

ELECTROPHYSICAL PROPERTIES OF NONCONDUCTIVE LOOSE MATERIALS

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The electrophysical properties of loose granular systems of radioceramic materials are studied, and the functions and coefficients relating these properties to system porosity, temperature, and solid-phase properties are presented.

Loose materials of varying grain size are widely used in industry. Studies of electro- and thermophysical properties of mechanical mixtures as functions of the content and properties of their phases were performed in [1-3].

The relationships derived in those studies proved to have limited applicability in calculation of electrophysical properties of loose systems formed of materials with high dielectric permittivity.

The bulk materials investigated in the present study were densely packed 2-3-mm granules of insulating material (IF) and radioceramics (T-20, T-80, T-150, T-8000, and others) with dielectric permittivities from 7 to 8000 units [4]. The materials to be studied were poured into a capacitance transducer with open electrodes. The transducer was calibrated with bulk materials of known dielectric permittivity [5].

Studies were made first of the effect of system porosity on dielectric permittivity. Regulation of system porosity within the limits of 0.24 to 0.70 parts by volume was obtained by compression and use of grains of different fractional composition with dimensions of 3 mm and less. Results are presented in Fig. 1 (a and b). It is evident from Fig. 1 that with decrease in porosity of the poured materials the dielectric permittivity increases sharply. In all experiments there was a linear dependence between open porosity and the logarithm of dielectric permittivity:

$$\lg \epsilon_l = m \lg \epsilon_0 + \Pi \lg \epsilon_a, \quad (1)$$

$$\epsilon_l = \epsilon_0^m \epsilon_a^\Pi. \quad (2)$$

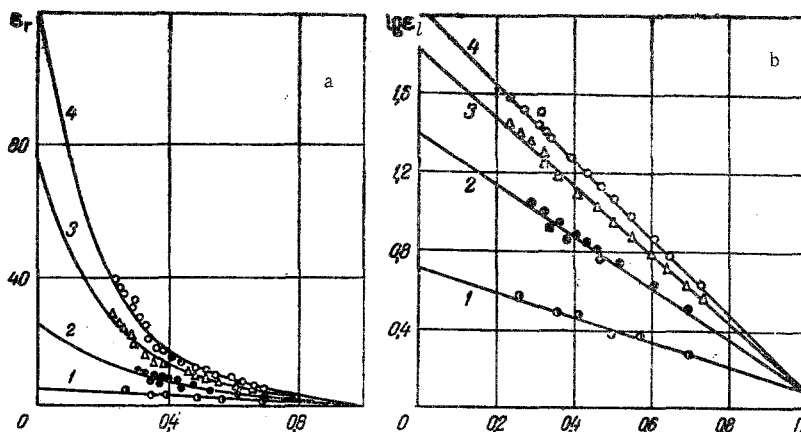


Fig. 1. Dielectric permittivity of loose bulk material versus porosity: 1) type IF ceramic; 2) T-20; 3) T-150; 4) T-8000.

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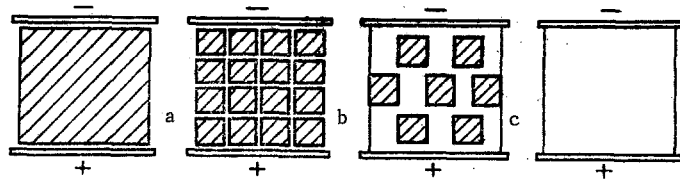


Fig. 2. Models of loose materials for dielectric-permittivity calculation: a) original solid phase $m = 1, \Pi = 0, \epsilon$; b) dense-grain system, $m = 1, \Pi = (6-8) \cdot 10^{-3}, \epsilon_0 = [(1/\epsilon) + \Pi]^{-1}$; c) loose system, $m + \Pi = 1, \epsilon_l = \epsilon_0^m \epsilon_a^{1-m}$; d) air, $m = 0, \Pi = 1, \epsilon_0 = 1$.

