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INFLUENCE OF VIBRATION ON HEAT AND MASS TRANSFER IN A CAPILLARY-POROUS MATERIAL

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This paper presents the results of an experimental study of the influence of vibration (frequency from 20 to 60 cps, double amplitude from 1.1 to 3.6 mm) on the rate of drying of capillary-porous material, and on the motion of moisture in a single capillary vibrating at a frequency of from 10 to 80 cps.

The chief parameters of vibrations that affect heat and mass transfer processes are amplitude and frequency. The quantitative results obtained by a number of authors on the effects of vibration differ, inasmuch as it is possible to have numerous combinations of the parameters of the vibration process with the hydrodynamic flow conditions, the physical properties of the medium, and, for heat and mass transfer, with the physicochemical properties of the material, its structure, etc. Explanations of the vibration effect are extremely contradictory. Lemlikha [1], for example, postulates the presence near a vibrating wire of a "closed boundary layer," whose thickness decreases with increasing amplitude and frequency. Most probably, the vibration causes a change in flow and complex eddies in the boundary layer [2]. The large acceleration and deceleration to which the solid is subjected during vibration must influence not only the external heat and mass transfer due to turbulence and vortex formation, but also the internal transfer.

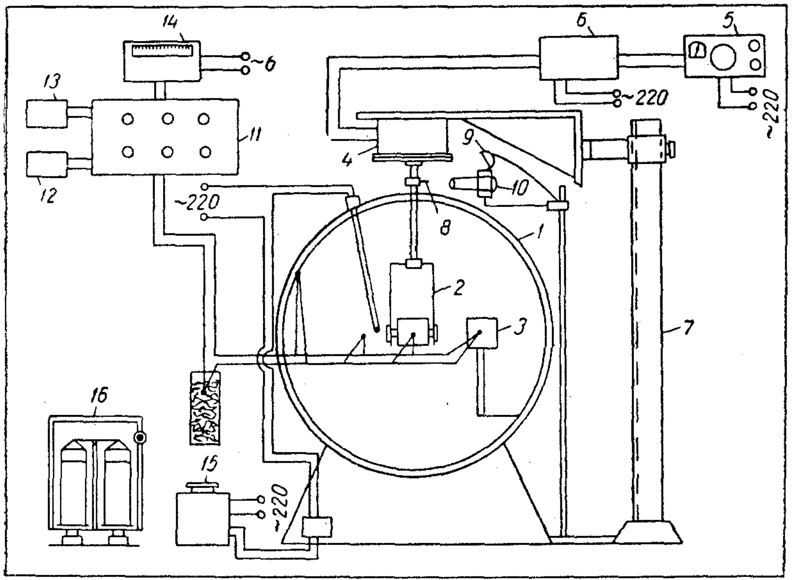

Fig. 1. Diagram of experimental apparatus: 1) drying chamber; 2) holder with specimen; 3) control specimen; 4) electrodynamic vibrator; 5) audiofrequency generator; 6) amplifier; 7) stand; 8) needle; 9) illuminator; 10) telescope; 11) potentiometer; 12) storage battery; 13) standard cell; 14) mirror galvanometer; 15) laboratory autotransformer; 16) ADV-200 balance.

We carried out an experimental study of the influence of vibration on the rate of drying of moist capillary-porous material and the movement of moisture in a single capillary. For this purpose we used a 20-W electrodynamic vibrator connected to an audiofrequency generator across an amplifier (Fig. 1). The amplitude of the vibrations was set by varying the power supplied to the vibrator coil. The double amplitude was registered by the movement of the illuminated tip of a needle attached to the specimen holder outside the drying chamber and observed by means of a telescope with an ocular scale. This arrangement could even be used to measure small amplitudes (of the order of a fraction of a millimeter). The holder, coupled with the vibrator, entered the drying chamber with a relay temperature regulator. To the end of the holder a capsule containing the test material was fixed. Silica gel powder was used as test material, after first being separated into three fractions: 3–1 mm, 0.5–0.25 mm, and less than 0.25 mm, and moistened with water (layer thickness about 20 mm). The region of constant drying rate was studied.

The following quantities were measured in the experiments: the amount of water evaporating every 15 min, by weighing on an analytical balance, the temperature and humidity of the air, the temperature of the material and drying chamber walls, frequency of vibration and double amplitude. The temperature was measured by copper-constantan thermocouples in series with a potentiometer and mirror galvanometer. In the experiments the vibration frequency was varied from 20 to 60 cps and the double amplitude from 1.1 to 3.6 mm. Apart from the vibrating capsule, a stationary control capsule containing silica gel was also examined.

The drying curves (Fig. 2) indicate that vibration intensifies the drying process, a greater influence being exerted by an increase in amplitude. The maximum increase in drying rate is observed with silica gel of the fraction 0.5–0.25 mm, the least for the fraction less than 0.25 mm. This is because the moist powder consisting of fine particles is so compacted on vibration that the insignificant increase which occurs can be referred only to the action of the external perturbations of the vapor–air medium in the layer adjacent to the surface of the material. During the drying of a coarser silica gel, as a result of vibration the particles develop a to-and-fro motion, the bed is loosened up, and the drying rate increases, as may be seen from the table.

