HEAT TRANSFER BETWEEN A FLUIDIZED BED AND A PLATE DURING DRYING

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Experimental data is given for the heat transfer between a fluidized bed and a plate during drying. Criterial equations are given for the calculation of the heat-transfer coefficient.

In recent years, the use of a fluidized bed of fine-grained material as an intermediate heat-transfer agent in the drying of various items has been finding increasingly broader application [1-3]. However, the choice of optimum parameters for the drying mode is hindered by insufficient study of this process. One such little-studied process is the heat transfer between a fluidized bed and a moist plate.

We made an attempt to study the effect of various factors (velocity of fluidizing agent, temperature of the bed, diameter of the particles of fine-grained material, size of the plate) on heat transfer from a fluidized bed to a moist plate and to obtain relations on the basis of the experimental study which would make it possible to calculate the heat transfer between a fluidized bed and a moist plate during drying.

The heat-transfer experiments were performed on the laboratory device described in [4]. The main unit of the device is a cylindrical drying chamber 270 mm in diameter and 900 mm high. A gas-distribution grid of the cap type was installed in the lower portion of the chamber. The air needed for drying and for producing the required hydrodynamic regime was sent into a heater and then directed into the drying chamber.

Test samples were prepared from a thermal insulating material – sovelite – in plate form 120, 170, and 250 mm long, 25, 40, and 60 mm thick, and 120 mm wide.

The initial moisture content of the samples was 200% of the dry mass. Corundum with equivalent diameters of 120, 320, and 500 μ was used as the fine-grained material for the fluidized bed. The temperature of the fluidized bed was varied over the range 150-300°C, and the actual air velocities varied from 0.2 to 1 m/sec.

In the study of heat transfer between the fluidized bed and the moist plate, the fundamental drying equation [5]

$$r\frac{dw}{d\tau}\cdot\frac{1}{100}+\left(c_0+c_\text{в}\frac{W}{100}\right)\frac{dt}{d\tau}=\frac{\alpha F}{G_\text{d}}(t_1-t_\text{s}). \tag{1}$$

was used for the determination of the heat-transfer coefficient for various values of moisture content.

Experiments on heat transfer during drying of a material in a fluidized bed showed that drying takes place entirely at the time of decreasing velocities. The heat-transfer coefficient achieves its maximum value (α_max) at the beginning of drying. It was established that the value of α_max decreases as the temperature of the fluidized bed increases, since the rise in thermal flux to the surface of the plate produces a considerable increase in the intensity of evaporation from the surface of the plate, i.e., of transverse mass flow, and there occurs as a consequence an increase in the thickness of the boundary layer and a decrease in the temperature gradient of the vapor–gas mixture at the surface [6]. The strong effect of the diameter of the particles of fine-grained material on the maximum value of the heat-transfer coefficient

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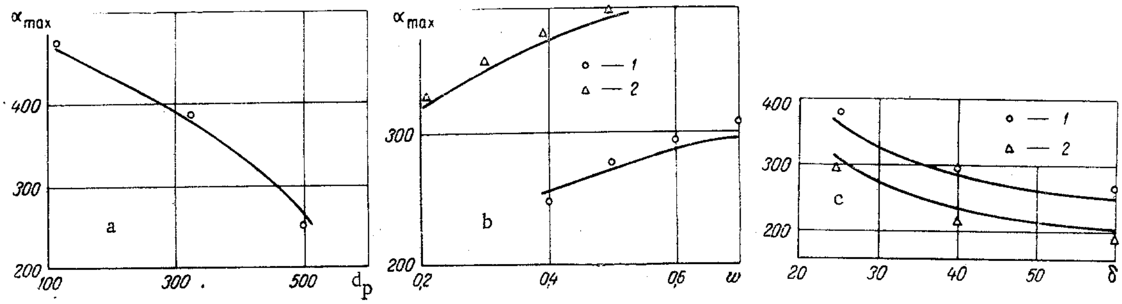

Fig. 1. Effect of: a) particle diameter d_p (μ) (t_l = 150°C, w = 0.4 m / sec); b) fluidization velocity w (m / sec) [t_l = 150°C; 1) d_p = 500 μ; 2) d_p = 320 μ]; and c) plate thickness (mm) [d_p = 320 μ; w = 0.3 m / sec; 1) t_l = 200°C; 2) t_l = 300°C] on the heat-transfer coefficient α_{max} (W / m^2 · deg).

was also established. It turned out that the value of α_{max} decreased rather significantly when the diameter of bed particles was increased from 120 to 500 μ (Fig. 1a). Thus, the value of α_{max} was 480 W/m^2 · deg for a particle diameter of 120 μ and was 250 W/m^2 · deg for 500-μ particles with all other parameters remaining the same. This is probably connected with the fact that particle mobility is reduced as particle diameter is increased and the agitating effect of the particles at the surface of the plate decreased.

