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MASS TRANSFER DURING EXTRACTION OF A SOLID SUBSTANCE FROM A MIXTURE OF POLYDISPERSE POROUS PARTICLES

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Mass transfer during the extraction of a solid soluble phase from a mixture of polydisperse porous particles is considered. Equations are obtained which permit prediction of the kinetics of the extraction.

Few cases of the extraction of a soluble solid phase from porous particles are known in practice (hydrometallurgy, chemical industry, nutrition, etc.). Realization of the processes mentioned under production conditions requires knowledge of the kinetic regularities permitting computation of the extraction apparatus.

Mainly, the kinetics of extraction from monodisperse porous particles under conditions of constancy of the moving force are examined in papers devoted to this problem [1-4]. However, cases of extraction from a polydisperse mixture with a variable moving force almost always occur in practice. The present paper is devoted to a study of this problem.

If it is assumed that the porous particles have a spherical shape and an isotropic structure with respect to diffusion, then the quantity of material being transferred into solution can be determined from the fundamental diffusion equation

$$\frac{d(G_0-G)}{dt} = -D_{\mathrm{m}}F\left(\frac{\partial c_1}{\partial r}\right)_{r=R}. \tag{1}$$

Taking the concentration distribution with the porous particle [5] in the form

$$\frac{c_s-c_1}{c_s-c} = \frac{1-\dfrac{r_0}{r}}{1-\dfrac{r_0}{R}} \tag{2}$$

and the mass of material remaining within the porous particle at the time t equal to

$$G = \frac{4}{3}\pi r_0^3 m = \frac{4}{3}\pi\varphi_0^3 R^3 m, \tag{3}$$

Eq. (1) reduces to the form

$$\frac{d\varphi_0}{dt} = -\frac{D_{\mathrm{m}}}{mR^2}\cdot\frac{(c_s-c)}{\varphi_0(1-\varphi_0)}. \tag{4}$$

In combination with the material-balance equation

$$M_0\left(1-\frac{M}{M_0}\right) = W(c-c_1)$$

we can use (4) to describe the kinetics of extraction from a polydisperse mixture of particles. To do this the polydisperse mixture is considered as a set of separate fractions, each of which introduces its contribution to the total kinetics of extraction.

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TABLE 1. Fractional Composition of Polydisperse Mixtures

Mixture number	Mass M_{0i}, g per each fraction				$M_0=\sum\limits_{i=1}^{n} M_{0i}$, g
	$2R_1=2.0$ mm	$2R_2=3.0$ mm	$2R_3=4.25$ mm	$2R_4=6.0$ mm	
I	32	32	8	8	80
II	16	24	24	16	80
III	8	8	32	32	80

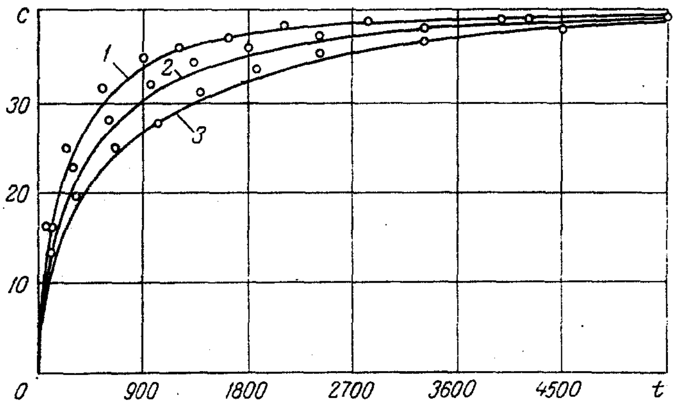

Fig. 1. Extraction kinetics for sulfur from a mixture of polydisperse particles of sulfur ore by tetrachlorethylene (c, kg/m^3; t, sec): 1, 2, 3) curves computed according to the system (6) for the mixtures I, II, III (Table 1), respectively; points denote experimental values.

