KINETICS OF THE REMOVAL OF LIQUID FROM CAPILLARY-POROUS BODIES IN A FLUIDIZED BED UNDER NONISOTHERMAL CONDITIONS

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A theory of mass transfer in capillary-porous bodies is proposed which allows for thermogradient transfer of a bound substance in liquid form. The results obtained are used to calculate the process of drying of ceramic articles in a fluidized bed.

Existing methods of calculating processes of drying of capillary-porous bodies under isothermal and non-isothermal conditions are based mainly on analytical solutions of the system of differential equations of heat and mass transfer known from the phenomenological theory of irreversible processes [1, 2]. The main obstacle to the wide use of these equations is the considerable nonlinearity of the problem—the dependence of the kinetic coefficients appearing in them on the concentration of the bound substance and the temperature [3-5]. Under isothermal drying conditions (in the case of bodies of small size), calculations with allowance for the dependence $\sigma_m = f(\theta, t)$ are made by zonal methods [4]. In the presence of a temperature gradient within the material being dried, the number of criteria determining the kinetics of the process grows considerably [6], and it becomes impossible to use the zonal method of calculation. In such cases one artificially separates the heat- and mass-exchange processes and allows for the influence of the temperature field on the kinetics of the mass transfer using functions obtained from experiment for the relation between the volumetric-mean concentration and temperature [7], which are subsequently used in calculations of transfer processes in systems having a solid phase under quasi-isothermal conditions. However, numerous experimental data give evidence of temperature gradients which exert considerable influence on the kinetics of the drying process [8-10].

Moreover, it should be noted that a phenomenological examination of the stated problem does not allow one to characterize the fluxes of the bound substance in a porous body.
In contrast to the well-known reports [1, 2], we will seek solutions on the basis of an investigation of the flow of a bound substance in the form of a liquid in the pores of a model capillary-porous system with allowance for film transfer. In doing this we will be confined to consideration of the case when transfer in the vapor phase can be neglected. Such conditions occur, for example, in the low-temperature heat treatment of ceramic articles [11], where the binding is paraffin.

As the model pore structure we use a system consisting of capillaries of two different radii: $R_1$ and $R_2$, joined over the entire length (Fig. 1). Such a model fully corresponds to a number of ceramic materials for which a pore size distribution of a bimodal character has been established experimentally [12-14].

Before the final firing, articles made of commercial ceramic are subjected to low-temperature heat treatment to remove from them the organic binder, in the given case paraffin. The process of removal of the binder proceeds most efficiently in a medium of disperse fluidized adsorbent [15], when a capillary-porous body is submerged in a fluidized bed at a temperature which excludes the evaporation of the liquid, external mass transfer takes place through the drawing up of liquid by porous particles colliding with the surface of the solid body [16].

Let us write the equations for the liquid fluxes in the model capillary-porous system. In narrow capillaries one observes a viscous flow of liquid due to the difference between the pressures at the menisci of the wide capillaries and the surface of the porous body,

$$j_1 = \frac{6R_2^2}{8\eta(L - x_0)} \Delta P,$$

where $\Delta P = P_0 - 2\sigma(x_0)/R_1$. In wide capillaries the liquid flows in the form of a film under the action of the gradient of the disjoining pressure. In contrast to isothermal mass transfer [16], however, flow also occurs in the films under the action of the temperature gradient, which is significant inside the solid body. Adopting the hypothesis of additivity of these fluxes, we can write [17]

$$j_2 = \frac{2\rho h^3}{3\eta R_1} \frac{\partial \Pi}{\partial x} + \frac{\rho h^3}{\eta R_1} \frac{\partial \sigma}{\partial T} \frac{\partial T}{\partial x} = j_1 + j_{11}.$$

In (2), $\Pi = P - \sigma/R_1$ is the disjoining pressure.

Let us examine the liquid fluxes in Eq. (2) separately. Taking the isothermy of the disjoining pressure for nonpolar liquids in the form [18]

$$\Pi = A/h^3,$$

after differentiation of (3) and its substitution into the first term of Eq. (2), we obtain

$$j_1 = -\frac{2\rho A}{\eta R_1 h} \frac{\partial h}{\partial x}.$$

We rewrite (4) in the form

$$\frac{\partial \ln h}{\partial x} = -\frac{j_1 \eta R_1}{2\rho A} = -\bar{\alpha}.$$

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