EFFECT OF POROUS STRUCTURE AND ABSORBED MOISTURE ON PROPAGATION OF ULTRASOUND IN MODEL CAPILLARY-POROUS SUBSTANCES

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The results of an experimental investigation of the attenuation of ultrasound in a moist capillary-porous substance (fractionated quartz river sand) are given.

The acoustic parameters of capillary-porous substances are closely correlated with their structure and water-retaining properties and, hence, the determination of these parameters is of great scientific and practical interest. There have been a few theoretical and experimental investigations of capillary-porous substances by ultrasonic methods [1, 2]. The results obtained, however, have not been subjected to a critical analysis from the viewpoint of the structure and water-retaining properties of the investigated capillary-porous substances. To fill this gap we investigated in the present work the attenuation of ultrasound in moist capillary-porous substances and its dependence on the porous structure and the position of moisture in the pores. From a wide range of dispersed materials we selected for investigation capillary-porous substances in which the moisture is retained by physicochemical binding (six fractions of quartz river sand). The sizes of the particles in the individual fractions of quartz sand varied from 0.712 mm (largest fraction) to 0.094 mm (smallest fraction).

The investigations of the attenuation of ultrasound in quartz sand and its dependence on moisture content were made with an automatic pulsed ultrasonic device [3]. With this apparatus we obtained two kinetic curves – the curve of variation of the weight of the investigated quartz sand sample during gradual and

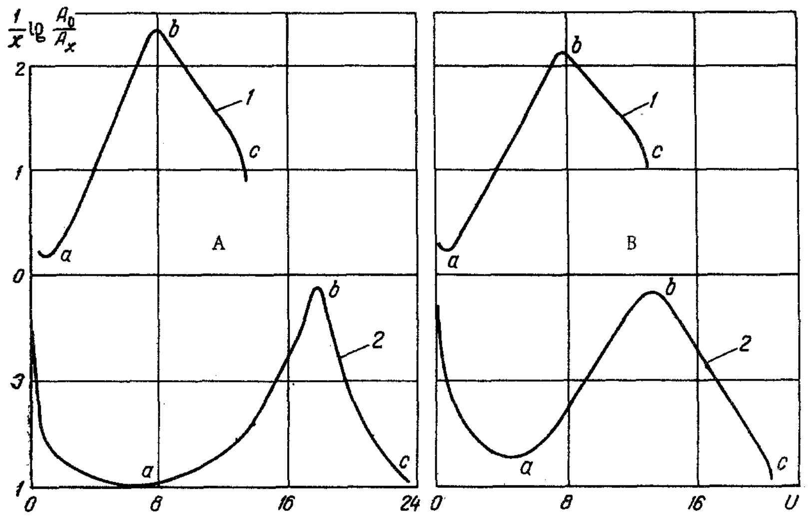

Fig. 1. Attenuation of ultrasound (cm^{-1}) in quartz sand fractions [1) 0.5-1.0 mm; 2) 0.074-0.105 mm] as function of moisture content (%) (A) and toluene mass content (%) (B).

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TABLE 1

Fraction, mm	Point a		Point b		Point c	
	I	II	I	II	I	II
0,5 —1,0	1,0	5,8	8,0	46,0	13,5	78,5
0,25 —0,5	2,1	11,9	10,0	57,0	16,0	92,0
0,21 —0,297	2,8	12,4	12,5	56,0	18,0	80,0
0,149—0,21	4,0	18,3	14,5	66,0	21,5	98,0
0,105—0,149	4,5	19,0	15,4	65,0	21,5	91,0
0,074—0,105	6,2	25,0	18,0	72,0	24,5	98,0

Note: I) Moisture content, %; II) relative filling of pores, %.

TABLE 2

Fraction, mm	Point a		Point b		Point c	
	I	II	I	II	I	II
0,5 —1,0	0,5	3,7	7,8	59,0	13,0	97,0
0,25 —0,5	1,3	8,5	8,5	55,6	14,0	92,0
0,21 —0,297	1,6	8,3	9,3	48,5	17,4	90,0
0,149—0,21	2,9	15,5	11,0	58,0	18,0	95,0
0,105—0,149	3,4	16,4	11,2	54,0	18,5	90,0
0,074—0,105	4,5	21,0	13,4	62,0	20,5	95,0

Note: I) Toluene mass content, %; II) relative filling of pores, %.

continuous drying, and the variation of the amplitude of an ultrasonic pulse transmitted by the investigated sample and recorded by a receiver – and were thus able to investigate the attenuation of ultrasound in different fractions of quartz sand with a wide range of moisture content.

