

SOLVENT EXTRACTION IN A STATIC BED WITH SOLVENT
 RECIRCULATION AND LONGITUDINAL MIXING

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UDC 66.061.3/5

A numerical solution has been obtained for extraction from a static bed with solvent recirculation, where allowance is made for the longitudinal mixing and for the variable mass-transfer coefficient in the solid.

Extraction of a static bed is one of the common extraction methods, since in combination with solvent recirculation, it provides a good contact between the phases and a high degree of extraction. In the mathematical simulations of such a process, one should incorporate the longitudinal mixing in the transport equations by means of a term of $\epsilon D_\ell \partial C_1 / \partial z^2$ type [1-4]. The longitudinal-mixing coefficient D_ℓ is much larger than the free-diffusion coefficient [5, 6] and is dependent on the Peclet and Prandtl numbers [6]. In [7], there is a detailed discussion of the effects of longitudinal mixing on extraction. A complete formulation was given on the extraction from a moving bed on the assumption that the mass-transfer coefficient in a grain was constant. The treatment was simplified for three different cases: 1) a stationary concentration distribution along the apparatus, 2) a non-stationary periodic process with vigorous mixing of the two phases, and 3) a nonstationary process in a static bed. In the first case, an analytic solution was obtained for spherical particles. In the third one, a solution was found on the assumption that $Pe \gg 1$ ($v_z \partial c_1 / \partial z \gg D_\ell \partial^2 C_1 / \partial z^2$) by using Laplace transformation (the inverse transformation is not given in [8]) together with solutions for the limiting conditions of a very short bed ($w = \beta D_z / v_z R^2 \gg 1$) and a very long one ($w \gg 1$). Others [9, 10] have obtained simpler solutions for $C_{1i} = 0$ with the constraints ($w \ll 1$, $w^2 \ll \tau' \ll 1/\pi$) $\tau' = \tau - z/v_z$; in all these solutions, the mass-transfer coefficient is taken as constant.

Here we consider a numerical solution for the model of extraction in a static bed with solvent recirculation, where allowance is made for the longitudinal mixing and the variable mass-transfer coefficient in the solid, where we employ the solution of [11] for extraction with ideal mixing.

Extraction in a static bed of length L is [1-5] described by

$$\epsilon \frac{\partial C_1}{\partial \tau} + v_z \frac{\partial C_1}{\partial z} + \epsilon_1 (1 - \epsilon) \frac{\partial \bar{C}_2}{\partial \tau} = \epsilon D_l \frac{\partial^2 C_1}{\partial z^2}, \quad (1)$$

in which D_ℓ is taken as constant and the term $\epsilon_1 (1 - \epsilon) \partial \bar{C}_2 / \partial \tau$ expresses the flux of the extracted component from the solid phase along the height of the bed. This is calculated from the expression

$$\bar{C}_2 = \frac{T+1}{R^{T+1}} \int_0^R x^T C_2(x, \tau) dx, \quad (2)$$

where C_2 is the concentration in a particle, which is determined from the equation

$$\frac{\partial C_2}{\partial \tau} = \frac{1}{x^T} \frac{\partial}{\partial x} \left[x^T D_e(C_2) \frac{\partial C_2}{\partial x} \right]. \quad (3)$$

Equations (1)-(3) are supplemented with the following boundary conditions:

$$\frac{v_z}{\epsilon} [C_{1i} - C_1(\tau)] = -D_l \left(\frac{\partial C_1}{\partial z} \right)_{z=0}, \quad (4)$$

$$D_l \left(\frac{\partial C_1}{\partial z} \right)_{z=L} = 0, \quad (5)$$

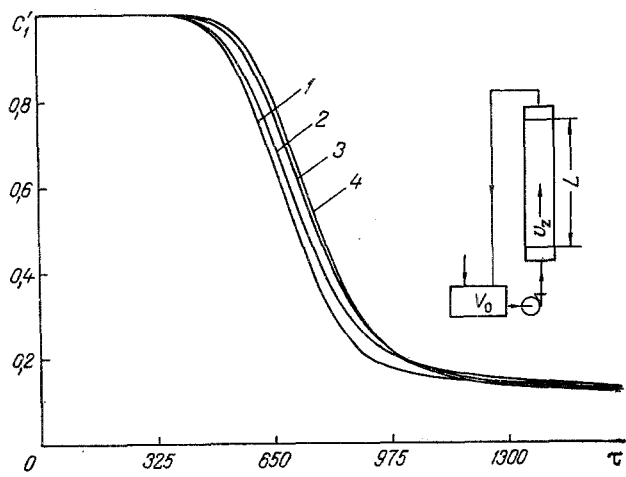


Fig. 1

Fig. 1. Effects of a variable coefficient D_e in the solid phase (m^2/sec) on the output curve ($C_1/C_0 = f(\tau)$): 1) $D_e = const$; 2) $\alpha = 0.5$; 3) 0.8; 4) 0.9.

