EFFECT OF AN ELECTRIC FIELD ON THE KINETICS OF WATER SORPTION BY A CAPILLARY-POROUS MATERIAL

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UDC 541.18:537

Experimental studies have been made concerning the effect of various kinds of external electric fields on the kinetics of water sorption by grade KSK-2 silica gel – a typical capillary-porous material.

The internal mass transfer during drying can be accelerated by maintaining severe operating conditions (heating the material to a high temperature, holding the partial pressure of water vapor in the ambient air down), by vacuum drying, by infrared drying, etc. Under such conditions, however, there often occur undesirable irreversible structural transformations in the dried material. As recent studies by various authors have shown [1-4], the rate of internal mass transfer can be increased appreciably by means of electromagnetic fields.

It is well known [1, 3] that moist capillary-porous materials constitute polarized systems in which applied electric and magnetic fields undergo relaxation, i.e., such systems are relaxation-polarized.

Applying the thermodynamic laws of irreversible processes to an analysis of such systems [1, 3] has shown that a superposition of electric and magnetic fields should appreciably affect the rate of moisture transfer. It should most pronouncedly affect, first of all, the kinetics of water sorption or desorption in a capillary-porous material at a constant ambient air temperature and humidity.

It is well known that very few experimental data are available on this subject, especially concerning the effect of a nonuniform constant or alternating (at industrial frequency) electric field.

For this reason, the authors used vacuum-type sorption scales of the updated K. V. Chmutov design [5] and thermostatically controllable within 0.05°C. The electrode system consisted of a cylindrical metal furnace, in sufficiently close contact with the sorption tube made of glass (d = 3 mm), with a molybdenum spring soldered to it inside and connected to a straight metallic conductor passing through the dielectric container with the colloidal dispersion specimen.

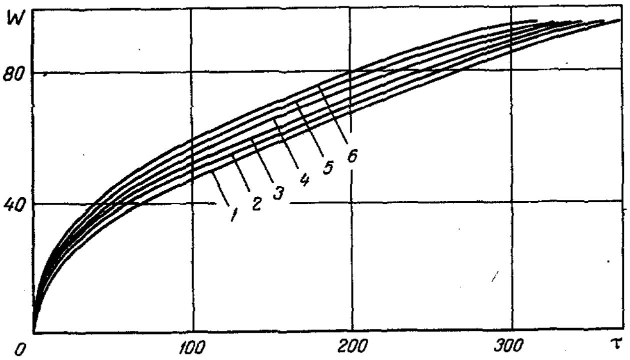

Fig. 1. Curves of moisture content W (%) in grade KSK-2 silica gel, as a function of time τ (min) in which water vapor is sorbed: 1) without an electric field; 2) U = 600 V; 3) 700 V; 4) 800 V; 5) 900 V; 6) 1000 V. Relative pressure of water vapor $\varphi \cong 1$, temperature T = 303°K.

In this way, the moist specimen was placed almost at the axis of a cylindrical electric field with lines of force entering or leaving. The test specimen was thus placed in a highly nonuniform field. The potential difference applied across the electrodes was varied from test to test in 100 V steps from 200 V to 1000 V, both in the dc and in the ac (f = 50 Hz) case. The intensity gradient per unit specimen length was of the order of (14-41) $\cdot 10^6$(V/m)/m, with the effect of the sorption tube material and of the container material as well as of the variation of permittivity ε during humidification [6] all taken into account.

Manuilskii Pedagogical Institute, Rovno. Gor'kyi Pedagogical Institute, Kiev. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 22, No. 5, pp. 801-805, May, 1972. Original article submitted September 3, 1971.

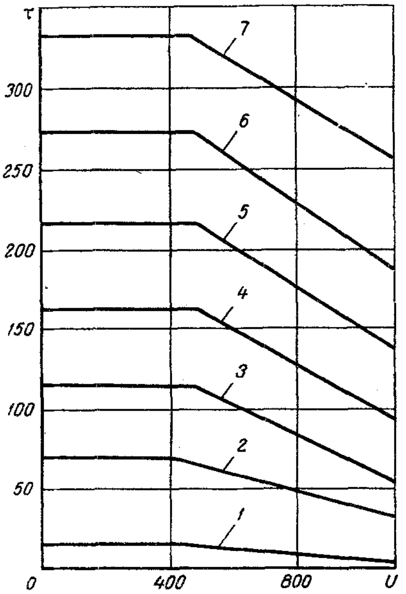

Fig.2

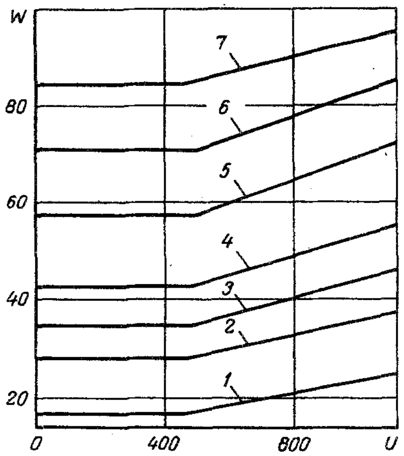

Fig.3

Fig.2. Time τ (min) necessary for grade KSK-2 silica gel to reach the moisture levels W (%): 1) 20; 2) 40; 3) 50; 4) 60; 5) 70; 6) 80; 7) 90%, as a function of the potential difference U (V) applied to the plates of the cylindrical capacitor.

Fig.3. Moisture content W (%) in grade KSK-2 silica gel, as a function of potential difference U (V) across the plates of the cylindrical capacitor, with fixed lengths of sorption time: 1) 10; 2) 30; 3) 50; 4) 80; 5) 150; 6) 220; 7) 300 min.

