KINETIC CALCULATION OF HEATING OF A MOIST DISPERSE MATERIAL IN A VIBRO-FLUIDIZED BED WITH CONDUCTIVE HEAT SUPPLY

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A method is proposed for an approximate analytic calculation of the heating kinetics of a moist disperse material in a vibro-fluidized bed with conductive heat supply.

In the dehydration of certain disperse, thermally unstable materials, one of the most effective methods is drying in a vibro-fluidized bed with a conductive heat supply. In equipment of this type, fluidization of the bed of disperse material may be accomplished through vibration of the heating surface—the bottom of the working chamber. Then the material being dried experiences periodic disturbances due to the harmonic motion of the heating surface, is intensely mixed, uniformly heated throughout its whole mass, and moved from the loading point to the point of discharge of the end-product.

At the Moscow Technological Institute of the Food Industry, experimental and theoretical investigations have been conducted into the drying of a moist disperse material in a vibro-fluidized bed. The material chosen for drying was crystalline granular sugar containing mainly surface moisture, which is usually removed in the constant rate stage.

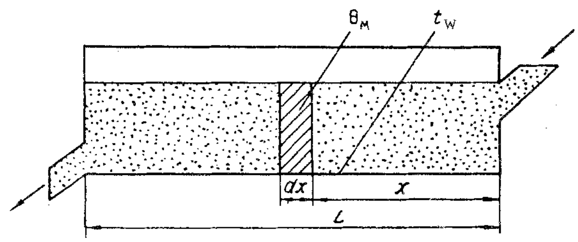
The experimental results indicate that this method of drying allows the process to be considerably intensified, while fully retaining the quality of the thermally unstable material. The intensity of heat and mass transfer in a vibro-fluidized bed is determined by the temperature of the heating surface, the properties of the disperse material, and the vibration regime, i.e., the frequency and amplitude of the oscillations of the system.

It is known that in drying thermally unstable materials, the variation and the absolute value of the temperature are amongst the most important factors influencing the quality of the end-product. The present paper attempts an analytic investigation of the heating kinetics of the material, applicable to the stage of constant drying rate, with the object of obtaining a design relationship based on the established laws of drying of a moist disperse material in a vibro-fluidized bed.

In deriving the calculation equations the following assumptions were made:

1. The temperature of the material being dried in the section of the chamber under examination (see figure) is assumed to be constant at a given instant of time over the height of the vibro-fluidized bed. This assumption ensures an optimum hydrodynamic regime of vibro-fluidization with intense mixing of the particles in the bed.

2. Zero-gradient heating of the particles is assumed. This assumption with regard to heat transfer in the fluidized bed may be considered permissible for values of the Biot number less than unity (Bi < 1).



Calculation scheme for equipment with vibro-fluidized bed.

3. The effective heat transfer coefficient in the system studied, referred to the heat-emitting contact surface, is assumed to be constant. We note that the value of effective heat transfer coefficient takes into account both heat transfer from the heating surface (see figure), and heat transfer between particles in the bed.

4. The temperature of the heating surface over the entire area of the equipment is assumed to be invariant and equal to t_W.

5. The heat losses to the external medium are assumed to be negligibly small.

As a result of these assumptions, we have, for a volume element of a vibro-fluidized bed of moist disperse material of length dx

$$\alpha_{\text{eff}} F_{\text{sp}} (t_W - \Theta_м)\, dx = G_м C_м d\Theta_м + \frac{G_м r}{100+W_1}\, dW. \qquad (1)$$

The length of the elementary segment dx of the apparatus in the direction of motion of the material may be represented as follows:

$$dx = v_м d\tau. \qquad (2)$$

Substituting (2) into (1), after certain transformations we have

$$\frac{d\Theta_м}{d\tau} - \frac{\alpha_{\text{eff}} F_{\text{sp}} v_м}{G_м C_м}(t_W - \Theta_м) = -\frac{dW}{d\tau}\,\frac{r}{C_м(100+W_2)}. \qquad (3)$$

In the stage of constant drying rate, $(dW)/(d\tau) = N = \text{const}$. We put

$$-Nr/C_м(100+W_1) = A, \qquad (4)$$

$$\alpha_{\text{eff}} F_{\text{sp}} v_м / G_м C_м = B. \qquad (5)$$

From (3), taking (4) and (5) into account, we have

$$d\tau = d\Theta_{M}/[A + B(t_{\omega} - \Theta_{M})]. \qquad (6)$$

Integrating (6) over the appropriate limits, we obtain the following expression for calculating the heating kinetics of the moist material:

$$\tau = \frac{1}{B} \ln \frac{A + B(t_{\omega} - \Theta_{M}^{i})}{A + B(t_{\omega} - \Theta_{M})}. \qquad (7)$$

The temperature of the material being transported over the vibrating heating surface at any instant of time is

$$\Theta_{M} = t_{\omega} + A/B - B^{-1}[A + B(t_{\omega} - \Theta_{M}^{i})]\, e^{-\tau B}. \qquad (8)$$

It may be seen that Eq. (8) takes into account the main factors mentioned above as determining the heating kinetics of a moist disperse material undergoing drying in a vibro-fluidized bed.

The results of the experimental investigation indicate sufficiently good agreement between the test data and the theoretical data calculated from Eq. (8).

NOTATION

α_{eff}—effective heat transfer coefficient, referred to contact area of heating surface; F_{sp}—specific area of contact surface, referred to unit length of apparatus; N—rate of drying in constant rate stage; G_M—capacity of drying equipment; r—specific heat of vaporization; τ—time; v_M—rate of transport of material along heat transfer surface; C_M—heat capacity of material; Θ_M, Θ_M^i—ambient and initial temperature of material, respectively; W_i—initial moisture content material; t_w—temperature of heating surface.

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