INFLUENCE OF PROPERTIES OF FILTERING LIQUIDS ON THE PERMEABILITY OF DISPERSE SYSTEMS

P. P. Olodovskii and M. G. Murashko

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A method is proposed for determining the filtration characteristics of finely dispersed systems (clayey soils) through a calculation of their adsorption and rheological properties.

Our purpose in this study was to determine the relationship between the permeability of disperse systems and their structural and adsorptive properties in the filtration of liquids of various molecular structures and to develop a basis for a method of calculating the permeability of clayey soils as a function of the processes occurring at the solid surface. As the systems for the solution of the first problem we chose natural Glukhov kaolin, Chasov-Yar monothermite clay, the Na form of Crimean kill, and several liquids: water, butyl alcohol, isopropyl alcohol, toluene, diethylamine, and carbon tetrachloride.

The specific surface areas of the particles were calculated by a method based on a determination of the density of the adsorbed water as a function of its mass and the change in the density of the disperse medium in the solid – adsorbed water – liquid system. The average dimensions of the microscopic aggregates were determined through an electron-microscopic analysis. The apparatus and procedure of the filtration experiment are essentially similar to those described in [2], except that the soil porosity was varied, not by using different contents of the liquid filling the pores, but by using different degrees of compression of the samples in a press (from 10 to 100 kg/cm^2). Linear relations analogous to those found for systems of clay, water, and aqueous solutions of inorganic compounds [3] were obtained between such dimensionless parameters as the porosity coefficient and the product of the permeability and the square specific surface area per unit volume of the disperse system. Table 1 shows the specific effective porosity for various porosity coefficients for the filtration of water and organic compounds.

The next step was to determine the number of liquid layers which do not participate in the filtration. For each liquid we constructed a model for the arrangement of adsorbed molecules on the surfaces of the solid particles and calculated the projections of the length of the chemical bond on the plane perpendicular to the adsorbent surface. The masses of the "monolayers" of the adsorbed compounds, P_m, and the number of layers L were determined from

$$P_m = S d_a^0 D_p, \tag{1}$$

$$L = \frac{\varepsilon_0 d''}{P_m d}. \tag{2}$$

The calculated results are shown in Table 2. Analysis of these results revealed that the relation between the permeability and the structural and adsorption characteristics of the soils during the filtration of liquids of various molecular structures is governed by an equation found previously for clays of various mineral compositions in their natural and ion-substituted forms during the filtration of water and aqueous solutions [3]. This equation is

$$K = \frac{(\varepsilon - \varepsilon_0)(\varepsilon + 1)^2 \varphi}{d^2 S^2 (L - 1)^3}. \tag{3}$$

It should be noted here that for the Na form of montmorillonite during the filtration of water, Eqs.

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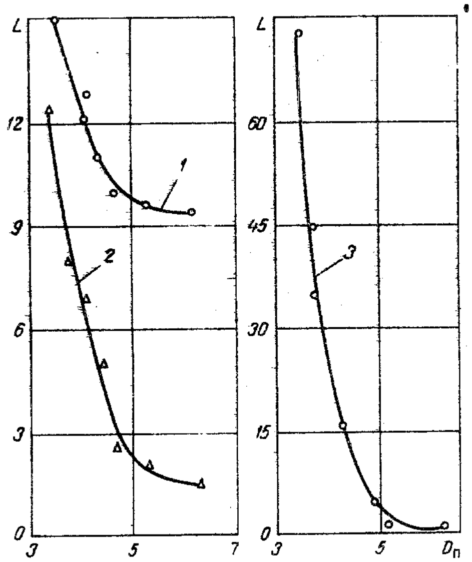

Fig. 1

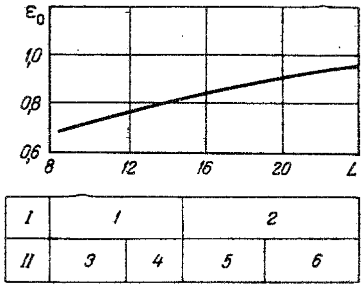

Fig. 2

Fig. 1. Number of liquid layers not participating in the filtration (L) as a function of the projection of the length of the chemical bond of the adsorbed molecule onto the plane perpendicular to the surface of the mineral (D_p, Å). 1) Glukhov kaolin; 2) Chasov-Yar clay; 3) Na form of Crimean kill.

Fig. 2. Glukhov kaolin. I: ionic forms. 1) Natural form; 2) Na form. II: structure of the filtering liquids. 3) Organic compounds; 4) water and aqueous solutions of inorganic compounds; 5) organic compounds; 6) water and aqueous solutions of inorganic compounds.

(1) and (3) take into account the total surface area of the particles, while in Eq. (2) the mass of a monolayer of adsorbed water which appears on the internal surfaces of the crystal lattice is used. For the filtration of organic compounds the external surface area and the mass of the monolayers of adsorbed materials formed on the external surfaces of the crystal lattice are taken into account.

