THE TEMPERATURE FIELD OF A FLUIDIZED BED IN CONTINUOUSLY OPERATIONAL EQUIPMENT

A. G. Gorelik

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We examine the nonsteady distribution of temperatures in a fluidized bed when granular material is fed continuously into the bed.

Let us examine the temperature field of a fluidized bed in a continuously operational apparatus. The nonsteadiness of the field in this case is characteristic of the start-up period or for a change in the regime of the process. We will examine an idealized homogeneous fluidized bed which is continuously replenished from above with a granular material of temperature θ_1^*, starting at the instant $\tau = 0$. The material is removed from the bottom. In a one-dimensional bed of fine particles, we can assume that the temperature difference between the particles and the gas is virtually equal to zero over the entire height of the bed [1, 2]. The initial temperature of the bed is assumed to be equal to the inlet gas temperature θ_0.

The problem is formulated in the following manner:

$$\frac{\partial\theta}{\partial \mathrm{Fo}} = \frac{\partial^2\theta}{\partial y^2} - (\mathrm{Pe_g} - \mathrm{Pe_m}) \frac{\partial\theta}{\partial y}, \tag{1}$$

$$\theta(y, 0) = 0, \tag{2}$$

$$\frac{1}{\mathrm{Pe_g}} \frac{\partial\theta(0, \mathrm{Fo})}{\partial y} = \theta(0, \mathrm{Fo}), \tag{3}$$

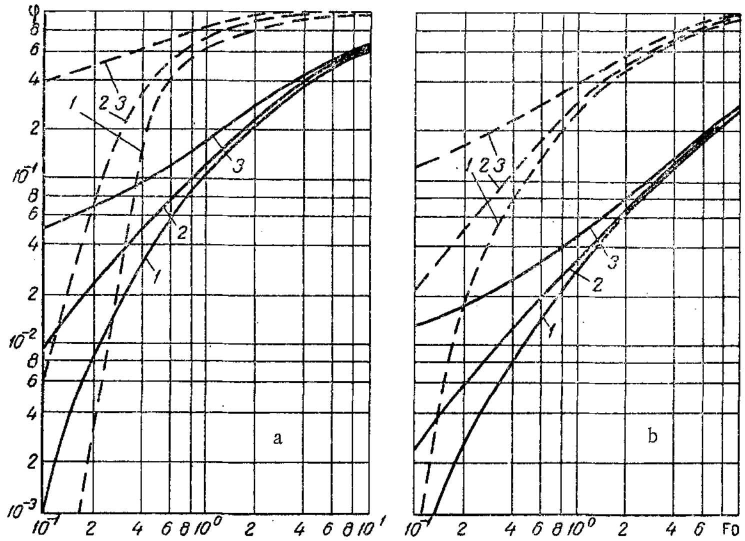

Fig. 1. Relationship between $\varphi = \theta/\theta_1$ and Fo ($w_m = 0.1 \cdot 10^{-3}$ m/sec, which is denoted by the solid line; $w_m = 1.0 \cdot 10^{-3}$ m/sec is given by the dashed line; $w_g = 0.86$ m/sec (a) and 1.22 m/sec (b)): 1) y = 0; 2) 0.5; 3) 1.0.

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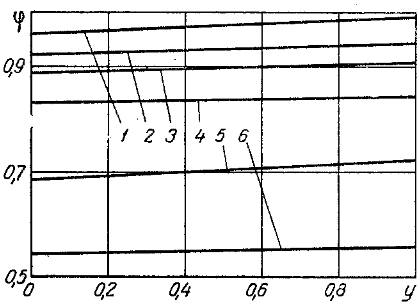

Fig. 2. Relationship between $\varphi = \theta/\theta_1$ and y as $Fo \to \infty$: 1) $w_g = 0.86$ m/sec, $w_m = 1.0 \cdot 10^{-3}$ m/sec; 2) 1.22 and $1.0 \cdot 10^{-3}$; 3) 1.53 and $1.0 \cdot 10^{-3}$; 4) 2.06 and $1.0 \cdot 10^{-3}$; 5) 0.86 and $0.1 \cdot 10^{-3}$; 6) 1.22 and $0.1 \cdot 10^{-3}$.

$$\frac{1}{Pe_m} \frac{\partial\theta(1, Fo)}{\partial y} = \theta_1 - \theta(1, Fo). \tag{4}$$

The Pe_g and Pe_m numbers are referred to the effective thermal conductivity of the fluidized bed.

