4. M. K. Pis'men, Hydrogen Production in the Oil Refining Industry [Russian translation], Khimiya, Moscow (1976).
5. V. D. Borisevich, V. Yu. Kozhevnikov, N. I. Laguntsov, and G. A. Sulaberidze, "On the separation of multicomponent mixtures in membrane elements," Teor. Osn. Khim. Tekhnol., 17, No. 1, 60-65 (1983).
6. A. G. Bondarenko, I. F. Golubev, and I. M. Britan, "Method of computing membrane separation processes for a multicomponent gas mixture," Teor. Osn. Khim. Tekhnol., 17, No. 1, 106-108 (1983).
7. Yu. A. Buevich, "Mass transfer for chemical or phase transformation in a solid," Inzh.-Fiz. Zh., 46, No. 2, 233-240 (1984).
8. D. A. Frank-Kamenetskii, Diffusion and Heat Transfer in Chemical Kinetics, Plenum Publ. (1969).

KINETICS OF DISSOLUTION OF THE FACES OF A SLOT CHANNEL IN A SEAM

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The mathematical model for slot channel wall dissolving at a constant liquid velocity under continuous pumping through of the fresh dissolvent and circulation of its fraction is developed. The treatment of the experimental data suggests the values of mass transfer coefficients for kerosene dissolving of sulfur at different temperatures. Estimate is made of liquid front concentration during hydrobreak of the salt layer.

In the geotechnological processes of subterranean sulfur extraction and recovery of NaCl, KCl, and other salts, the solvent is kept in motion between wells by hydraulic fracturing of the bed or seam at a constant rate of $1.6 \cdot 10^{-3}$ to $3.5 \cdot 10^{-3}$ m/sec with a solvent mass flow rate of $8.3 \cdot 10^{-5}$ m³/sec [1]. In many cases the drift or "slot channel" collapses under the action of rock pressure after hydraulic fracturing. It is advisable to dissolve the top and bottom faces of the channel in order to stabilize it and allow continued removal of the ore.

The objective of the present study is to investigate analytically and experimentally the kinetics of dissolution of the faces of a slot channel at a constant fluid velocity in two working regimes; the continuous once-through pumping of fresh solvent and the circulation of a predetermined volume of solvent. The problem of the kinetics of dissolution of the surface of a horizontal seam with a continuous incoming supply of fresh solvent has been solved by Aksel'rud [2]. Using the latter's method, we solve the stated problems of dissolving the walls of a slot channel.

A diagram of the process is shown in Fig. 1. The solvent moves along a channel of length L, width b, and height H from left to right at a velocity w. The dissolution concentration is reduced from C_S at the solid surface to C_1 in flow. Such a process can be described from the system of equations [2]:

$$\frac{\partial C_1}{\partial x} = \frac{K\sigma}{w}(C_s - C_1); \tag{1}$$

$$\frac{\partial h}{\partial t} = \frac{K}{\rho_т}(C_s - C_1). \tag{2}$$

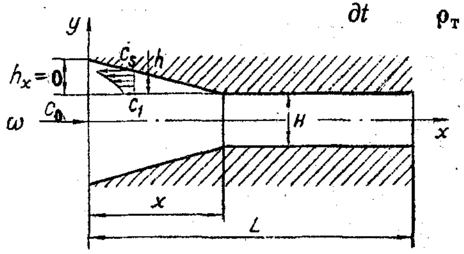

Fig. 1. Diagram of dissolution of the slot channel.

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Substituting the value of C_1 from Eq. (2) into the left-hand side of Eq. (1), and the value of $C_s - C_1$ into its right-hand side, and integrating the result with respect to t, we obtain

$$\frac{\partial h}{h} = -\frac{K\sigma}{w}\partial x. \tag{3}$$

The integration of this equation yields

$$\ln h = -\frac{K\sigma}{w}x + A(t). \tag{4}$$

At x = 0 we have $h = h_0$, $A(t) = \ln h_0$, and Eq. (4) acquires the form

$$h = h_0 \exp\left[-\frac{K\sigma}{w}x\right]. \tag{5}$$

We obtain h_0 by integrating Eq. (2), because $h = h_0$ and $C_1 = C_0$ at x = 0:

$$h_0 = \frac{K}{\rho_T}(C_s - C_0)t. \tag{6}$$

Taking (5) and (6) into consideration, we obtain from Eq. (2)

$$\frac{C_s - C_1}{C_s - C_0} = \exp\left[-\frac{K\sigma}{w}x\right]. \tag{7}$$

This equation coincides with Aksel'rud's result [2] for the dissolution of a seam by a turbulent fluid flow under the following conditions, which are valid in practice:

$$\frac{K\sigma D}{w^2} \ll 1; \quad \frac{wx}{D} \gg 1.$$

It follows from Eq. (5) that saturation of the fluid sets in at a distance $x = \infty$. Consequently, recirculation of a certain portion of the fluid of volume V is necessary in order to obtain a concentrated solution. To form the balance of dissolved matter we determine the average height $\bar{h}$ of the dissolved zone with allowance for (5):

$$\bar{h} = \frac{1}{x}\int_0^x h\,dx = \frac{h_0}{x}\int_0^x \exp\left[-\frac{K\sigma}{w}x\right]dx = \frac{wt}{\sigma x \rho_T}(C_s - C_0)\left(1 - \exp\left[-\frac{K\sigma}{w}x\right]\right). \tag{8}$$

Then the balance of dissolved matter is

$$2Lb\bar{h}\rho_T = (C_1 - C_0)V. \tag{9}$$

Dividing this expression by $C_s - C_0$, we obtain the degree of saturation of the solution:

$$\eta = \frac{C_1 - C_0}{C_s - C_0} = \frac{2Lb\bar{h}\rho_T}{(C_s - C_0)V}; \quad 0 < \eta < 1. \tag{10}$$

Substituting the value of C_1 from Eq. (9) into (2) for $h = \bar{h}$ and integrating the result, we obtain

$$\eta = 1 - \exp(-\tau), \tag{11}$$

where $\tau = \frac{2Lb}{V}Kt$ is the dimensionless time.

