterizing the matrix material and the saturating liquid: density $\rho_m = 2.65$ g/cm^3; sonic velocity $c_m = 4.5 \cdot 10^3$ m/sec; shear modulus $G_m = 10^4$ MPa; shear strength $Y = 10^2$ MPa. For the pore liquid, the density $\rho_{m_0} = 1$ g/cm^3 and sonic velocity equaled 10^3 m/sec. The counterpressure was assumed to be equal to 50 MPa in all of the computational variants.

The calculations showed that in the event of complete saturation of the medium by liquid, there is almost no change in the porosity of its matrix after passage of the SW. Meanwhile, the liquid in the pores prevents their plastic deformation and helps restore the initial porosity after removal of the load. In other words, no irreversible changes in matrix porosity and, accordingly, matrix permeability take place in this case. When the pores are completely saturated with liquid, they undergo plastic flow. Here, the change in porosity after removal of the load is nearly equal to the fraction of porosity filled with gas. This means that the passage of a SW is accompanied by an irreversible reduction in the porosity of the medium due to flow of the pores that contain the gas phase. Figure 6a shows typical radial dependences of the porosity of the medium for different ratios of liquid and gas. Figure 6b shows the corresponding radial dependences of matrix permeability. We used the Kozeni formula [4] $K \sim m^3$ to calculate the radial dependences of matrix permeability.

Figure 6c shows the radial dependence of total permeability (dilatational and block) obtained for the given parameters of the medium. We took $K_{b_0} = 0.5$ D in the calculations. It is evident that here too the permeability relation is nonmonotonic. In Fig. 6, line 1 corresponds to $m_0 = 10\%$ (100% liquid), line 2 corresponds to $m_0 = 10\%$ (50% liquid and 50% gas) and line 3 corresponds to $m_0 = 20\%$ (25% liquid and 75% gas).

Thus, the results of the theoretical part of our investigation make it possible to explain the nonmonotonic change in post-explosion permeability in the region affected by the explosion. In the case of an explosion in a porous medium completely saturated with liquid, the nonmonotonic dependence of the permeability tensor on radius is due to the presence of residual stresses in the medium and elastic displacements outside the fracture zone. The presence of residual stresses in the medium leads to a change in the permeability tensor. These changes are reversible, however, since they are connected with elastic deformation of the porous medium. When the medium is not completely saturated with liquid, an explosion leads to irreversible changes in block permeability in the fracture zone due to plastic flow of the pore space containing the gas phase. The dependence of the permeability coefficient on radius is also nonmonotonic in this case. Block permeability decreases in the fracture zone.

It is interesting to examine the dependence of the form of the function for the radial component of the permeability tensor on the initial porosity of the medium in which the explosion takes place. It was shown in [9] that in the case of an explosion in a porous gas-saturated medium, the distribution of permeability in the fracture zone depends to a significant extent on initial porosity. At $m_0 < 5\%$, the medium behaves as a monolith and the permeability distribution function is monotonically decreasing, regardless of the level of saturation. At $m_0 > 15\%$, an explosion in a porous gas-saturated medium leads to a decrease in permeability in the fracture zone. As was shown in [9], this result is connected with the fact that at a porosity $m_0 > 15\%$ there is a large number of contacts between grains not separated by a cementing material. Thus, loading may cause both destruction of the grains (especially their contacts) and flow of the cement in the spaces between the grains. In the case of an explosion in a medium saturated with liquid, the liquid acts as a cement in the contacts. After completion of the dynamic stage of the explosion, the field of residual stresses may cause the cementing liquid to filter into the region where pressure is reduced. As a result, the pressure of the liquid compensating for the external load (residual stresses) on the blocks decreases and the permeability of the blocks diminishes due to plastic deformation of the pores. Naturally, the larger the number of contacts where the intergranular space is not filled by cement, the more sensitive the medium will be to such changes. It was shown in [9] that the fraction of such contacts and their effects on the permeability of the medium increases with an increase in porosity $m_0 > 15\%$. Thus, the permeability of the medium also begins to decrease significantly at high values of porosity ($m_0 > 15\%$) in the case of an explosion in a porous medium saturated with liquid. The experimental data shows that a region associated with a local deterioration in permeability develops at an initial porosity $m_0 > 18\%$.

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SHAPE OF AN INCOMPRESSIBLE, WEAKLY CONDUCTING JET IN A STRONG ELECTRIC FIELD

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The question of jet formation in an electric field has mainly been investigated experimentally. The generation of jets of various fluids in an electrostatic field was systematically studied by Zeleny [1], who found a number of empirical conditions for the interelectrode voltage and the fluid head governing the transition from droplets to a continuous jet flow. In [2] the effect of the field strength and the flow rate on the length of the continuous part of the jet and in [3] the effect of conductivity on the breakup length were investigated for fluids with a broad range of viscosities, conductivities and surface tensions (water–glycerol mixtures, salt solutions, organic and inorganic oils, etc.). Many studies have been devoted to the atomization of charged jet flows. For example, in [4] jets of insulating cryogenic liquids were examined in connection with the possibility of obtaining spherical microtargets of controllable size for laser thermonuclear synthesis. In [5, 6] electrostatic microfiber spinning from polymer solutions and melts was studied experimentally.

It is assumed that the fluids being investigated possess ionic conductivity with a characteristic electric time parameter less than the characteristic capillary outflow time. Because of the small relaxation time in the immediate vicinity of the fluid-emitting electrode the charge flows away towards the surface of the jet. The electric forces are determined by the interaction of the external field and the injected surface charges, the mutual repulsion of the latter, and the polarization interactions. For a thin, weakly decaying jet profile the polarization forces are small, there are no electric body forces, and the electric and hydrodynamic fields interact across the jet boundary. Strong electrostatic fields are considered. For these fields the field strength associated with charge transfer UI exceeds the initial power of the hydrodynamic flow $\rho Q^3/2\pi^2 r_0^4$, i.e., the parameter $\delta = \rho Q^3/2\pi I U r_0^4 \ll 1$ (I is the current transported by the jet, U is the potential difference on the coordinate interval investigated, ρ and Q are the density and volume flow rate of the fluid, and r_0 is the initial radius of the jet). This makes it possible to omit the initial conditions of jet

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