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SOME PROPERTIES OF A VIBRATING FLUIDIZED BED

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The effect of vibration on loose materials and conductive drying in a vibro-fluidized bed is investigated.

In a whole series of papers by Soviet and foreign authors, it has been shown that vibration has an appreciable influence on the structure of a fluidized bed [1, 2, 3]. Many processes and reactions, however, do not require gas to be blown through the material. In this case the vibrating action is a qualitatively new factor with an independent effect on the properties of the bed of disperse material. In particular, such processes include a proposed method of contact drying of granulated sugar on a heated vibrating surface [4].

An examination of the laws of variation of internal friction, bed porosity, and the aerodynamic properties and motion of the particles shows that a layer of material located on a vibrating surface has two states: vibro-fluidization and vibro-boiling [5].

These two states also correspond to two ways of applying the vibration. Vibro-fluidization is used in vibro-compaction and vibro-stamping, vibro-boiling for intense mixing and increasing bed porisity [6, 7].

The increase of bed porosity due to the separation of the particles in the vibro-boiling state has been shown in special tests to depend both on the frequency and on the amplitude of vibration (Fig. 1). The lower the frequency of oscillation of the surface, the greater the bed porosity that can be created at identical accelerations.

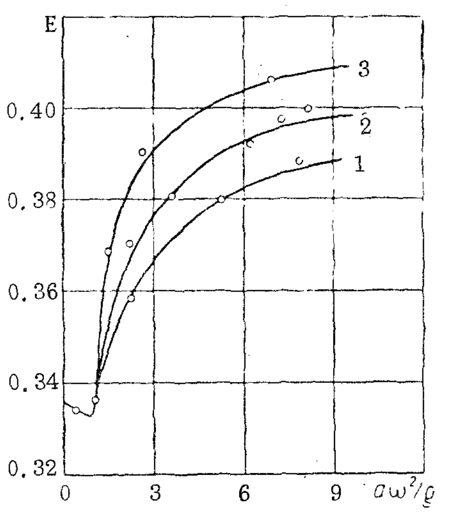

Fig. 1. Variation of porosity of a vibro-boiling bed of quartz sand with acceleration of the vibrating surface: 1) f = 60 cps; 2) 50; 3) 40.

An excellent illustration of the existence of two states of a loose material subjected to vibration in the vertical direction is the change in pressure losses when gas or air is blown through the material. The point of transition from vibro-fluidization to vibro-boiling is characterized by maximum compaction of the material and maximum pressure losses in the bed (Fig. 2). In the vibro-boiling state, in spite of the sharp decrease in friction between particles, the vibration causes not compaction, but an increase in the porosity of the bed and correspondingly reduced pressure losses. The change in pressure losses depends on the frequency and amplitude of vibration of the surface, but the transition point for a bed of air-dried loose material lying freely on a vibrosurface always corresponds to the acceleration g. As the authors have shown, increase of the vibration parameters leads to a point at which the pressure losses in the bed may not only become equal to zero, but even change sign, assuming negative values.

The phenomenon of formation of a static air pressure differential in the vibro-boiling bed depends on the frequency and amplitude of vibration of the surface, the dimensions and gas permeability of the bed, the size of the particles, the moisture content of the loose material, and the self-friction of the particles [8].

The air currents in the bed due to the formation of a pressure differential entrain the separated particles and cause "spouting" of the material. Special experimental investigations on air-dried quartz sand in a flat-bottomed cylindrical glass vessel 60 mm in diameter, fastened to a vibrating table, showed that the characteristic particle motion is a vertical oscillation when the vibration is applied in vacuum, all other conditions being equal. The different amplitudes of motion of the individual particles lead to a gradual passage of material from one layer to another. When a gas is present in the reactor, the "spouting" motion involves the whole volume of material and particle migration proceeds considerably more briskly.

Therefore, "spouting" in a vibro-boiling bed with vertical oscillation of the surface is determined not by the direct vibrating action, but by the motion of the gas or air due to the pressure differential formed in the bed of loose material.

