INVESTIGATION INTO CAPILLARY EFFECTS IN A V-SHAPED SLIT

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The kinetics of the development of pressure generated by the action of the capillary forces between two disperse particles are investigated using a slit model of a capillary-porous body. The moisture vaporization mechanism is also studied.

The process of drying various capillary-porous bodies is characterized by a change in their structure and volume [1]. The internal stresses formed as a result of a drop in the internal pressures between zones with different moisture contents are generated in mixed macroscopic volumes of a material due to the nonuniformity of the volumetric changes taking place under the action of capillary contraction forces [2].

The development of the pressure generated by the action of the capillary forces between two disperse particles is investigated on a device permitting the construction of a slit model of a capillary-porous body from two horizontal plates, the joining surfaces of which form a dihedral angle. According to Churaev [3] this model is the best approximation of real systems characterized by a fixed distribution of pore dimensions or of the limiting radii of the curvature of the menisci formed in the pores during drying. In addition, the pressure inside the fluid held between two horizontal plates is determined by the relation

$$L_\sigma = 2\sigma\left(\frac{1}{a} - \frac{1}{b}\right),$$

which corresponds to the capillary pressure of the junction fluid [4].

The device for investigating capillary effects (Fig. 1) is installed on a vibration-proof base (1) and comprises a microthermostat (2) with a temperature regulator (TR), a read-out-measurement microscope (3), and plates (4) and (5) making up the capillary slit. The joining surfaces of the plates form a dihedral angle of 1° 24'. Plate (4) is made in the form of thin circular membrane rigidly restrained around the circumference. Plate (5) is fixed to the viewing hood (6) in which the microscope is installed. The viewing hood with the plate can be displaced in the plane perpendicular to the membrane surface, establishing the required width of the gap between the plates. The viewing hood is displaced by the mechanism (7). The slit width is measured by the spring-actuated contact comparator (8) of the Institute of Applied Geophysics 01 type.

The membrane is 0.17 ∓ 0.03 mm thick and 15 ∓ 0.01 mm in diameter and is made of glass with a modulus of elasticity of $E = 66{,}500$ MN/m^2 and a Poisson coefficient of $\gamma = 0.22$. The plate (5) is 40 mm thick and made of K-8 quartz glass. The unevenness of the surface in contact with the membrane is not greater than 0.07 μ.

The plates are in a microthermohygrostat in which a predetermined temperature t is maintained with an accuracy of 0.5°. The predetermined relative moisture content of the air φ is maintained by saturated solutions of salts placed in the tank (9).

The capillary pressure which develops in the slit is due to the deflection of the membrane, which is measured by a mechanotronic displacement transducer (10), the basic component of which is a 6MKhZS electron tube. The electrode current of this tube is varied by the mechanical displacement of its electrodes which are connected to the membrane. The sensitivity of the transducer to displacements in terms of current is not less than 100 μA/μ. The tube current is measured by a bridge circuit. The bridge is balanced in advance using an M 266M microammeter, and an R 33 resistance box is connected into one of the arms of the bridge for

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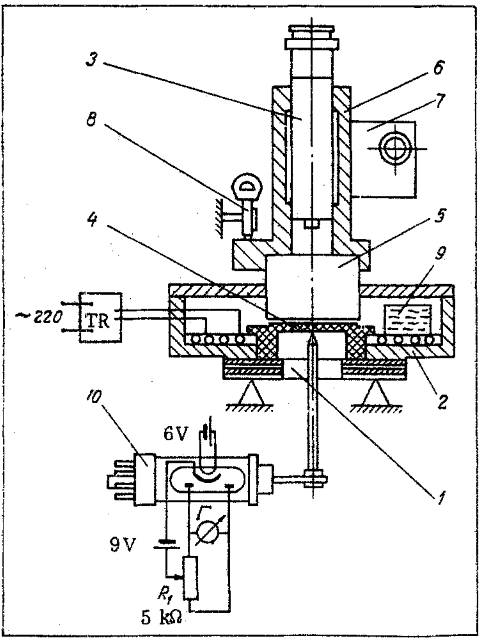

Fig. 1

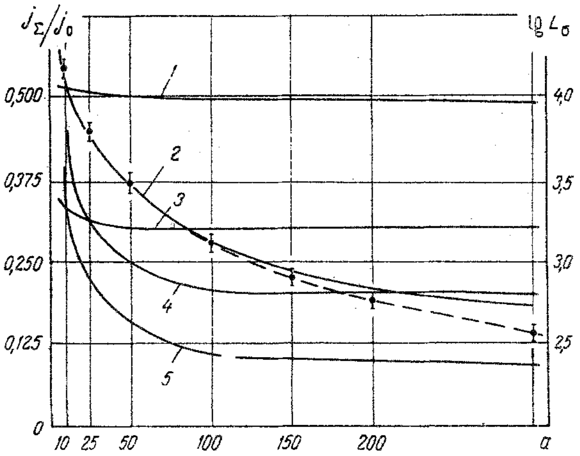

Fig. 2

Fig. 1. Line diagram of device for investigating capillary effects.