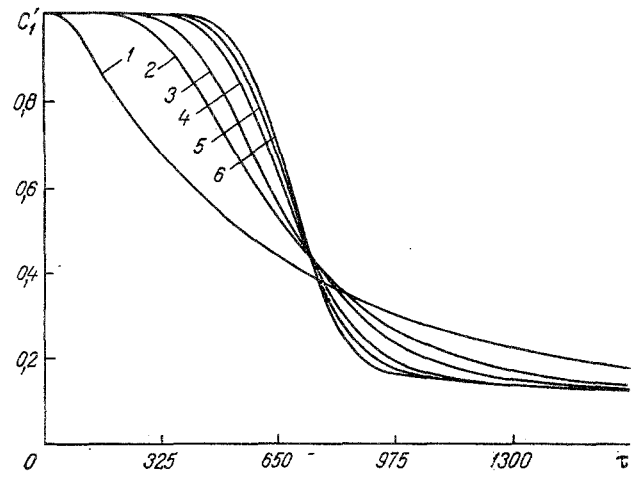


Fig. 2

Fig. 2. Effects of longitudinal mixing expressed in terms of the Pe number on the output curve $C_1/C_0 = f(\tau)$: 1) $Pe = 1$; 2) 10; 3) 19; 4) 43.2; 5) 64; 6) 94.18.

$$\left(\frac{\partial C_2}{\partial x} \right)_{x=0} = 0, \quad (6)$$

$$-\left(\frac{\partial C_2}{\partial x} \right)_{x=R} D_e = k(C_2|_{x=R} - C_1), \quad (7)$$

$$C_2 = C_0(0), \quad (8)$$

$$C_{1i} = C_1(0). \quad (9)$$

The $C_{1i}(\tau)$ in (4) is determined from the material balance for the recirculating extractant:

$$V_0 \frac{dC_{1i}}{d\tau} = v_z S (C_1|_{z=L} - C_1|_{z=0}). \quad (10)$$

System (1)-(10) when rendered dimensionless is

$$\varepsilon \frac{\partial C_1'}{\partial \bar{\tau}} + \frac{T+1}{2} \varepsilon_1 \delta (1-\varepsilon) Bi (C_1' - C_2'|_{\varphi=1}) = \frac{1}{Pe} \frac{\partial^2 C_1'}{\partial Z^2} - \frac{\partial C_1'}{\partial Z}, \quad (11)$$

$$\frac{\partial C_2'}{\partial \bar{\tau}} = \frac{\delta}{\varphi^T} \left(\varphi^T \bar{D}_e \frac{\partial C_2'}{\partial \varphi} \right), \quad (12)$$

$$C_1'(0, \bar{\tau}) - \frac{1}{Pe} \frac{\partial C_1'(0, \bar{\tau})}{\partial Z} = C_{1i}'(0, \bar{\tau}), \quad Z=0, \quad (13)$$

$$\left(\frac{\partial C_1'}{\partial Z} \right)_{Z=1} = 0, \quad (14)$$

$$\left(\frac{\partial C_2'}{\partial \varphi} \right)_{\varphi=0} = 0, \quad (15)$$

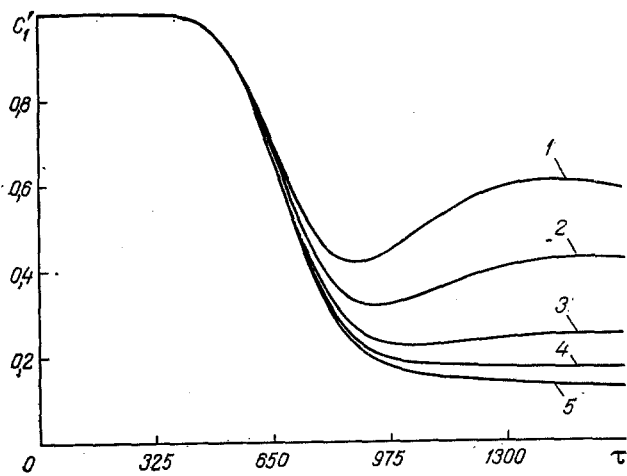


Fig. 3. Hydromodulus effect ξ (m^3/kg) on output curves: 1) $\xi = 1 \cdot 10^{-3}$; 2) $2 \cdot 10^{-3}$; 3) $5 \cdot 10^{-3}$; 4) $10 \cdot 10^{-3}$; 5) $20 \cdot 10^{-3}$.

$$\left. \frac{\partial C'_2(Z, \bar{\tau})}{\partial \varphi} \right|_{\varphi=1} = \frac{\text{Bi}}{2} [C_2(Z, \bar{\tau})|_{\varphi=1} - C_1(Z, \bar{\tau})], \quad (16)$$

$$C'_2 = C_0(0), \quad (17)$$

$$C'_{1i} = C_1(0) = 0, \quad (18)$$

$$\frac{dC'_1}{d\tau} = \frac{1}{\xi} (C'_1|_{z=1} - C'_0|_{z=0}), \quad (19)$$

where $\text{Pe} = Lv_2/D_0\varepsilon$; $\delta = D_{e_0}L/R^2v_z$; $\text{Bi} = k2R/D_{e_0}$; $\bar{D}_e = D_e/D_{e_0}$; $C_1 = C'_1/C_0$; $C'_2 = C_2/C_0$; $Z = z/L$; $\bar{\tau} = \tau v_z/L$; $f = x/R$. This system describes a scheme for extraction from a solid material with repeated solvent recirculation (Fig. 1).