Equations (5)-(7), and (9)-(11) can be used to determine the quantity K from experimental data and to calculate the time t required to attain a prescribed degree of saturation η under any specific conditions. For processing the experimental data it is convenient to use Eq. (11) if the form

$$\Phi = Kt, \tag{12}$$

where

$$\Phi = -\frac{V}{2Lb}\ln(1 - \eta).$$

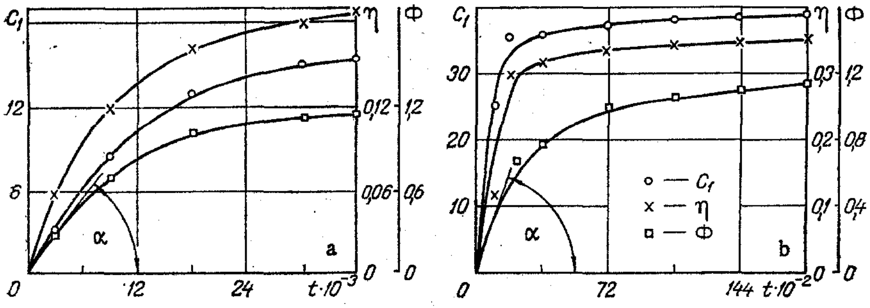

Fig. 2. Kinetics of dissolution of sulfur from a core sample of sulfur ore mildly impregnated with kerosene at T_{av} = 378°K (a) and 408°K (b); $K = C_1 \cdot \tan \alpha$, kg/m³; $t \cdot 10^{-2}$, sec; Φ, m.

To calculate the stabilization time of hydraulic fracturing fissures in subterranean sulfur extraction it is of practical interest to estimate the value of K in the dissolution of sulfur ore by kerosene. We determined its value from experimental data obtained on a test apparatus consisting of an enameled vessel with a mixer, in which a batch of kerosene was heated and kept at a constant temperature. A core sample of sulfur ore with all but one of its surfaces insulted by epoxy resin was submerged below the kerosene level. The surface to be dissolved was evened and measured beforehand. Samples of the solution were withdrawn at set time intervals for determining the instantnaeous concentration C_1. Figure 2 shows the experimental data and the results of their processing at temperatures below and above the melting point of sulfure (392°K) according to relation (12).

The inflections of the Φ(t) curves indicate a change in the mass-transfer mechanism with time; the rapid dissolution of sulfur from large inclusions goes over to slow leaching from the porous matrix formed by the undissolved limestone. The values obtained for K are close to the experimental data of [3-5] and make it possible to calculate the necessary parameters of the process according to Eqs. (7) and (11) in any specific situation. For example, according to Eq. (7), the concentration of the water at the flow front in a slot (fissure) formed by hydraulic fracturing of a salt bed [1] for x = 250-300 m, b = 1.5 m, $H = 5 \cdot 10^{-3}$, and $K = 2 \cdot 10^{-5}$ m/sec is close to the saturation concentration.

NOTATION

η, degree of saturation of solution; C, concentration of solution, kg/m³; C_s, saturation concentration, kg/m³; H, L, b, height, length, and width of slot channel, m; V, volume of solvent batch, m³; x, y, coordinates, m; D, diffusion coefficient, m²/sec; t, time, sec; τ, dimensionless time; K, dissolution rate factor, m/sec; $\sigma = 2bdx/Hbdx = 2/H$, specific surface of dissolution, m²/m³; ρ, material density, kg/m³; h, depth of layer, m; w, solvent flow velocity, m/sec. Indices: 0, initial value or value at x = 0, 1, instantaneous; T, solid.

LITERATURE CITED

1. R. S. Permyakov, V. S. Romanov, and M. P. Bel'dy, Technology of Salt Mining [in Russian], Nedra, Moscow (1981).
2. G. A. Aksel'rud, Mass Transfer in a Solid—Liquid System [in Russian], Lvov Univ. (1970).
3. E. G. Gordienko, "Process of sulfur extraction from sulfur ores by tetrachloroethylene," Author's Abstract of Candidate's Dissertation, Engineering Sciences, Lvov (1978).
4. M. Zelin'ski "Mass transfer processes in a solid—liquid system, accompanied by gas production, under conditions of mechanical and pneumatic mixing," Author's Abstract of Candidate's Dissertation, Engineering Sciences, Lvov (1974).
5. A. I. Dubynin, "Mass transfer in a solid—liquid system, compounded with the liberation of a gaseous phase," Author's Abstract of Candidate's Dissertation, Engineering Sciences, Lvov (1974).