Fig. 2. Dependence of capillary pressure L_σ, N/m^2 (calculated values, solid line; experimental data, dashed line) and relative intensity of moisture vaporization from the slit model j_Σ/j_0 on width of gap between plates a, m.

accurate balancing. A reading of the deflection of the membrane is obtained from the scale of an M 195/1 zero-galvanometer with a current scale division of $9.2 \cdot 10^{-9}$ A/div. Sets of "Mars"-type galvanic elements are used as supply sources for the measurement circuit and the filament circuits of the mechanotron.

The magnitude of the capillary pressure is determined taking into account the fact that the pressure generated by the deflection of the membrane is distributed uniformly over the surface of a circle, the diameter of which is smaller than that of the membrane and the center of which does not coincide with that of the membrane. The calculations are based on the formulas obtained by Gershgorin [5] for determining the elastic surface of circular plates with rigidly held edges subject to nonsymmetrical circular loads. These formulas are defined more accurately by the present authors with reference to determining the capillary pressure in the slit model under investigation.

The capillary pressure for the case in which the center of the membrane is covered by the circle of load application is

$$L_\sigma = \frac{\frac{32}{3} \cdot \frac{E\delta^3}{b^2(1-\gamma^2)} W_{(0,0)}}{\left(2c^2 + \frac{b^2}{4}\right) \ln \frac{d^2}{4c^2} + \frac{d^2}{2} + 2c^2}. \tag{1}$$

The diameter and eccentricity of the drop relative to the membranes are determined through the optically transparent plate (5) by a microscope (3) with a scale division on the Huygen's eyepiece scale of 15 div./mm.

The device described is also used to study the mechanism for the vaporization of moisture from the slit model under various thermal and moisture conditions. The intensity of vaporization j_Σ is assessed from the change in one unit of time $\Delta\tau$ in the amount of bidistillate held in the slit $\rho\Delta V$, referred to the initial side surface of the crushed drop S without taking into account the curvature of the meniscus and the dihedral angle between the plates:

$$j_\Sigma = \frac{\rho \Delta V}{S \Delta\tau} = \frac{\rho (b_H^2 - b_K^2)}{4 b_H \Delta\tau}.$$

A glass vessel 19 ±0.001 mm in diameter and 5 mm deep is used to determine the intensity of moisture vaporization from the free surface j_0, which is a characteristic of the thermal and moisture conditions established in the thermostat chamber. The vessel with the fluid under investigation, degassed distilled water from a double distillation, is placed in the thermostat chamber. After stationary conditions are established in the chamber, the vessel with the water is weighed periodically on A-31 W microanalysis scales with a readout accuracy of 0.05 g. The intensity of vaporization from the free surface j_0 is assessed from the change in the amount of moisture being vaporized $\rho\Delta V_0$ relative to the vaporization surface S_0 over the period of time between two consecutive measurements, $\Delta\tau_0$.

The initial diameter of the drop crushed between the plates is 6.0-6.5 mm for all the experiments. The errors in the measurement of capillary pressure and in the measurement of moisture vaporization intensity, as calculated taking into account the law of summation of individual indirect measurement errors for all experiments, are less than 3.5 and 5.0%, respectively. The minimum necessary number of repetitions of the experiment, calculated by a generally accepted procedure [6], is six. The membrane deflection is not more than the units of the micrometer, so that the change in the membrane surface curvature during the experiment can be neglected.

Before each experiment the surfaces of the plates are washed carefully with acetone and ethyl alcohol. After drying the plates with purified warm air, the capillary slit is filled with water. The plate (5) (Fig. 1) is moved to the extreme top position for this purpose. A drop of water is applied to the surface of the membrane (it must be in the center!). Then by displacing the plate (5) and thus crushing the drop, the required slit width is established.