Taking the latter into account for a mixture consisting of n fractions

$$M=\sum_{i=1}^{n} M_i=\sum_{i=1}^{n} M_{0i}\varphi_{0i}^3$$

the material-balance equation can be represented in the form

$$\beta\left(1-\frac{1}{M_0}\sum_{i=1}^{n} M_{0i}\varphi_{0i}^3\right)=c-c_{\text{I}}. \tag{5}$$

Therefore, the mathematical formula of the problem is determined by a system of equations whose analytic solution raises definite difficulties:

$$\begin{gathered}\frac{d\varphi_{0i}}{dt}=-\frac{D_{\text{m}}}{mR_i^2}\cdot\frac{(c_s-c)}{\varphi_{0i}(1-\varphi_{0i})},\quad i=1,2,\ldots,n,\\ \beta\left(1-\frac{1}{M_0}\sum_{i=1}^{n} M_{0i}\varphi_{0i}^3\right)=c-c_{\text{I}},\\ c|_{t=0}=0,\quad \varphi_{0i}|_{t=0}=1.\end{gathered} \tag{6}$$

The case when the extraction process proceeds at a constant moving force is simpler. Such a process holds in practice when extraction is accomplished for low finite concentrations of the substance being extracted as compared with its solubility.

Then integrating (4) with subsequent manipulation yields an equation of the form

$$1-3\varphi_0^2+2\varphi_0^3=\frac{t}{T}. \tag{7}$$

According to [6] the analytic solution of (7) has the form

$$\varphi_0=\frac{1}{2}\pm\cos\left[60^0+\frac{1}{3}\arccos\pm\left(1-2\frac{t}{T}\right)\right], \tag{8}$$

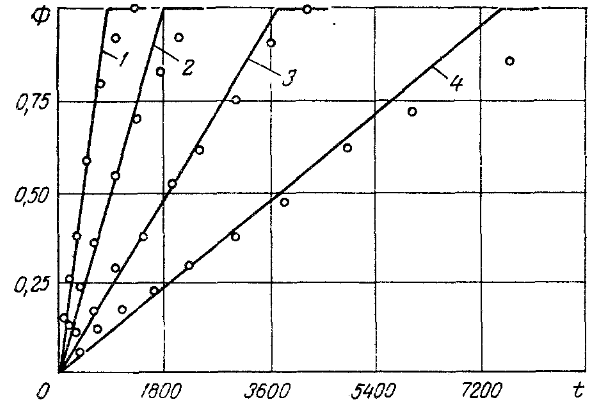

Fig. 2. The dependence of $\Phi = 1 - 3\varphi_{0i}^2 + 2\varphi_{0i}^3$ on t, sec; 1-4) experimental results for fractions with the particle sizes 2.0, 3.0, 4.25, and 6.0 mm, respectively.

$$+ \text{ for } \frac{t}{T} \leqslant \frac{1}{2}; \quad - \text{ for } \frac{t}{T} > \frac{1}{2}.$$

Substituting (8) into the material-balance equation (5) results in the expression

$$c = \beta\left[1 - \frac{1}{M_0}\sum_{i=1}^{n} M_{0i}\left\{\frac{1}{2} \pm \cos\left[60^0 + \frac{1}{3}\arccos \pm \left(1 - 2\frac{t}{T_i}\right)\right]\right\}^3\right] + c_{\mathrm{I}}, \tag{9}$$

which permits establishment of the extraction kinetics from a polydisperse mixture with a constant moving force if T_1, T_2, ..., T_n are known.

