SIZE OF THE ACTIVE ZONE IN A WETTED FLUIDIZED BED WITH THE EVOLUTION OF REACTION HEAT

V. F. Volkov, G. I. Shishkin,
V. V. Ukhlov, and S. L. Safronova

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A scheme is developed for the determination, by a numerical method, of the height of the active zones, saturated by moisture h_{az}^{Z} and heated by gas h_{az}^{Θ}, in a wetted fluidized bed. The dependence of these quantities on the basic parameters of the process is shown.

For calculations, design, and operation of fluidized-bed equipment, a knowledge of the active height of the bed h_{az}^{Θ} at which the temperatures of the solid particles and the gas are almost equalized and the active height of the bed h_{az}^{Z} at which mass-exchange processes are almost completed is important.

Until recently, the problems of calculating the height of the active zones have been inadequately worked out [1], especially for the case of a wetted fluidized bed, when complex heat- and mass-exchange processes take place in it. Formulas for determining the heights of the active zones h_{az}^{Θ} and h_{az}^{Z} in a fluidized bed are completely lacking in processes that are complicated by the evolution of reaction heat.

We have undertaken the determination of h_{az}^{Θ} and h_{az}^{Z} by means of the system of equations developed earlier [3], which connect the outlet parameters of the material and the gas with the inlet parameters. The course of the heat- and mass-exchange processes in the wetted fluidized bed and, consequently, the height of the active zone depend on a large number of factors, which make the investigation and, especially, the presentation of the results in graphical form difficult. Because of this, we have chosen a course of fixing certain quantities (for example, the parameters of the gas and the material at the inlet to the apparatus) and of showing the dependence of the height of the active zone on other parameters, mainly those of most interest in practice: the specific productivity of the apparatus and the magnitude of the heat evolved in the process.

We undertook the investigation and analysis of the heights of the active zones by the consideration of a process (similar to that which we described previously in [2]) for the wetting of sodium sulfate in a fluidized bed with the removal of the reaction heat; however, the results obtained are interesting for a wide circle of similar processes.

The specific charge of the apparatus was assumed to be 0.8n kg of material per 1 kg of dry air. Numerical values of n were varied and were assumed equal to 0, 1, and 2. The evolved heat μ during wetting of the material was assumed to be equal to 0, 50, 100, and 150 kcal per 1 kg of water consumed in wetting the material. It was assumed that the quantity of water fed into the apparatus wets the material to 9%.

Figure 1 shows the dependence of the quantities Θ and Z on the height of the fluidized bed for fixed parameters of air at the inlet Θ_0 and Z_0. It can be seen that in the case of an unlimited increase of the height of the bed H, the values of Z_H, Θ_H, and, in addition, T tend to certain quantities which we shall call limiting: Θ_∞, Z_∞, and T_∞. In this case Θ_∞ becomes equal to the temperature of the particles T_∞, and the value of Z_∞ is equal to the saturation value at the temperature T_∞. The projection on the plane Z0H indicates the saturation process of the current of air by water vapor and Θ0H indicates the change of the air temperature at the outlet from the bed of height H.

The projection of the curve of the process on the plane Z0Θ indicates the relation between the wetting of the air and its temperature at the outlet from the bed of height H.

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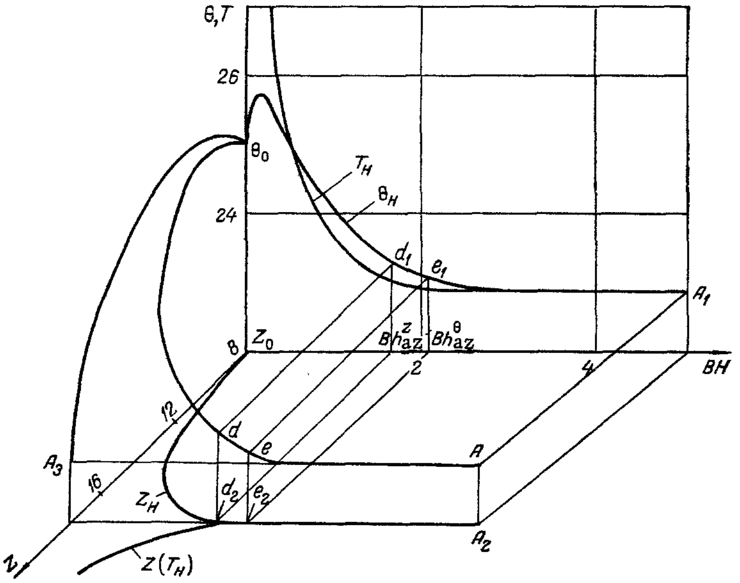

Fig. 1. Dependence of the temperature Θ and the moisture content of the gas Z on the height of the fluidized bed H. The initial parameters of the air are $\Theta_0 = 25°C$; $Z_0 = 8$ g/kg; specific charge of the apparatus n = 2; heat evolved $\mu = 75$ kcal/kg; the points d and e correspond to heights of the active zones Bh_{az}^{Z} and Bh_{az}^{Θ} for values of $a^Z = b^\Theta = 0.95$; T_H is the temperature of particles in the bed with height H; and Z_{T_H} is the equilibrium moisture content of the gas at temperature T_H; Θ, T, °C; Z, g/kg.