The tests were performed at a temperature of 303°K and a relative water vapor pressure $\varphi \cong 1$ with a typical capillary-porous material, namely a $0.25 \leq d \leq 0.5$ mm fraction of grade KSK-2 silica gel. The sorption and the structural-geometrical properties of this specimen had been studied by the authors earlier and are given in [7].

In Fig.1 are shown curves of the moisture content in KSK-2 as a function of the sorption time in the presence of and without electric fields. According to the graphs, obviously, the application of a nonuniform electric field results in a higher rate of moisture transfer inside the colloidal material over the entire range of hygroscopic moisture levels. This becomes understandable if one considers that this particular silica gel contains rather long narrow pores and that, in order to reach the equilibrium level of moisture content, more time is necessary for the diffusion of adsorbed molecules through these pores. As is well known, dipolar molecules of water in a nonuniform electric field move always in the direction of the maximum intensity gradient. Therefore, a large intensity gradient toward the center of a specimen accelerates the diffusion of water vapor molecules inside the material. Obviously, an intensity gradient toward the periphery should retard the process of sorptive humidification.

One can also deduce from Fig.1 that the presence of a nonuniform electric field affects only the kinetics of water vapor sorption but not the maximum hygroscopic moisture level in a specimen. This is in agreement with the hypothesis by A. V. Lykov [1] concerning the relative effects of a nonuniform magnetic field on the kinetics of capillary adsorption.

The time necessary for a specimen to reach a definite moisture level is shown in Fig.2 as a function of the potential difference applied to the plates of the cylindrical capacitor. As the voltage across the plates is raised, according to the diagram, above a certain voltage level the time necessary to reach the given moisture level decreases linearly. This critical voltage is approximately 480 V. From this voltage level on, therefore, the presence of a nonuniform electric field begins to appreciably affect the internal moisture transport in the given colloidal material. It follows from the same diagram that the effect of an electric field on the time to reach a given moisture level is greater at higher initial moisture levels. Least affected by a nonuniform electric field is physicochemically bonded moisture, which again confirms the high energy of a such a bond to the skeleton of a capillary-porous material.

We have also plotted the kinetic characteristics of water sorption by the same specimen material in the presence of a uniform constant and a uniform alternating (f = 50 Hz) electric field with an intensity up to $2 \cdot 10^5$ V/m superposed. Here the test specimen was placed in the field of a plane circular capacitor whose plates were 0.2 m in diameter. Not even very careful measurements have revealed any significant differences between values in a uniform field and without a field, which means that the sorption kinetics were the same in both cases. The indication is that, under our test conditions, only a nonuniform electric field of even a very low intensity can affect the moisture transport in a colloidal material.

It must be emphasized here that, apparently, the rate of internal moisture transport is increased not only by the action of an electric field intensity gradient on dipolar molecules of water vapor but also by the effect of such a gradient on other polarized phases of the system, namely on the retained moisture and the capillary-porous skeleton. This has been demonstrated as follows. After the curve of sorption kinetics in a nonuniform constant field with a certain potential difference across the plates of the cylindrical capacitor had been plotted, the specimen was subjected to desorption by pumping it down to the original weight and the test was then repeated for 2 h without an electric field. The curves of sorption kinetics were almost identical in both cases, i.e., the specimen of silica gel which had been subjected to a nonuniform constant field behaved for some time as an "electret." Similar tests run for longer periods of time have shown that such a specimen gradually loses these properties.

Considering that industrial specimens of silica gel always contain various ionic impurities [8], one may assume that the acquisition of so-called "electret" properties by an amorphous specimen held for a long time in a nonuniform electric field has to do with the process of ion-relaxation (high-voltage, volume) polarization [9] in a capillary-porous material. In this case, evidently, one must conclude that the rate of internal moisture transfer is increased not only by the action of an electric field intensity gradient on dipolar water vapor molecules but also by its effect on the mobility of hydrated ions when the moisture content in the material is close to the maximum hygroscopic level. The displacement of ions which have been distorted by a nonuniform electric field [10] results in an accumulation of volume charges in the specimen, which then gradually vanish as a result of a reverse ion current and their entropic thermal motion after the field has been removed.

In a nonuniform electric field, of course, "rigid" dipoles of water vapor molecules should not be moving along the force lines.

According to Fig. 3, the sorption rate increases with the voltage and, consequently, with the nonuniformity of the cylindrical electric field in a specimen. In this case the relation $W(U)_\tau$ becomes a direct proportion. The longer the fixed sorption time is, the steeper becomes the $W(U)_\tau$ curve. At $\tau = 300$ min, then, $(\partial W/\partial U)_\tau$ becomes as high as 0.02 wt.%/V.

Note should be taken, in conclusion, of the closeness between the kinetics of water sorption by a specimen in a constant and in an alternating (f = 50 Hz) nonuniform electric field respectively. This leads one to conclude that such a frequency of the alternating field is still too low to influence the sorption process significantly.

Similar measurements were made with grade KSK-2 silica gel and carbon tetrachloride molecules, the dipole moment of the latter being equal to zero. Within test accuracy, we have not detected any effect of external nonuniform electric fields on the sorption kinetics.

NOTATION

f	is the frequency of the alternating field;
W	is the moisture content in the colloidal specimen;
U	is the potential difference across the plates of the cylindrical capacitor;
τ	is the sorption time;
φ	is the relative pressure of water vapor;
ε	is the dielectric permittivity of moist specimen.

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