Figure 1 shows the relation between the number of liquid layers not participating in the filtration and the projection of the length of the chemical bond of the adsorbed molecule in the monolayer onto the plane perpendicular to the surface of the solid phase. These results and the experimental results (Table 1) can be interpreted in the following manner: The system consisting of the natural Glukhov kaolin and a liquid is not a coagulating system, since the dimensions of the microscopic aggregates are in all cases roughly the same. The permeability of the mineral varies only due to the formation of different numbers of liquid layers not participating in the filtration. There is a decrease in the value of this number and thus in the permeability with increasing linear dimension (the "projection") of the adsorbed molecule. The system consisting of the Chasov-Yar clay and a liquid and the Na form of Crimean kill and a liquid are dispersed in water and form large microscopic aggregates in other liquids, primarily due to the interparticle interaction. This circumstance is responsible for the sharp difference between the number of layers not participating in the filtration in the case of water and this number for the filtration of organic compounds. In these systems there is a particularly marked increase in the permeability with increasing linear dimension of the adsorbed linear molecules.

On the basis of these results we can deduce the basic principles for using various structure-conditioning materials for improving the filtration properties of heavy soil:

1) The solubility in water should be good.

2) The binding energy between the surface of the soil and the molecules of the structure conditioners, particularly polyelectrolytes, should be higher than for water.

3) The material should display a good coagulating (adhesive) capability, as is usually provided for the polyelectrolytes by an extended chain of active centers.

4) Under otherwise equal conditions, it is preferable to use those structure conditioners whose molecules have a large linear dimension in the direction into the interior of the liquid from the solid surface.

TABLE 1. Specific Effective Permeability K for Various Porosity Coefficients ε of the Clay for the Filtration of Water and Organic Liquids

Glukhov kaolin							Na form of Crimean kill						Chasov–Yar clay					
ε	water	butyl alcohol	isopropyl alcohol	carbon tetra-chloride	toluene	diethyl-amine	water		isopropyl alcohol		carbon tetra-chloride		water		isopropyl alcohol		diethylamine	
	$K \cdot 10^{12}$ cm^2						ε	$K \cdot 10^{12}$ cm^2	ε	$K \cdot 10^{12}$ cm^2	ε	$K \cdot 10^{12}$ cm^2	ε	$K \cdot 10^{12}$ cm^2	ε	$K \cdot 10^{12}$ cm^2	ε	$K \cdot 10^{12}$ cm^2
0,96	2,06	2,99	3,49	2,32	2,23	4,60	7	0,01	0,9	19,26	0,70	197,67	2,0	0,14	1,1	8,85	0,85	0,70
1,16	4,99	6,53	8,01	7,89	5,88	10,36	9	0,04	1,0	44,78	0,75	384,03	2,5	1,74	1,2	15,98	0,90	6,04
1,36	8,95	9,69	14,08	18,90	10,79	18,06	11	0,10	1,1	75,23	0,80	590,97	3,0	4,31	1,3	24,31	0,95	11,94
1,56	14,04	11,26	21,87	25,34	17,15	27,96	13	0,18	1,2	110,93	0,85	819,34	3,5	8,02	1,4	33,92	1,00	18,43

TABLE 2. Structural Parameters of the Soils for the Filtration of Liquids with Various Molecular Structures

Clayey minerals	Filtering liquid	S, m^2/g	D_p, Å	P_m, %	ε_0	L	D_{ma}, μ
Natural Glukhov kaolin	Water	55,04	3,49	1,94	0,76	14,97	0,49
	Diethylamine	55,04	5,192	3,14	0,73	9,7	0,22
	Isopropyl alcohol	55,04	4,69	2,08	0,74	9,9	0,41
	Butyl alcohol	55,04	4,06	1,81	0,71	12,17	0,43
	Toluene	55,04	4,3	2,06	0,79	12,73	0,41
	Carbon tetrachloride	55,04	6,088	5,34	0,85	9,67	0,38
Chasov–Yar clay	Water	200	3,49	5,8	1,94	12,4	0,208
	Diethylamine	200	5,192	11,4	0,843	3,04	0,356
	Isopropyl alcohol	200	4,69	7,64	0,945	3,65	0,51
Na form of bentonite	Water	543,6	4,014	2,8	5,67	73	0,12
	Isopropyl alcohol	163,7	5,204	6.79	0,81	3,45	0,63
	Carbon tetrachloride	163,7	6,178	15,27	0,64	2,28	0,719