We introduce the quantity $a^Z = (Z_H - Z_0)/(Z_\infty - Z_0)$, which defines the degree of saturation by water vapor of the air emerging from the bed of height H, and the quantity $b^\Theta = (\Theta_H - \Theta_0)/(\Theta_\infty - \Theta_0)$, which is the degree of preheating of the air.

Figure 1 shows the heights of the bed when $a^Z = b^\Theta = 0.95$. It can be seen that these heights are significantly different. The difference between the quantities h_{az}^{Z} and h_{az}^{Θ} for identical values of a^Z and b^Θ is due to the different nature of the heat- and mass-exchange processes, to the difference between the motive powers of these processes, and also to the different numerical values for the coefficients of heat and mass exchange. There is also the mutual effect of the heat- and mass-exchange processes.

Figure 2 shows the projections on the plane $Z0\Theta$ of the curves that define the relation between the heat- and mass-exchange processes in the wetted fluidized bed, with a different specific productivity of the apparatus n and with different magnitudes of heat evolution μ. All the curves emerge from a single point O, which corresponds to the parameters of the air at the inlet to the apparatus. On the line $a$bc are the points corresponding to the states of the gas at the outlet from the bed of height $H = \infty$. It is obvious that the curve $a$bc corresponds also to the line of total saturation of air by water vapor at the temperature Θ_∞. The straight lines joining the origin and the ends of the curves, i.e., straight lines similar to Ob, are the lines of identical numerical values of a^Z and b^Θ. Actually, it follows from the equation $a^Z = b^\Theta$ that

$$Z = Z_0 + (\Theta - \Theta_0)\frac{Z_\infty - Z_0}{\Theta_\infty - \Theta_0},$$

which corresponds to a linear dependence of Z on Θ, and that this line passes through the point O with angular coefficient

$$\frac{Z_\infty - Z_0}{\Theta_\infty - \Theta_0}.$$

For every point of the straight line the scale of a^Z and b^Θ will be their own, different from the others, but uniform over the whole length of the line.

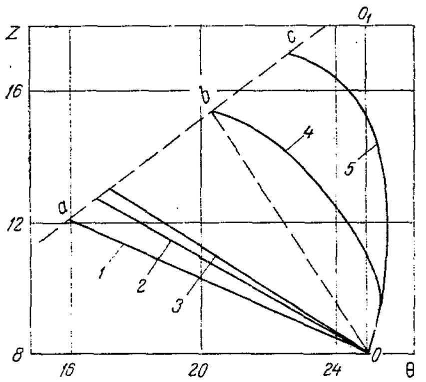

Fig. 2

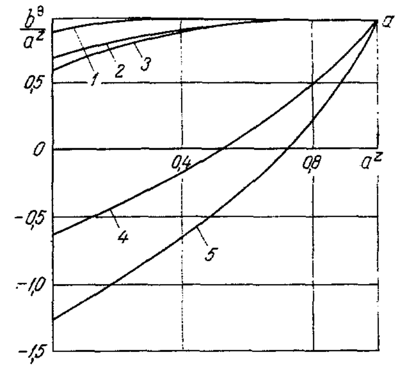

Fig. 3

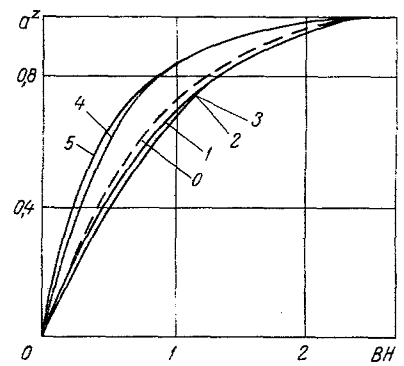

Fig. 4

Fig. 2. Relation between the moisture content of the gas Z and the temperature of the gas Θ for processes with different parameters, with increasing height of the fluidized bed. The point O defines the gas parameters at the inlet to the fluidized bed ($\Theta_0 = 25°C$, $Z_0 = 8$ g/kg); $a$bc is the line of total saturation of the air by water vapor, corresponding to $Z(T_H)$ at T_H; Ob is the line of identical values for the degree of heating of the air b^Θ, i.e., the line $a^Z = b^\Theta$; when $\mu = 0$, n = 0 (1), n = 1 (2); n = 2 (3); when $\mu = 75$, n = 1 (4), n = 2 (5).

Fig. 3. Relation between a^Z and b^Θ for different values of the specific charge n and the heat evolution μ. See Fig. 2 for the values of the curves.

Fig. 4. Dependence of the degree of saturation of air by water vapor on the height of the bed H and the parameters of the process n and μ. The dashed curve is constructed by formula (1), and the other curves are plotted according to data from calculations on a computer.