System (11)-(19) was solved numerically by finite-difference methods. We used a five-point conservative Krank-Nicholson scheme [12-13]. Because of the nonlinearity, the problem was solved by successive approximation at each time step. The treatment converged after three or four iterations.

This solution was used under conditions close to real ones in numerical experiments to establish the effects of variable mass transfer coefficient $D_e = f(C_2)$ longitudinal mixing, and hydromodulus.

We examined $D_e = D_{e_0}/(1 + \alpha \bar{C}_2)$ for $\alpha \varepsilon < 0$; this relationship corresponds to D_e increasing with the concentration. Figure 1 shows output curves $C'_1 = f(\tau)$ for a bed of depth 0.5 m composed of spherical particles of diameter $1 \cdot 10^{-3}$ m. Column section $S = 2 \cdot 10^{-4}$ m^2 , $\text{Pe} = 64$, $\text{Bi} = 10^7$, $D_{e_0} = 1 \cdot 10^{-11}$ m^2/sec , liquid speed in free section of column $v_z = 0.4 \cdot 10^{-3}$ m/sec. One concludes that the effects of the variable diffusion coefficient are slight and merely serve to retard the curve.

The longitudinal mixing effect, as expressed by the Peclet number, is shown in Fig. 2; the Peclet number varied from 1 to 94.18. As D_0 increases, the emergence time decreases, but the curve becomes less steep.

Interest attaches to the effects of the hydromodulus, which are illustrated by Fig. 3. The conditions correspond to Figs. 1 and 2, while the hydromodulus varied over the range $1-20 \cdot 10^{-3}$ m^3/kg . Before the start of recirculation, the curves corresponding to the different hydromoduli coincide. As the hydromodulus decreases, C_1 increases after the start of recirculation. This increase is more pronounced for small hydromoduli.

NOTATION

α , coefficient in the relation $D_e = f(\bar{C}_2)$; C_1, C_2 , concentrations of the extracted component in the liquid and solid phases, respectively; kg/m^3 ; \bar{C}_2, C_0 , mean and initial concentration in solid phase, kg/m^3 ; C'_1, C'_2 , dimensionless concentrations in liquid and solid

phases, respectively; C_{1i} , initial concentration in liquid phase at bed input, kg/m^3 ; C'_{1i} , dimensionless concentration in liquid phase at bed input; D_e , mass conductivity, m^2/sec ; D_{e0} , initial mass conductivity, m^2/sec ; D_l , longitudinal diffusion coefficient, m^2/sec ; k , mass transfer coefficient, m/sec ; L , bed length in column, m ; x , spatial coordinate in grain, m ; R , particle size, m ; S , column section, m^2 ; T , parameter taking into account particle shape; V_0 , liquid volume in reservoir, m^3 ; v_z , liquid phase velocity in the total column section, m/sec ; z , spatial coordinate in bed, m ; Z , dimensionless spatial coordinate in bed; β , ratio of the amount of the extracted component in solid phase to flow rate of liquid phase, $\text{kg}/(\text{m}^3/\text{sec})$; ϵ , bed porosity, m^3/m^3 ; ϵ_1 , internal porosity of grain, m^3/m^3 ; τ , time, sec ; τ' , dimensionless time; φ , dimensionless spatial coordinate in grain; ξ , hydromodulus, m^3/kg ; Bi , Biot number; Pe , Peclet number; w , δ , dimensionless parameters.

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LIQUID AND GAS FILTRATION IN A TWO-LAYER POROUS MATERIAL

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UDC 532.546

A velocity distribution is obtained for a filtration boundary layer near an impermeable wall and near the boundary between two porous layers with differing permeabilities.

Increases in the efficiency of technological processes taking place in porous materials and improvements in apparatus and equipment which use such materials is to a great extent controlled by the need for deeper more detailed studies of the hydrodynamic structure of liquid and gas flows in porous media. One of the unique features of filtration flows which exist in various industrial equipment is that they are often realized under conditions such that the microgeometry of the porous medium, as defined by the size of pores or grainy material particles is comparable to the geometric dimensions of the porous layer itself. In this case, hydrodynamic effects which develop in filtration flow of liquids and gases along the surface of contact of porous materials with another permeable material or an impermeable wall become significant.

Volgograd Polytechnic Institute. Translated from *Inzhernerno-Fizicheskii Zhurnal*, Vol. 51, No. 4, pp. 542-555, October, 1986. Original article submitted August 12, 1985.