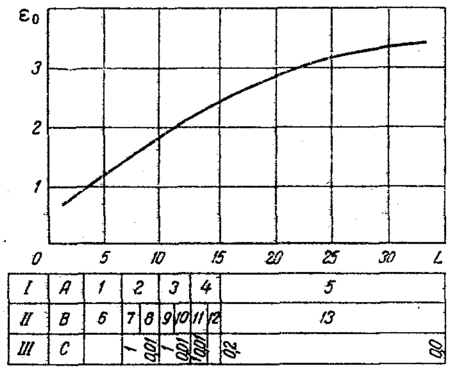

Fig. 3

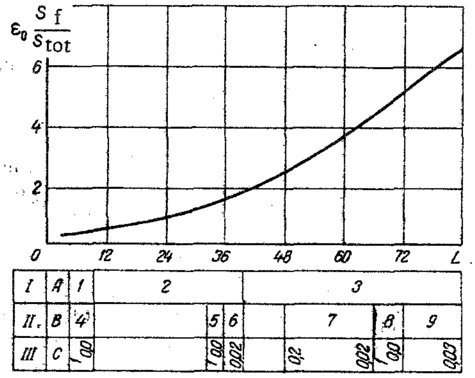

Fig. 4

Fig. 3. Monothermite. I: ionic forms. A) Arbitrary forms; 1) organic structure-conditioning materials; 2) Al and Fe forms; 3) Ca, Ba, and natural forms; 4) K forms; 5) Na form. II: structure of filtering liquids. B) Organic compounds; 6) water and aqueous solutions of inorganic compounds; 7) solutions of inorganic compounds; 8) water; 9) solutions of inorganic compounds; 10) water; 11) solutions of inorganic compounds; 12) water; 13) aqueous solutions of NaCl. III: solution concentration, g-eq / liter.

Fig. 4. Montmorillonite. I: ionic forms. A) Arbitrary forms; 1) Ca, Ba, Al, Fe, and natural forms; 2) K form; 3) Na form. II: structure of filtering liquids. B) Organic compounds; 4) water and aqueous solutions of inorganic compounds; 5) water and aqueous solutions of KCl; 6) aqueous solutions of KCl; 7) aqueous solutions of doubly charged ions; 8, 9) aqueous solutions of NaCl. III: solution concentration, g-eq / liter.

As we see from Eq. (3), the permeability of finely dispersed systems (clayey soils) is governed primarily by the porosity of the systems, the specific surface area of the solid particles, the density of these particles, and the characteristics of the immobile solvate shells, ε_0 and L. Further analysis of the experimental data and the calculated parameters (see [1-3]) yielded other results. Figures 2-4 show the relationship between ε_0 and L for each type of mineral studied: kaolin, monothermite, and montmorillonite. The total range of L is partitioned into regions corresponding to the formation of different ionic forms and the filtration of different liquids. For the aqueous solutions of inorganic salts, the concentration range is specified. It should be noted that for the montmorillonite the ordinate (ε_0) must be multiplied by a factor of S_f / S_p, where S_f is the specific area of the solid particles participating in the filtration, and S_p is the total surface area of the particles. This factor must be incorporated because either the entire surface or only part of it may participate in the filtration, depending on the ionic form and the structure of the solutions. For example, for the filtration of water and aqueous solutions of inorganic salts through the Li, Na, and K forms we have $S_f = S_p$, while for filtration through the forms formed by doubly or triply charged ions we have $S_f = S_e$, where S_e is the external specific surface area of the crystal lattice of the mineral.

The strictly monotonic functions $\varepsilon_0 = f(L)$ permit us to calculate ε_0 and L for any state of the soil, determined by the change in the properties of the filtering liquids. However, here we need preliminary information about the composition of the dissolved substances (organic and mineral compounds) in the water in the pores. Then the essence of this engineering method for calculating the filtration characteristics of the soils as a function of the properties of the filtering liquid can be summarized in the following operations:

1. The permeability is measured for the given soil in the field by a filtration test of the soil by pumping or similar method; the porosity of the soil is also measured.

2. In the laboratory, the functional relationship is determined among the parameters of the immobile solvate shells [ε_0 and L] for any state of the soil, due to the formation of various ion-substituted forms and the filtration of various aqueous solutions.

3. The correlation between the values of the filtration coefficients measured in the field and in the laboratory is determined.

4. On the basis of the proposed time evolution of the concentrations of dissolved materials and the function $\varepsilon_0 = f(L)$ found for the soil in question, the permeabilities of the soils are calculated. Here it should be noted that on the curves of the function $\varepsilon_0 = f(L)$ it is possible to distinguish between regions corresponding to the application of organic structure conditioners (polyelectrolytes) and mineral fertilizers. Then it is possible to make the optimum choice of the concentrations of the various additives, which are added directly to the soil or to irrigation water in order to control water transport in the soil.

NOTATION

S is the specific surface area of the particles;
d_a^0 is the density of adsorbed liquid corresponding to a monolayer coverage;
D_p is the projection of the length of the chemical bond onto the plane perpendicular to the adsorbent surface;
ε is the porosity of the soil;
ε_0 is the porosity corresponding to the permeability $K = 0$;
d'' is the density of the filtering liquid;
d is the soil density;
φ is the constant independent of the properties of the liquid and the solid;
D_{ma} is the dimension of the microscopic aggregates;
P_m is the mass of a "monolayer" of the adsorbed substance;
L is the number of liquid layers not participating in the filtration.

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