The logarithmic dependence thus obtained is widely employed for calculation of many properties of a heterogeneous mixture of two components. However, in the equations presented here a new concept has been used – the dielectric permittivity of a dense system of grains. An example of such a system would be densely packed cubes with disappearingly small open porosity. The presence of a phase boundary surface in the form of very fine air layers between the grains has a significant effect on the behavior of the dense grain system in an electric field and on other physicochemical properties.

The dielectric permittivity value for the dense grain system may be obtained by extrapolation from Fig. 1b. Analysis of the data so obtained leads to the conclusion that the dielectric permittivity of the dense grain system is determined mainly by the properties of the series-connected layers of the solid and air interlayer:

$$\frac{1}{\epsilon_0} = \frac{m}{\epsilon} + \frac{\Pi}{\epsilon_a}; \quad \epsilon_0 = \left(\frac{1}{\epsilon} + \Pi \right)^{-1}. \quad (3)$$

In this dense system it is evident that $m \approx 1$ and $\epsilon_a = 1$.

Thus, in calculations of electrophysical properties loose bulk nonconductive materials may be represented in the form of models as shown in Fig. 2. The limiting states of the loose system are the dense grain system, on the one hand, and air, on the other. The transition from solid phase to loose system occurs through the dense grain system.

Experimental creation of a dense grain system was impossible. Calculations with Eq. (3) revealed that in such a system the open porosity is $(6-8) \cdot 10^{-3}$ parts by volume.

The dielectric permittivity of a system of loose materials as a function of the dielectric permittivity of the solid phase and the content of the latter is described by the equation

$$\epsilon_l = \left(\frac{1}{\epsilon} + 8 \cdot 10^{-3} \right)^{-m}. \quad (4)$$

We will analyze Eq. (4), presenting the calculated data in Table 1. It is evident from this table that the measured and calculated dielectric permittivities of the loose system practically coincide. With increase in dielectric permittivity of the solid phase above 1000 the dielectric permittivity of the loose system increases insignificantly, not exceeding 20 units.

The change in dielectric permittivity of the loose materials as a function of porosity can be characterized by the coefficient introduced above $\Pi K \epsilon_l$:

$$\Pi K \epsilon_l = - \frac{1}{\epsilon_l} \cdot \frac{d\epsilon_l}{d\Pi} = - 2.3 \frac{d \lg \epsilon_l}{d\Pi} = - 2.3 \lg \epsilon_0. \quad (5)$$

The coefficient of relative change in dielectric permittivity of the loose material as a function of $\Pi K \epsilon_l$, is negative, and its absolute value increases with increase in dielectric permittivity and is constant for any given type of loose material.

The functions obtained have important significance for the study of the properties of loose materials. A small change in porosity leads to a sharp change in dielectric permittivity of the system. For example, the porosity of the ceramic granules is $40 \pm 5\%$, depending on the method of packing, and variation of the open porosity within the limits $\pm 5\%$ leads to change in dielectric permittivity of the system from 10 to 30%, depending on composition.

Dielectric losses and electrical resistance of the loose materials studied (Table 2) are determined by

TABLE 1. Dielectric Permittivity of Ceramic Materials

Ceramic type	Dielectric permittivity		
	ϵ solid phase, measured	ϵ_0 dense-grain system, calc.	ϵ_l loose system, calculated
IF	7,0	6,5	3,1
T-20	24,0	23,0	7,2
T-150	160,0	79,5	13,8
T-1000	1000,0	107,0	16,6
T-8000	8000,0	120,0	17,8

ϵ_l calculated at $m = 0,6$

TABLE 2. Some Properties of Densely Packed Ceramic Granules with Free Pouring

Parameter	Ceramic type				
	IF	T-20	T-80	T-150	T-8000
Poured density, g/cm ³	1,5	2,5	2,4	2,3	3,5
Dielectric-loss angle tangent, $\tan \delta \cdot 10^{-4}$	93,0	9,7	3,1	2,4	32,0
Specific volumetric resistance $\Omega \cdot m$					more than 10^{10}

TABLE 3. Temperature Coefficients of Solid-Phase Dielectric Permittivity and Loose-System Capacitance

Ceramic type	Solid phase	$TKE_l \cdot 10^{-6}$ loose material, deg ⁻¹
IF	550	590
T-20	-50	280
T-80	-700	50
T-150	-1500	-50

the properties of the solid phase and are little dependent on porosity and granularity. It was found in the study that the electrophysical properties of the nonconductive ceramic granules are insensitive to electric field frequency up to 10^8 Hz.

