KINETICS OF SOLUTION OF A BED OVERLAIN BY A SOLID POROUS MEDIUM

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The kinetics of solution of a bed dissolved by a liquid moving in a porous medium overlying the bed are examined. The theoretical and experimental studies described relate the kinetics with the diffusion and hydrodynamic parameters of the process.

The underground extraction of solids, mainly salts, is a highly economic mining technique. Among the factors dictating the relatively infrequent use of this method one of the most important is the lack of scientific and experimental data that would permit an evaluation of the efficiency of the process. There are two essentially different modes of occurrence of extractable material in an inert porous medium:

1. The material is dispersed in the porous medium and extraction is based on the percolation of liquid through the latter.
2. The material occurs in the form of a bed overlain by a porous medium.

The kinetics of extraction under conditions corresponding to the first mode of occurrence have already been examined by the authors [1]; therefore the present communication is concerned exclusively with the second.

As the liquid washes over the bed, the bed is dissolved, as a result of which a free space may form between the bed and the porous medium. We shall assume that (as frequently occurs in practice) this free space is filled as a result of the systematic settlement of the soil.

The determination of the rate of solution is based on the following equation obtained by one of the authors [2]:

$$q = \frac{2}{\sqrt{\pi}}(c_s - c_1) Db\sqrt{\mathrm{Pe}}, \quad \mathrm{Pe} = \frac{UL}{D}. \qquad (1)$$

The amount of material dissolved from the bed per second is picked up by the liquid leaving the region of the bed. Hence

$$q = \frac{2}{\sqrt{\pi}}(c_s - c_1) Db\sqrt{\frac{UL}{D}} = bhU(\bar{c}_2 - c_1). \qquad (2)$$

Assuming $c_1 = 0$, we get

$$\bar{c}_2/c_s = m\sqrt{L}, \qquad (3)$$

where

$$m = \frac{2}{\sqrt{\pi}}\sqrt{\frac{D}{U}}\frac{1}{h}.$$

The experiments performed to study the extraction kinetics were carried out on the experimental rig shown in Fig. 1, which consists of a horizontal apparatus and solvent supply and heating systems.

The apparatus 1 is a steel trough of rectangular cross section, to the front of which there is attached a brass gauze 2 (clear opening 0.16 mm). The solvent percolation rate is regulated by means of stopcock 3 at the outlet of chamber 4. At the opposite end, cover 5 houses a spring mechanism designed to compress the porous medium. The compression mechanism consists of a piston 6 of rectangular cross section with drilled openings for the passage of solvent over which a brass gauze is stretched. The piston is displaced and held in the working position by spring 7 which is secured between two discs of special mesh 8. The top of the apparatus is enclosed by a cover 9 which supports thermometers 10 for checking solvent temperature.

As solvent we used distilled water which was heated in a coil-type heat exchanger 11 with water preheated to T = 298° K in a temperature regulator 12 and continuously circulating in the temperature regulator—heat exchanger system. The water supply system consisted of two coupled vessels 17 supported at the +2-meter level above the apparatus. This system ensured a head large enough to overcome the resistance of the porous medium and provide the required percolation rate. The large capacity of the vessels combined with the relatively low consumption of liquid during the experiment ensured a constant head and hence constant percolation rate.

The test material 14, consisting of nine plates of $CaSO_4 2H_2O$ measuring 35 × 10 × 100 mm each, was attached to the bottom of the apparatus to form a single bed 900 mm long. To make sure that the attachment was strong enough and to prevent solution of the lateral surfaces of the plates, the latter were bonded in place in a cement grout 15, so that only the upper surface of the bed of prescribed length could be dissolved.

In each series of experiments we determined the concentration of liquid as a function of the length of the dissolved bed for a given velocity U and a definite porous medium particle size. The length of the bed was varied by coating the plates with bakelite lacquer.

As a porous inert medium 13 we used a mixture of particles of white corundum prescreened in order to obtain a monodisperse material and washed until traces of Ca disappeared. This material was loaded into the apparatus and compacted on a vibrating table, after which the apparatus was closed with cover 9, and the porous medium was kept in the compacted state by means of spring 7 (gasket 16).

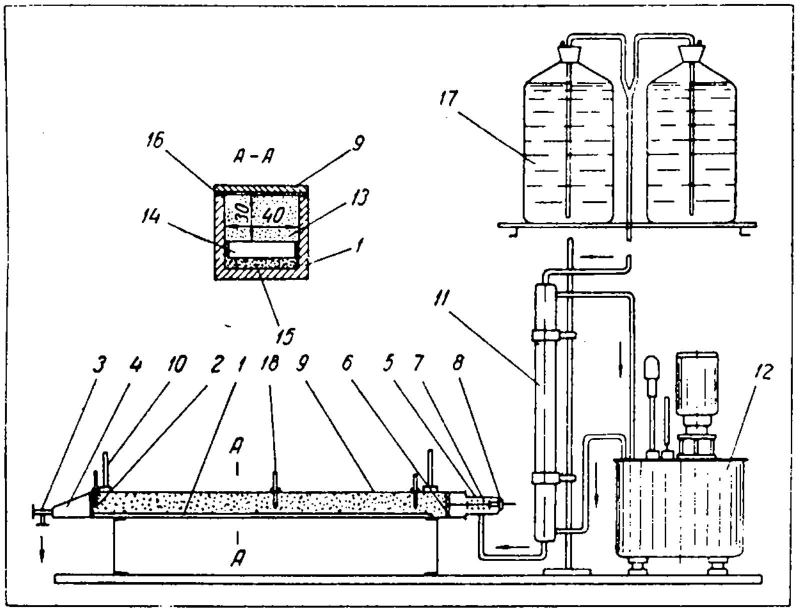

Fig. 1. Experimental rig (schematic).