For the solution of problem (1)-(4) we will use the Laplace transform with respect to the variable Fo. Finally, the solution for the original is written as follows:

$$\frac{\theta(y, Fo)}{\theta_1} = \frac{Pe_m \exp[-b(1-y)][Pe_g \exp(by) - Pe_m \exp(-by)]}{Pe_g^2 \exp b - Pe_m^2 \exp(-b)}$$
$$- \sum_{n=1}^{\infty} \{2 Pe_m \exp[-b(1-y)] \mu_n [(Pe_g - b) \sin \mu_n y$$
$$+ \mu_n \cos \mu_n y] \exp[-(\mu_n^2 + b^2) Fo]/(\mu_n^2 + b^2) [(Pe_g + Pe_m + 2) \mu_n \sin \mu_n$$
$$- (Pe_g + Pe_m + Pe_g Pe_m + b^2 - \mu_n^2) \cos \mu_n]\}. \tag{5}$$

Here $b = 1/2\,(Pe_g - Pe_m)$; μ_n denotes the roots of the characteristic equation

$$\operatorname{tg} \mu = -\frac{\mu(Pe_g + Pe_m)}{b^2 + Pe_g Pe_m - \mu^2}. \tag{6}$$

With Eq. (5) we can derive the expression for the average temperature of the fluidized bed when heat is supplied to the bed through the upper boundary by means of the material. The average bed temperature is written as follows:

$$\theta_{av} = \int_0^1 \theta(y, Fo)\, dy. \tag{7}$$

Substituting the value of $\theta(y, Fo)$ from (5) into (7) and integrating, after transformation, we derive the expression for the average bed temperature:

$$\frac{\theta_{av}}{\theta_1} = \frac{Pe_m [Pe_g \operatorname{sh} b - Pe_m \exp(-b)]}{Pe_g^2 \exp b - Pe_m^2 \exp(-b)} - \sum_{n=1}^{\infty} \{2 Pe_m \mu_n \{(Pe_g - b)[b \sin \mu_n - \mu_n \cos \mu_n + \mu_n \exp(-b)]$$
$$+ \mu_n [b \cos \mu_n + \mu_n \sin \mu_n - b \exp(-b)]\}/(\mu_n^2 + b^2)[(Pe_g + Pe_m$$
$$+ 2) \mu_n \sin \mu_n - (Pe_g + Pe_m + Pe_g Pe_m + b^2 - \mu_n^2) \cos \mu_n]\} \exp[-(\mu_n^2 + b^2) Fo]. \tag{8}$$

As an example we calculated the temperature field of the bed numerically with the aid of formula (5) for the experimental values of the longitudinal thermal conductivity of a fluidized bed of sand; these values had been derived earlier in [3]. In these calculations we employed various rates of material feed into the bed. The calculation results are shown in Figs. 1 and 2.

Analysis of these functions shows that with an increase in the gas velocity (an increase in the Pe_g number) there is a substantial increase in the duration of the nonsteady period of bed heating. Here there is also a reduction in the steady-state value of $\varphi = \theta/\theta_1$, which is associated with the more intensive mixing of the particles. The temperature difference over the height of the layer diminishes as the bed is heated by the incoming material. In the steady state the temperature difference over the bed height is slight; it increases somewhat with a reduction in the material feed rate and with a reduction in the gas velocity. An increase in the material feed rate (an increase in Pe_m) substantially reduces the duration of bed heating.

We should note that despite the high thermal diffusivity of the layer (when $w_g = 0.86$ m/sec, $a_{eff} = 0.48$ m^2/h, which is higher than the thermal diffusivity of copper and aluminum), during the initial heating period there exists a substantial temperature difference over the bed height, and this difference is greater the greater the material feed rate. Even with low gas velocities and a high material feed rate, the duration of a virtually steady-state regime is approximately Fo = 8, which for these conditions corresponds approximately to $\tau = 40$ min; this increases significantly as the gas velocity increases.

As noted in [4], with a continuous supply of material there are temperature differences across the bed height, but these are more characteristic of a nonsteady process.

With (5) and (8) we can also determine the maximum temperature level for the given gas velocity and the material feed rate; for low feed rate the average steady-state bed temperature differs substantially from the temperature of the material being supplied.

NOTATION

θ_1^*, θ^*	are, respectively, the temperatures of the material at the inlet to the bed and the temperature of the bed, in °C;
θ_0	is the gas temperature at the inlet to the bed;
$\theta = (\theta^* - \theta_0)/\theta_0$	is the dimensionless bed temperature;
θ_{av}	is the dimensionless average bed temperature;
h, H	are, respectively, the instantaneous and total bed height;
$y = h/H$	is the dimensionless bed height;
w_g, c_g, γ_g	are, respectively, the linear velocity, the heat capacity, and the density of the gas;
w_m, c_m, γ_m	are, respectively, the linear velocity, the heat capacity, and the density of the particle material;
ε	is the bed porosity;
λ_{eff}	is the longitudinal effective thermal conductivity of the bed;
$a_{eff} = \lambda_{eff}/(1-\varepsilon) c_m \gamma_m$	is the longitudinal effective thermal diffusivity of the bed;
τ	is the time;
μ_n	denotes the roots of the characteristic equation (6);
$Fo = a_{eff}\,\tau/H^2$	is the Fourier number;
$Pe_m = w_g c_g \gamma_g \varepsilon H/\lambda_{eff}$	is the Peclet number for the gas;
$Pe_m = w_m c_m \gamma_m (1-\varepsilon) H/\lambda_{eff}$	is the Peclet number for the material;
$\varphi = \theta/\theta_1$	is the relative bed temperature.

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