Sulfur ore of the Podorozhnensk deposits with a 21.8% mean sulfur content was used for the experimental study of the extraction kinetics, where tetrachlorethylene was the solvent. The ore was first pulverized and dissipated into fractions with the particle size 2.0, 3.0, 4.25, and 6.0 mm. Then polydisperse mixtures with a given distribution curve (Table 1) were composed from the fractions obtained. Tests to determine the extraction kinetics were performed in an apparatus with a 2.5-liter agitator, provided with a checking and regulation system. Tetrachlorethylene (W = 2000 ml) heated to the test temperature was poured into the apparatus. A charge of the polydisperse particle mixture was loaded therein after first having been heated to the given temperature. The tests were performed with the agitator moving at the constant number of turns 500 rpm and at the constant temperature 80°C. Samples of the solution were withdrawn after specific time intervals by using a special sampler. The sulfur concentration in the samples was determined by a weight method after the solvent had been removed in an RVO-64 rotor vacuum evaporator.

Results of the experiments are represented in Fig. 1 in the form of the dependence c = f(t), where kinetic curves computed on the basis of solving the system (6) on an electronic digital computer are also presented. Values of the constants in (6) were established experimentally at 80°C: $D_m = 1.06 \cdot 10^{-9}$ m²/sec; $c_s = 123$ kg/m³; $c_I = 0$; m = 533 kg/m³; $\beta = M_0/W = 40$ kg/m³. As is seen from Fig. 1, the experimental results agree satisfactorily with the theoretical curves 1-3.

To verify (9), values of T_1, T_2, ..., T_n were determined experimentally by the method mentioned above for each fraction separately. The results of the experiments for the fractions listed above are presented in Fig. 2 in the form of the dependence $\Phi = f(t)$ $(\Phi = 1 - 3\varphi_{0i}^2 + 2\varphi_{0i}^3)$. A material-balance equation of the form $M_{0i}(1 - \varphi_{0i}^3) = c - c_I$ was used to determine φ_{0i}.

According to (7), a linear dependence should exist between the quantities Φ and t. As is seen from Fig. 2, such a dependence actually exists. Hence, it is possible to determine the time T_1, T_2, ..., T_n for each fraction by means of the slope of the lines presented. For the fractions with the sizes 2.0, 3.0, 4.25, and 6.0 mm, this time is, respectively, 13, 29, 62, and 125 min.

The dependence c = f(t) was computed by means of (9) for mixtures of the same composition (Table 1) under the same conditions. Since the finite concentration of substance being extracted in our case was 40 kg/m^3, which is sufficiently low compared to the saturation concentration (c_S = 123 kg/m^3), then utilization of this method is legitimate. As computations have shown, the theoretical results (not shown in Fig. 1) agree satisfactorily with experiment. The root-mean-square deviation of the experimental from the theoretical results was 0.92 kg/m^3 in the first case and 1.08 kg/m^3 in the second. It should be noted that the more substantially the moving force changes during the process, the more significant the differences in the deviations presented above will be.

Therefore, a computation of the extraction kinetics from a polydisperse mixture with the change in moving force taken into account will be more accurate. Meanwhile, a computation of the extraction kinetics by the second method yields satisfactory results and can be used to predict the kinetics for a small change in the moving force.

NOTATION

G_0, initial mass of substance being extracted in the porous particle; G, mass of the substance being extracted in the porous particle up to the time t; t, running time; D_m, diffusion coefficient; F, mass transfer surface; r_0, radius bounding the domain containing the substance being extracted; R, radius of the porous particle; c_1, concentration of the substance being extracted within the porous particle at a point corresponding to the radius r; c_S, saturation concentration; c_I, initial concentration; c, concentration of substance being extracted in the fluid volume until time t; m, mass of substance being extracted per unit volume of the particle; $\varphi_0 = r_0/R$, dimensionless particle radius; M_0, initial mass of substance being extracted in the polydisperse mixture; M, mass of the substance being extracted in the polydisperse mixture until time t; M_i, mass of substance being extracted in the i-th fraction to the time t; M_{0i}, initial mass of substance being extracted in the i-th fraction; φ_{0i}, dimensionless radius of particles of the i-th fraction; R_i, radius of the porous particles of the i-th fraction; T, total extraction time; T_i, total extraction time for the i-th fraction; W, volume of solvent; β, ratio of solid to liquid phases in the substance being extracted.

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