The formation of a pressure differential, which determines the nature and intensity of particle motion, has a considerable influence on the course of technological processes taking place in a vibro-boiling bed. It has a special influence on the drying of loose material by the conduction method. When moist material is in direct contact with a heated horizontal vibrating surface whose temperature exceeds 100° C, two interrelated processes occur simultaneously. The main process is a change in the stage of aggregation of the moisture, accompanied by absorption of the heat of phase transformation and its transport by vapor to the free surface of the material. When the water vaporizes, its volume increases sharply, causing an increase of pressure under the bed. Second, and no less important, there is conductive heat transfer between the heated surface and the loose material, which is complicated by transfer of heat by the particles themselves as they are agitated in the vibro-boiling bed. The formation of a pressure drop in the bed has a quantitative and qualitative influence on the heat and mass transfer processes: it determines the intensity of particle motion, and also tends to dissipate the resulting partial pressures. An investigation of the drying of quartz sand by the conduction method in a vibro-boiling bed, including simultaneous measurement of the pressure under the bed, showed that the optimal vibration parameters create an underpressure under the bed, which is superimposed on the pressure of phase transformation. The vibro-boiling bed acts like a pump, drawing the vapor formed out of the boundary layer, carrying it to the surface, and expelling it into the gas volume above the bed. At low vibration levels and high initial moisture contents, a positive pressure first develops under the bed; this gradually decreases and then becomes negative. The positive over-all pressure gradient results from the hydraulic resistance of the bed of capillary-porous material, the rate of vapor formation exceeding its rate of transport to the surface [9]. The pressure under the bed is continuously restored due to mass transfer, while, at low vibration levels and high moisture contents, the underpressure does not bring about rapid and complete pressure relaxation.

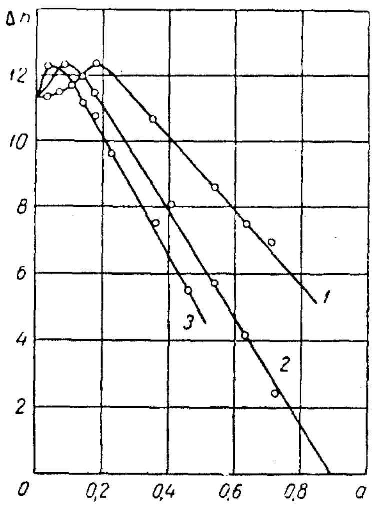

Fig. 2. Pressure drop in a vibro-boiling bed as a function of vibration amplitude with air blown upwards through the bed at a mean effective velocity of 0.016 m/sec: quartz sand of diameter 0.210–0.355 mm, bed thickness 4 cm; 1–3) see Fig. 1.

Investigation of the influence of the vibration parameters on the drying of quartz sand in a vibro-boiling bed has shown that, in the steady-state period, the drying rate increases with vibration frequency. For a quartz sand layer 3 cm thick and a vibration amplitude of 1.0 mm, a change of frequency from 40 to 70 cps (corresponding to acceleration from 6.9 to 19.8 g) increased the drying rate by a factor of 1.3. However, increase of vibration frequency does not cause an appreciable increase in the rate of mixing of the moist material, which increases the duration of the initial drying period. Increase of vibration amplitude causes a much greater change in drying rate in the first period, a reduced heating time, and also reduced periods of diminishing drying rate. For a layer of quartz sand 3 cm thick, change of amplitude from 0.5 to 2.5 mm at a frequency of 40 cps (corresponding to acceleration from 3.2 to 16 g) increased the drying rate in the steady-state period by a factor of 1.6. Moreover, the duration of the process was reduced because of a change in the heating period. At a heater temperature of 250° C, a frequency of 40 cps, and an amplitude of 2.5 mm, the rate of drying of quartz sand exceeds 600 $H/m^2 \cdot hr$. Increasing the thickness to 7 cm did not affect the drying rate. This not only makes it possible to use the conduction drying method for thin materials (cloth, paper, cellulose), but considerably extends the possibility of employing it on substantial layers of loose material in a vibro-boiling bed. The dependence of drying rate on amplitude, frequency, and acceleration is linear [10]. An attempt to generalize the test data and reduce them to a single function of the vibration parameters did not give a positive result.