The effect of temperature on the dielectric permittivity of the loose materials may be determined by differentiating Eqs. (1) and (3) with respect to temperature. After mathematical transformations, $TK\epsilon_l$ takes on the form

$$TK\epsilon_l = \frac{m}{1 + 8 \cdot 10^{-3} \cdot \epsilon} TK\epsilon + \Pi TK\epsilon_a \quad (6)$$

It was found experimentally that the temperature coefficient of capacitance of the granule system was larger than the temperature coefficient of dielectric permittivity of the same system by $280 \cdot 10^{-6} \text{ deg}^{-1}$:

$$TKE_l = TK\epsilon_l + 280 \cdot 10^{-6} \quad (7)$$

The positive component of TKE_l of the loose system is evidently produced by thermal expansion.

Values of the temperature coefficients of dielectric permittivity of the solid phase and capacitance of the loose systems for free pouring are presented in Table 3.

It is evident from Table 3 that if the grains are prepared from material with positive $TK\epsilon$, the loose system has a positive temperature coefficient of capacitance, while materials with high negative $TK\epsilon$ produce a system with low negative temperature coefficient. Proper selection of material will produce a thermo-stable loose system.

NOTATION

ϵ , ϵ_a , ϵ_l , ϵ_0 , dielectric permittivities of solid phase, air, loose, and dense-grain systems; m , Π , volumetric contents of solid phase and air, $m + \Pi = 1$; $TK\epsilon$, $TK\epsilon_a$, $TK\epsilon_l$, $TK\epsilon_0$, temperature coefficients of dielectric permittivities of above materials, deg⁻¹; TKE_l , temperature coefficient of capacitance of loose system, deg⁻¹.

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INFLUENCE OF WATER-SOLUBLE POLYMERS AND ELECTROLYTES ON THE PERMEABILITY OF WEAK-FILTERING DISPERSED SYSTEMS

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The mechanisms underlying the moisture-conducting properties of the sodium form of clay minerals after the adsorption of various polymers on their surfaces or during the filtration of electrolytes are studied.

A great deal of research has been carried out in connection with determining the optimum concentrations of water-soluble polymers and estimating the changes taking place in the filtering characteristics of soils under the influence of adsorbed organo-mineral complexes. The subject of the present investigation was the Na form of montmorillonite; the structure-forming agents were polyacrylamide, K-4, and K-6; the electrolyte was an aqueous solution of potassium nitrate with a concentration of 0.05 g-eq/liter.

These systems were subjected to filtration and adsorption analysis and examined under the electron microscope. The filtration technique was analogous to that set out in [1].

The specific surface of the particles in the Na form of montmorillonite was calculated from measurements of the density of the adsorbed water, and in the Na form modified with polymers by reference to the adsorption of a dye (methylene blue).

The specific surfaces and effective linear dimensions of the particles are indicated in Table 1.

In the filtration experiments we established a relationship between certain dimensionless parameters: the porosity coefficient and the product of the permeability coefficient by the square of the specific surface of unit volume of the system. As in the case of the filtration of water, aqueous solutions of inorganic substances, and organic compounds through various clay minerals not modified with polymers, this relationship was linear. Using the method of least squares, we calculated the parameters of the straight lines and (on the basis of the corresponding correlational relationships) the confidence intervals of these parameters as well. The relative error in measuring the permeability coefficients was no greater than 10-15%. Table 2 shows the results of these measurements for the Na form of montmorillonite modified with water-soluble polymers during the filtration of water and aqueous KNO₃ solutions. The relationship between the permeability coefficient and the concentration of the polymers so introduced is shown in Fig. 1; the changes in the relative permeability coefficients of the systems associated with the combined use of polymers and electrolytes appear in Fig. 2.

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