Figure 2 depicts the dependences of the relative intensity of vaporization j_Σ/j_0 and the capillary pressure L_σ on the width of the slit a. As follows from the results obtained, with a width of $< 100\ \mu$ for the gap between the plates the theoretical and experimental values of the capillary pressure coincide with an accuracy falling within the limits of measurement error. When $a > 100\ \mu$, a certain discrepancy between the calculated values of the capillary pressure and the experimental data is observed. The intensity of moisture vaporization is also dependent on the slit width and grows when the temperature of the environment rises and the slit width and relative moisture content of the air φ fall.

The results obtained can be explained as follows. As the gap between the plates increases, the correlation between the forces acting within the fluid changes and an increase is then noted in the contribution of the forces of gravity to the overall balance of forces. This redistribution of the forces causes a change in the curvature of the meniscus, which gives rise to an increase in the diameter of the membrane surface wetting spot. Since the pressure L_σ, as determined by formula (1), is dependent on the square of the diameter of the spot of fluid on the membrane surface, even small changes in the curvature of the meniscus give rise to a discrepancy between the experimental and theoretical results when $a > 100\ \mu$.

The nature of the change in the relative intensity of vaporization j_Σ/j_0 is attributable to the fact that for a capillary model with a slit width of $> 100\ \mu$ the bulk of the moisture is transferred by diffusive flow at virtually any φ values. The first circumstance is related to the growth in the thickness of the adsorption film h and to the increase in its conducting capacity and the second is related to the increase in the ratio of the adsorption film thickness to the double curvature of the meniscus which governs the degree of participation of pellicular transfer. It should also be noted that the change in the intensity of moisture vaporization from the slit j_Σ, which is related to the width of the gap between the plates, is caused by the disequilibrium of the processes of moisture vaporization from the slit, vapor condensation, and moisture absorption by the solutions of salts which take place simultaneously in the thermohygrostat chamber.

No change is revealed in the intensity of vaporization from the capillary slit which is dependent on the position of the drop of fluid relative to the membrane center with equal widths for the gap between the plates. This is due to the fact that the initial volume of the drop is considerably greater than the change in its volume caused by the vaporization and in addition the experiments are terminated when the drop volume is reduced to 20-25% of the original volume. For the same reason and also because the drop is located only at the center of the membrane, no change is revealed in the intensity of vaporization due to the change in the distance from the mouth of the capillary slit to the meniscus.

Thus, the results of an investigation into the process of moisture vaporization from the capillary slit show that the contribution of pellicular flow becomes perceptible when the width of the gap between the plates $< 100\ \mu$ and $\varphi > 50\%$. This is in good agreement with the theoretical conclusions drawn in [7, 8].

By transforming the results obtained to the processes of structuring capillary-porous materials, it can be concluded that the magnitude of the internal pressure developing during the vaporization of moisture from these materials is dependent on the mobility of the disperse particles (i.e., on the degree of dispersion and, consequently, on the coefficient of shrinkage) and, to a lesser extent, on the intensity of moisture vaporization from the material.

NOTATION

L_σ, capillary (Laplace) pressure, N/m^2; σ, surface tension, N/m; a, width of gap between plates, m; b, diameter of fluid drop held between plates, m; E, modulus of elasticity of membrane material, N/m^2; γ, Poisson coefficient of membrane material; t, temperature in thermohygrostat chamber, °C; φ, relative moisture content of air, %; δ, membrane thickness, m; $W_{(0,0)}$, deflection of center of membrane, m; c, eccentricity of fluid drop relative to membrane, m; d, diameter of membrane, m; j_Σ, intensity of moisture vaporization from slit, kg/m$^2\cdot$sec; ΔV, increase in drop volume, m^3; S, surface of vaporization of moisture from slit, m^2; τ, duration of process, sec; j_0, intensity of vaporization from free surface of water, kg/m$^2\cdot$sec; S_0, vaporization surface, m^2.

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FORMATION ON SOLID SURFACES OF A GAS MONOLAYER PROVIDING PROTECTION AGAINST FRICTION IN RAREFIED MEDIA

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The dynamics of formation of a monomolecular gas layer on an exposed surface are analyzed on the basis of a solution of the kinetic adsorption equation, with allowance for adsorption, desorption, and the migration of molecules to the free parts of the surface under equilibrium external conditions.

It is known [2, 3] that gas films adsorbed on the surface of rubbing bodies have an important influence on the variation of the friction and wear characteristics. This effect is especially significant in connection with studies of friction processes in a high vacuum, where the use of liquid lubricants and greases is impossible owing to their evaporability. Adsorbed gas films protect the surfaces from "juvenile" contact, thus reducing

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