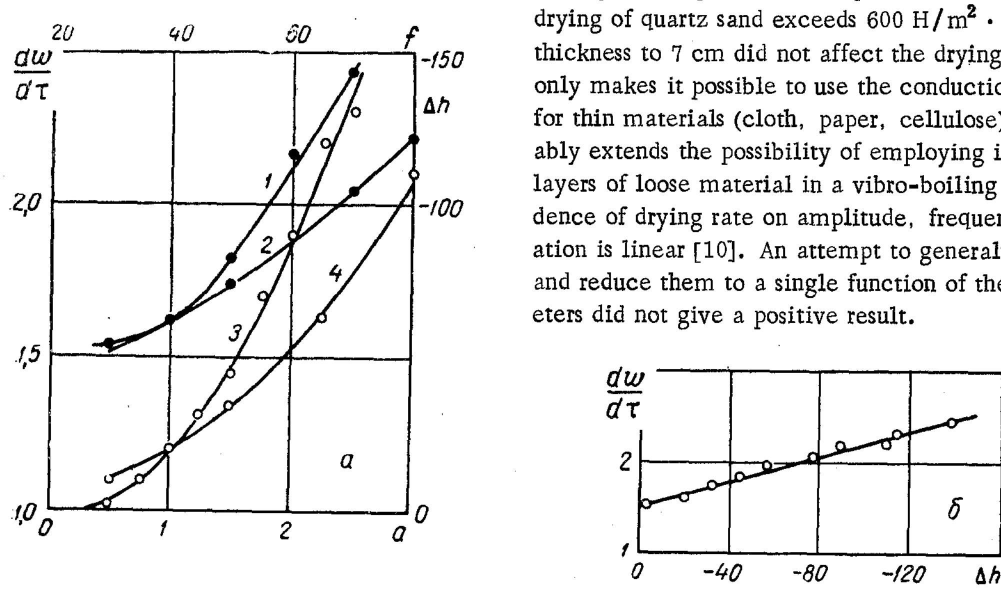

Fig. 3. a) Variation of drying rate $dw/d\tau$ (%/min) in the steady-state period (1) with amplitude of vibration; 2) with frequency), and of underpressure beneath vibro-boiling bed, N/m^2; (3) with vibration amplitude; 4) with frequency); and b) dependence of drying rate on underpressure beneath vibro-boiling bed.

Therefore, using the analogy with heat and mass transfer phenomena in contact drying under steady conditions [11], we may assume that in contact drying of loose materials at heated surface temperatures above 100° C, the molar mass flow density is directly proportional to the over-all pressure gradient developed in the vibro-boiling bed. However, measurements of the positive pressure and underpressure during drying show considerable scatter, which is connected with phase transformation of moisture in the boundary layer. Conversion of all the liquid in the contact layer into vapor does not take place immediately, but gradually at a varying rate, depending on the rate of phase transformation. Therefore, the dependence of the over-all pressure head in the material on the vibration parameters is mainly determined by the pressure differential effect in the vibro-boiling bed.

This makes it unnecessary to create optimal drying conditions directly each time the vibration parameters are determined, and enables the pressure differentials to be measured in a vibro-boiling bed without the equipment being heated. If maximum underpressure beneath the vibro-boiling bed is obtained by a correct choice of frequency and the required vibration amplitude, the best conditions for carrying vapor away from the contact surface should be assured. This in turn gives the optimal drying conditions from the point of view of a correct choice of vibration parameters.

The assumption was checked by a series of tests. The experimental data were used to construct drying curves, from which the rate in the first period and the dependence of underpressure beneath the vibro-boiling bed on the vibration parameters were determined. In determining the pressure differential, the quartz sand moisture content was taken to be the average for the steady drying rate period. The underpressure was measured without heating the equipment.

The data obtained in this way were combined into a general graph of variation of drying rate in the steady-rate period and underpressure as functions of vibration frequency and amplitude (Fig. 3a).

This graph shows the over-all nature of the variation of the parameters mentioned. The drying rate in the steady-state period as a function of the underpressure beneath a vibro-boiling bed of quartz sand is linear over a wide range of vibration frequencies and amplitudes (Fig. 3b). The data encompass the following ranges: frequency 40–80 cps, vibration amplitude 0.5–2.5 mm, and acceleration 3.2–39.5 g. For any vibration parameters, the larger the absolute value of the underpressure beneath the vibro-boiling bed created by the action of vibration on the loose material, the greater the drying rate in the steady-state period. This fully confirms the assumption made above.

Therefore, the main driving force of molar vapor transfer in drying by the conduction method on a vibrating heated surface (in addition to the mass transfer due to temperature and humidity gradients) is the pressure differential developed in the vibro-boiling bed.

NOTATION

a—vibration amplitude; f—vibration frequency; ω—angular frequency; ε—porosity of bed; g—acceleration due to gravity; Δh—gas pressure head; w—moisture content of material; τ—time.

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