A weaker effect on the value of the maximum heat-transfer coefficient was noted for the fluidization velocity as compared to other parameters (Fig. 1b). When the velocity was increased by a factor of 2, the heat-transfer coefficient increased by a factor of 1.2 for a particle diameter of 320 μ and a bed temperature of 150°C.

The geometric dimensions of the plate have a strong influence on the value of the maximum heat-transfer coefficient. The value of the maximum heat-transfer coefficient decreases when the thickness of the plate is increased. As shown by hydrodynamic experiments [7], a high-porosity field is formed around the surface in this case. The zone of intense mixing of material is pushed back from the surface. In addition, just as in convective drying, internal diffusion resistance against deepening of the vaporization zone increases when the plate thickness is increased. As shown in Fig. 1c, increase in plate thickness from 25 to 60 mm leads to a reduction in the maximum heat-transfer coefficient from 300 to 210 W/m^2 · deg.

When the length of a plate is increased, the maximum heat-transfer coefficient decreases in value because of the rise in the average thickness of the thermal boundary layer along the length.

The experimental results were analyzed in criterial form on the basis of dimensional analysis. For the calculation of the values of the maximum heat-transfer coefficient during drying of material in a fluidized bed, we obtained the equation (Fig. 2)

$$\mathrm{Nu}_{max} = A\mathrm{Re}^{0.25}\left(\frac{T_l}{T_w}\right)^2 \mathrm{Ar}^{1.1}\left(\frac{\delta}{d_p}\right)^{-0.375}. \tag{2}$$

The defining parameters are the plate length, fluidization velocity, and bed temperature. The quantity A depends on the criterion Ar, and A = 9.48 for Ar = 45-100, A = 0.227 for Ar = 800-2000, and A = 0.028 for Ar = 3000-7000. The criterial dependence given is valid for Re = 800-4000, T_l / T_w = 1.8-3.0, and δ / d_p = 0.14-0.20.

The variation of the heat-transfer coefficient in time is described by the following critical relation (Fig. 3):

$$\mathrm{Nu} = \mathrm{Nu}_{max}\exp(-\beta\,\mathrm{Fo}), \tag{3}$$

where β is determined from the equation

$$\beta = 0.0935\left(\frac{l}{\delta}\right)^{1.251}. \tag{4}$$

Equation (3) is applicable when Fo ≥ 0.04.

The data obtained is well approximated by a relation similar to that proposed in [8] by Lykov, Kuts, and Ol'shanskii,

$$\mathrm{Nu} = 0.91\mathrm{Nu}_{max}N^{0.76}. \tag{5}$$

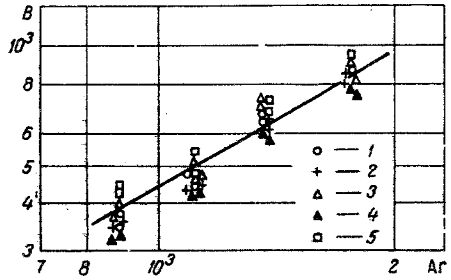

Fig. 2

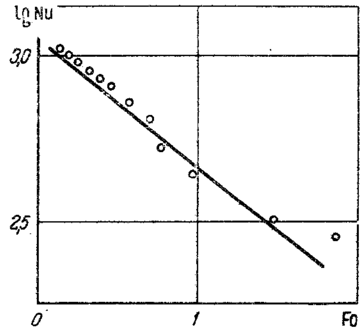

Fig. 3

Fig. 2. Generalized curve for maximum heat transfer, l = 170 mm: 1) δ = 25 mm; 2) 40 mm; 3) 60 mm; 4) l = 120 mm, δ = 25 mm; 5) l = 250 mm, δ = 25 mm; $B \equiv Nu_{max}/Re^{0.25}(T_l/T_W)(\delta/d_p)^{-0.375}$.

Fig. 3. Nu as a function of Fo.

The drying experiments in a fluidized bed showed considerable intensification of heat transfer in comparison with convective drying. The equations obtained can be used for design of commercial installations for drying plates of thermal insulation where a fluidized bed of fine-grained material is used as an intermediate heat-transfer agent.

NOTATION

α_{max}, α	are the maximal and instantaneous heat-transfer coefficients;
r	is the heat of evaporation;
W	is the sample moisture per dry mass;
τ	is the time;
c_0	is the absolute dry-body heat capacity;
F	is the sample surface;
G_d	is the weight of absolute dry body;
T_l, t_l	are the temperature of layer;
t_s	is the mean sample surface temperature;
T_W	is the wet-bulb temperature;
δ	is the plate thickness;
d_p	is the particle diameter;
w	is the filtration velocity;
Nu_{max}, Nu	are the maximal and instantaneous Nusselt numbers;
Re	is the Reynolds number;
Ar	is the Archimedean number;
Fo	is the Fourier number;
N	is the relative drying velocity.

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