The nature of the curves for different values of n and μ is very different. Curves for processes without heat evolution ($\mu = 0$) are close to straight lines, from which it follows that values of a^Z and b^Θ in this case do not differ so significantly with change of height of the bed. In the presence of heat evolution ($\mu > 0$) the curves are deflected significantly to the right of the straight lines, corresponding to $a^Z = b^\Theta$. It follows from this that the values of a^Z with increasing height of the bed increase considerably more rapidly than the values of b^Θ. In the case of high values of heat evolution μ, there is a departure of the curves to the right of the vertical line OO_1, which corresponds to heating up of the gas due to the heat of reaction. In this case, the curves drift to the side opposite from the point at which the parameters correspond to infinite height of the bed H.

In view of the mutual effect of mass and heat exchange, and also due to the presence of heat evolution in the wetted fluidized bed, the active zones of heat exchange are extended considerably in comparison with the active zone for "pure" heat exchange. In the wetted fluidized bed, when the conditions are as described in [2], the calculated size of the active zone of heat exchange h^Θ_{az} reaches 470 mm.

The relation between a^Z and b^Θ for different values of n and μ is shown in Fig. 3. It can be seen that when n = 0 and $\mu = 0$, the ratio is close to 1 over the whole range of values of a^Z. Consequently, the degrees of conversion with respect to Θ and Z are close to each other at any bed heights.

When $\mu = 0$ and n ≠ 0, once again there is quite close agreement between the values of a^Z and b^Θ. The magnitude of the ratio b^Θ/a^Z does not go beyond 0.5.

In the presence of heat evolution ($\mu \neq 0$), the proportionality of b^Θ and a^Z breaks down significantly. Values of b^Θ/a^Z differ greatly from 1, and for a wide range of values of a^Z they even become negative. In Fig. 2 this corresponds to the cases when the curves go off to the right beyond the line OO_1, i.e., when the fluidized bed is not cooled but is heated up.

Earlier [4] we obtained formula (1) theoretically for determining the height of the active zone h^Z_{az} for an adiabatic process taking place in a wetted fluidized bed:

$$h^z_{az} = -K_1K_2K_3\frac{\ln(1-a^z)\,wd\rho_c}{\beta(1-\varepsilon)P_0}. \qquad (1)$$

Formula (1) is obtained by solving the differential equation of mass exchange for a filtration model of a wetted fluidized bed and verified experimentally in [4] for the condition when the particle temperature T < 40°C. In this case $(1-P_H)^2 \approx 1$, which ensures an accuracy of up to 10% with respect to the degree of saturation a^Z for a fixed value of h^Z_{az}.

In order to explain the suitability of formula (1) also for other processes taking place in a fluidized bed, Fig. 4 graphically shows the dependence of the degree of saturation of air by water vapor a^Z on the height of the fluidized bed H for different values of n and μ. The curve constructed according to formula (1) is also plotted on this graph.

It can be seen from Fig. 4 that the curve plotted according to formula (1) is close to the curves constructed for processes taking place in the wetted fluidized bed without heat evolution ($\mu = 0$) over the whole height of the bed H. In the presence of significant heat evolution, a significant difference can be seen between the path of the curves (in the direction of increase of a^Z) for a given height H and the curve obtained by formula (1). However, for values of $a^Z > 0.95$, all the curves practically coincide. Thus, we may assume that formula (1) can be used for estimating the height of the active zone h^Z_{az} for a wide circle of heat- and mass-exchange processes taking place in a wetted fluidized bed.

NOTATION

H, total height of fluidized bed, m; Z_0, Θ_0, humidity and temperature of the air at the inlet to the apparatus, kg/kg and °C; Z_∞, Θ_∞, humidity and temperature of the air at the outlet from the fluidized bed of infinite height; T, temperature of particles in the fluidized bed, °C; μ, quantity of heat evolved per 1 kg of assimilated moisture; g_c, mass flow rate of air, kg/m^2·h; F, surface area of particles in the fluidized bed, 1/m; α, β, coefficients of heat- and mass-exchange, respectively; P_0, atmospheric pressure, atm; w, linear velocity of air, m/sec; coefficients of Eq. (1): $K_1 = 0.36 \cdot 10^4$; K_2, shape factor of particles, equal to 1/6 for the case of spheres; K_3, ratio of the gas constants of the vapor supplied to the fluidized bed of liquid and fluidizing agent, equal to 0.622 in the case of water vapor and air; HB, dimensionless complex, where $B = \beta F P_0 / g_c$.

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FORCED-CONVECTION HEAT TRANSFER IN POROUS MEDIUM WITH JOULE–THOMSON EFFECT

A. I. Filippov

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The heat-conduction effect on the thermal field of the throttle effect is investigated close to the boundary of a porous medium at low pressure gradients.

A thermal field is considered in two semiinfinite media, one of which is impenetrable and the other of which is a porous medium; in the latter a fluid motion takes place accompanied by the Joule–Thomson effect. Such a problem arises when thermal fields are investigated in collector-carriers of oil and gas [1] or in various installations for studying and utilizing the Joule–Thomson effect. A wide range of heat-exchange problems on the boundary of two different throttle fluids can be reduced to the above problem.

It is known that the heat-conduction effect due to fluid motion is small [2]. A low pressure gradient arises in the direction of convection so that the derivative of temperature due to throttling is small; the latter

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Bashkiria State University, Ufa.

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