Figure 1A shows the attenuation of ultrasound of frequency 70 kHz in the two extreme (largest, 0.5-1.0 mm and smallest, 0.074-0.105 mm) fractions of quartz sand as a function of the moisture content. We have plotted the moisture content of the sample as a percentage of its dry weight on the x axis, and on the y axis we have plotted the logarithm of the ratio of the amplitude A_0 of the ultrasonic pulse registered by the receiver with the cuvette empty to the amplitude of the ultrasonic pulse A_x transmitted by a layer of quartz sand of thickness x, referred to unit thickness of the sample.

The figures show that in quartz sand with low moisture content there is a marked increase in amplitude of the ultrasonic signal transmitted by the layer of quartz sand, and the curve representing the attenuation of ultrasound in relation to moisture content of the sand passes through a minimum at point a on the curves. The minimum attenuation of ultrasound in sand with different moisture content depends on the grain size. This is revealed by curves 1 and 2 in Fig. 1A, and also by the data, given in Table 1, for all the quartz sand fractions investigated. Our calculations indicate that point *a* on the curves of ultrasound attenuation in the larger-grained samples corresponds to a relatively small filling of the pores with liquid in comparison with the smaller-grained fractions (Table 1).

With further increase in moisture content of the sand the plot of attenuation of ultrasound against moisture content for all the investigated quartz sand fractions passes through a maximum at point b (Fig. 1A, Table 1), which is attained at a larger relative filling with liquid, the smaller the particles in the investigated sample. When the moisture content of the quartz sand was greater than at point b there was less attenuation of the ultrasound, and when the point c was reached the amplitude of the ultrasonic pulse transmitted by the sample became much greater. We found that this occurred when the pores in the quartz sand were almost completely filled with water (Table 1).

To determine the effect of capillary forces on the attenuation of ultrasonic waves in capillary-porous substances we carried out a series of experiments in which we determined the attenuation of ultrasound in quartz sand in relation to the mass content of toluene, which has density and viscosity close to those of water, but differs considerably in its surface tension coefficient.

Figure 1B shows the attenuation of ultrasound of frequency 70 kHz in the two extreme (largest and smallest) fractions of quartz sand in relation to the toluene mass content of the pores. The results of the experiments indicate that the variation of the ultrasound attenuation in quartz sand in relation to the toluene content of the pores is the same as in the case of moistening with water. The curves show a distinct minimum and maximum of ultrasound attenuation, which move towards higher toluene mass contents with increase in dispersion of the sample. The position of the points a, b, and c on the curves showing the attenuation of ultrasound in quartz sand in relation to the toluene content of all the investigated sand fractions are shown in Table 2.

A comparison of the data (Tables 1 and 2) obtained when quartz sand was moistened with distilled water and toluene indicates that the critical point on the curves representing the attenuation of ultrasound in relation to the toluene content of its pores occurred at a lower relative filling of the pores with liquid than in the case where the sand was moistened with distilled water.

Thus, we can conclude from an analysis of the obtained results that the attenuation of ultrasound in moist quartz sand is determined by its porous structure and the position of moisture in its pores. The reduction of the ultrasound attenuation in quartz sand with low moisture content coincides with the formation of liquid collars at the points of contact of the individual sand grains. These collars reduce the friction loss [4] and lead to additional compression of the whole system due to the action of capillary forces [5]. Capillary compression lasts until the surfaces bounding the liquid between the individual particles begin to fuse together [5], and isolated air bubbles appear within the sample. After this the attenuation of ultrasound increases. As the bubbles are displaced from the pore space of quartz sand by the liquid the attenuation of the ultrasound decreases. In quartz sand with the interstices filled with liquid the attenuation of ultrasonic oscillations depends mainly on the thermal effects occurring at the interface of the solid and liquid phases due to the transmission of an elastic wave [6] and at low ultrasonic frequencies is much less than in dry sand.

LITERATURE CITED

1. B. A. Belinskii and L. L. Sinii, in: Application of Ultraacoustics to the Investigation of Matter [in Russian], No. 20, Moscow (1964).
2. G. I. Petkevich and T. Z. Verbitskii, Investigation of the Elastic Properties of Porous Geological Media Containing Liquids [in Russian], Naukova Dumka, Kiev (1965).
3. B. N. Stadnik and M. F. Kazanskii, in: Investigation of Heat and Mass Transfer in Technological Processes and Apparatuses [in Russian], Nauka i Tekhnika, Minsk (1967).
4. G. I. Pokrovskii, Friction and Cohesion in Soils [in Russian], Stroiizdat, Moscow–Leningrad (1951).
5. G. I. Pokrovskii, Research on the Physics of Soils [in Russian], ONTI, Moscow–Leningrad (1937).
6. N. L. Byzova and V. S. Nesterov, Akust. Zh., 5, No. 4 (1959).