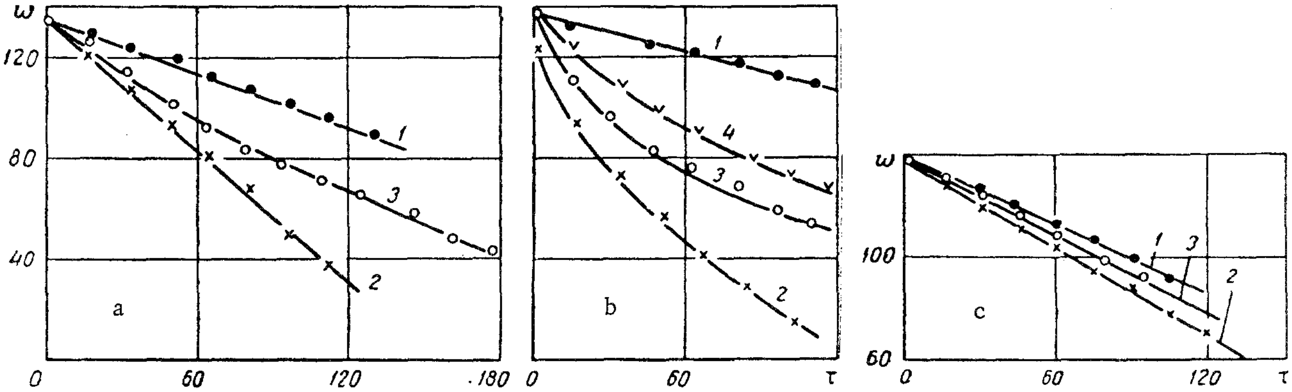

Fig. 2. Drying curves for silica gel: a) particles 3–1 mm [1) $f = 0$; 2) $f = 30$ cps, $2a = 3.58$ mm; 3) 40, 1.43]; b) particles 0.5–0.25 mm [1) $f = 0$; 2) $f = 30$ cps, $2a = 3.94$ mm; 3) 40, 1.43; 4) 50, 1.25]; c) particles less than 0.25 mm [1) $f = 0$; 2) $f = 30$ cps, $2a = 3.58$ mm; 3) 50, 1.1].

Evaporation of Moisture from Silica Gel
(ambient temperature 68–70° C, φ = 25–27%)

f, cps	Double amplitude $2a$, mm	Initial moisture content of material, dry weight · · 100, w, %	Evaporation rate kg/m² · hr	
			Test specimen	Control
		Particle size 3–1 mm		
30	3.58	134.5	2.590	0.845
40	1.43	136.0	1.524	0.720
		Particle size 0.5–0.25 mm		
30	3.58	121.5	3.600	0.550
40	1.43	136.0	1.690	0.690
50	1.25	137.0	1.320	0.680
		Particle size less than 0.25 mm		
20	3.58	133.5	1.080	1.025
30	3.58	139.5	1.220	1.060
40	1.78	126.0	1.030	0.860
50	1.10	160.0	1.250	1.110

In order to study the internal moisture transfer in the material under the action of vibration, experiments were carried out with single capillaries. In these experiments capillaries of diameter 0.350, 0.574, and 0.848 mm (length 160 mm) were clamped successively in a vertical position by means of a holder connected with a vibrator. After being filled with water, the capillary was set in vertical reciprocating motion at a frequency of from 10 to 80 cps, controlled by an audiofrequency generator. The initial height reached by the water and the height of the water column remaining in the capillary after five minutes vibration were measured.

Figure 3 shows that the frequency is not uniquely determined by Δh (difference between initial and final water levels in the capillary). The curve has a region of maximum Δh; at large amplitudes (5–6 mm) and frequencies 30–40 cps water is either completely expelled from the capillary or broken up into beads separated by air. This relates to a capillary 0.350 mm in diameter. In the capillaries of larger diameter only an insignificant reduction in water level was observed at frequencies of 30–40 cps. Expulsion of water from the small-diameter capillary is apparently due to the fact that the natural frequency of the liquid column in it is close to the frequency of the forced oscillations; at the same time, the natural frequency of the liquid column in the large-diameter capillary is less than the forced frequency. In this case the alternating inertia forces are insufficient to weaken the surface film. It may be assumed that if the frequency of the forced vibrations approaches the natural vibrational frequency of the molecules, then the molecular bonds between the water and the material will be affected.

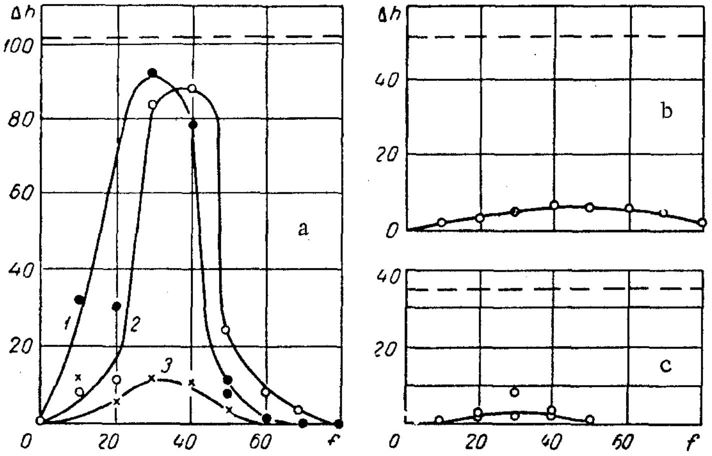

Fig. 3. Change of Δh with frequency: a) capillary diameter 0.350 mm [1) V on acoustic generator 30V; 2) 26.6; 3) 3 V]; b) capillary diameter 0.574 mm; V = 30V; c) capillary diameter 0.848 mm; V = 30V (height of lift of water for each capillary shown by dashed line).

Thus, vibration affects not only the external heat and mass transfer but also the transfer of moisture inside the material. It has been established that vibration influences the drying rate of disperse materials with different particle sizes in different ways. In our experiments we also confirmed that the effect of amplitude at constant frequency exceeds the effect of frequency at constant amplitude [1].

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