KINETICS OF ACOUSTIC DRYING OF CAPILLARY-POROUS MATERIALS

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Investigations have been made of the drying of quartz sand and specimens of foam polyurethane in an acoustic field. The layerwise distribution of moisture and temperature during elimination of moisture is given.

The recent literature contains a number of articles on the acoustic method of drying, which is considered promising for heat-sensitive, easily-oxidized, and hard-to-dry materials [1–4]. The authors of these articles present data showing that the acoustic method accelerates drying and lowers the final moisture content without appreciably increasing the temperature of the material. The actual mechanism of acoustic drying is not yet clear, however.

An experimental equipment with a gas-jet type GSI-4 radiator [5] has been used to investigate the kinetics of moisture transfer in acoustic drying. The capillary-porous material tested was quartz sand with saturated weight of $1.736 \cdot 10^3$ kg/m^3; grains 0.355–1 mm in size made up most of the mass (88.3%). Sand with a moisture content of 0.164 kg/kg was packed into a plastic cylinder (internal diameter 60 mm). The specimen, 32 mm in height, was subjected to acoustic vibration at various sound pressure levels (158, 163, and 167 dB) for a definite time. Then the device was withdrawn from the equipment, and the sand sampled in layers for moisture content, for which purpose the specimen was pushed out of the cylinder by a piston and divided into eight parts.

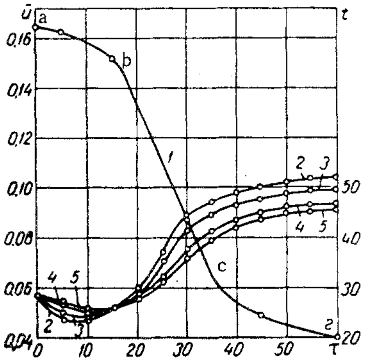

Fig. 1. Distribution curves of moisture content $\bar{u}$, kg/kg, over depth of sand layer b, mm, at a sound pressure level j = 167 dB (the compressed air pressure was $P = 2.16 \cdot 10^5$ N/m^2, the frequency f = 7 kc/s): 1) duration of drying $\tau = 5$ min; 2–15; 3–30; 4–60.

The initial moisture content of the sand was found by statistical analysis. The moisture content of the cut layers was determined by weighing. The tests were duplicated, and it was considered satisfactory if the divergence in moisture content readings for parallel samples did not exceed 1.0%.

As well as the moisture content in the layers, the temperature of the material was also measured using copper-constantan thermocouples embedded in the specimen and a type EPP-09 potentiometric recorder.

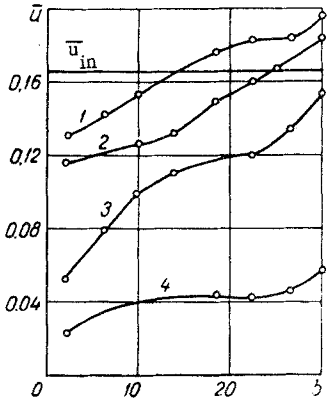

Fig. 2. Curves of drying (1) and temperature field (2) for sand ($\bar{u}$ in kg/kg, t in °C, τ in min) in different layers of the specimen (2) 6 mm from the specimen surface; 3) 14; 4) 22; 5) 30.

Since the tests were conducted at acoustic frequencies (7–15 kc/s), all the equipment was located in a special soundproof chamber. In the tests the air blown through the emitter was extracted through lateral holes in the reflector in such a way that the specimen surface was exposed only to acoustic waves.

In the first stage of drying, elimination of moisture from the specimen took place slowly (e.g., during the first 5 min the moisture content changed only from 0.164 to 0.162 kg/kg). It should be noted that here the water, under the influence of gravity (Fig. 1), is redistributed over the specimen height; the lower layers acquire greater humidity. Subsequently, the drying rate increases, and the slope of the moisture content curve changes, indicating that moisture is diffusing from the lower layers to the upper, whence it evaporates.

It may be seen from Fig. 2 that the drying curve consists of three sections: ab—a period of increasing, bc—a period of constant, and cd—a period of falling drying rate. We obtained the gently sloping section ab at high acoustic energy density (167 dB) only for comparatively thick specimens (in our case 32 mm); for thinner specimens (e.g., 10 mm) this section was absent.

The temperature curves in four layers of the sand specimen are also shown in Fig. 2. The results indicate that a temperature drop in the first stage of drying is characteristic of the acoustic method, the temperature gradient here being 2 deg/cm. At the end of the first stage the temperature becomes equal at all points of the specimen. Later temperature gradient changes direction and reaches 3–5 deg/cm.

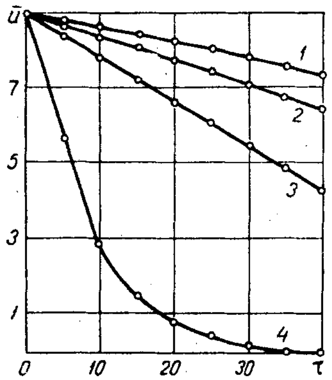

Fig. 3. Curves of acoustic drying of a specimen of foam polyurethane at various field intensities: 1) 155 dB; 2) 165; 3) 167; 4) 169.

The first test material used was foam polyurethane, which has a high moisture absorption coefficient (up to 800%). The volume weight of the specimen corresponded to 40 kg/m^3; the porosity was 63.2% open pores; the mean pore diameter was 0.4 mm. The specimen diameter was 140 mm at thickness 15 mm.

Drying was done at sound pressure levels of 155, 165, 167, and 169 dB. The results of the tests are shown in Fig. 3.

Examination of the curves shows that the intensity of irradiation has a substantial influence on the drying rate. Thus, while 40 min is required at 167 dB to halve the moisture content (from 9 to 4.5 kg/kg), only 7 min is required at 169dB, i.e., a factor of 5.7 less.

It should be stressed here that the mechanism of moisture removal at sufficiently high moisture content and a definite intensity is not limited only by evaporation of moisture; mechanical removal also plays an appreciable part. At high enough sound energy levels (J = 169 dB) intense separation of moisture drops from the specimen is observed during the initial drying phase.

Since the investigations were carried out in an acoustic field which was nearly diffuse, the location of the specimen relative to the emitter had no appreciable significance. Drying of the specimen for 10 min from an initial moisture content of 8.9 kg/kg with horizontal arrangement of the material reduced the moisture content to 4.0 kg/kg, and with vertical arrangement to 4.3–4.4 kg/kg, i.e., the difference is only 7–10% in favor of a horizontal arrangement.

The tests conducted with the capillary-porous materials used give grounds for considering that the acoustic method allows drying to be accelerated several times in comparison with other methods, and simultaneously reduces the temperature of the material being treated. At the same time, some increase of temperature of the material (arising from absorption of acoustic energy) is observed at high acoustic field intensities, and this probably leads to additional increase in drying rate.

The intense mechanical removal of moisture observed at high levels of acoustic field and material moisture content leads us to suppose that this mechanism occurs in all cases of acoustic drying in the initial stage of the period of constant drying rate.

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