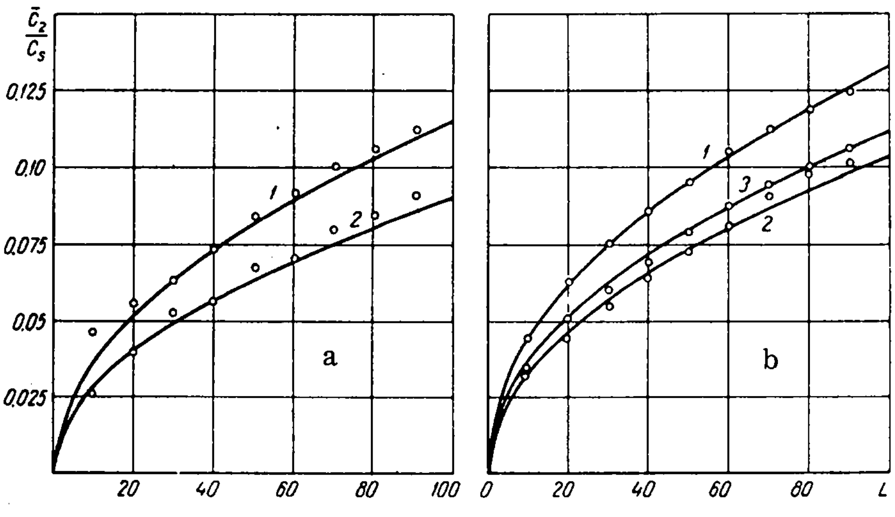

Fig. 2. Solution kinetics for bed with d = 0.13 mm (a) and d = 0.18 mm (b): 1, 2, 3) kinetic curves based on Eq. (3) for U = 0.003, 0.0019, and 0.00084 m/sec, respectively; circles—experimental results (L, mm).

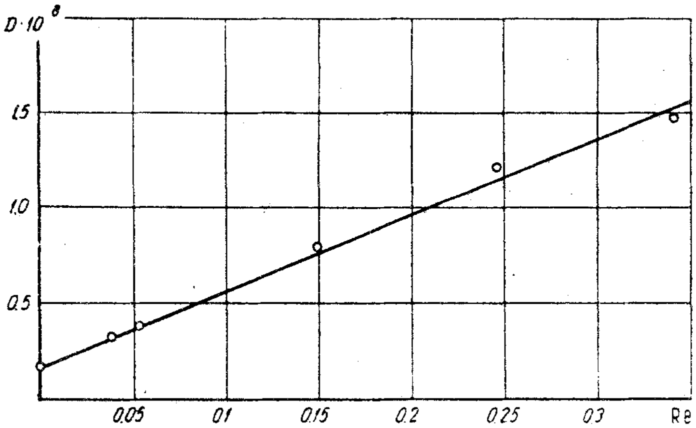

Fig. 3. Mass transfer coefficient D, m^2/sec, as a function of Reynolds number.

Distilled water at temperature T = 298° K and pressure $2 \cdot 10^5$ N/m^2 entered the apparatus 1 at a given velocity and, passing over the part of the bed that was not coated with a protective film, dissolved the plate material. After leaving the apparatus, the water was analyzed for Ca ion content using Trilon-B.

The experiments were conducted at different porous medium particle sizes and at different percolation rates in the range $3 \cdot 10^{-5}$ m/sec to $2 \cdot 10^{-4}$ m/sec. Figure 2 presents typical results showing the increase in concentration with respect to length of bed.

The curves in the figure are based on Eq. (3) for a rational choice of the constant m. As we see, theoretical equation (3) is in satisfactory agreement with experiment. The mass transfer coefficient is given by

$$D = \frac{\pi}{4} h^2 m^2 U \ \mathrm{m^2/sec} \qquad (4)$$

and the dependence of this coefficient on Reynolds number is shown in Fig. 3.

At Re = 0 the assumed value $D = 1.5 \cdot 10^{-9}$ m^2/sec, which corresponds to the molecular diffusion coefficient.

We also determined the distribution of liquid concentration over the height of the bed. The liquid for analysis was sampled through sliding tubes (18 in Fig. 1) secured in the cover. The concentration fell over the height as follows: in the direct proximity of the bed surface it was equal to the saturation concentration c_s, but at a certain point at distance y it vanished. The value of y increased with distance from the point at which the liquid was introduced.

Thus, within the porous medium there is formed a boundary diffusion layer, which confirms the starting assumptions on the basis of which Eq. (1) was obtained.

NOTATION

q—amount of material going into solution in unit time, c_s—saturation concentration, c_1—concentration of liquid washing the bed, D—mass transfer coefficient, b—width of bed, U—percolation rate, L—length of bed, $\bar{c}_2$—concentration of liquid at outlet from apparatus, h—height of layer of porous medium, d—particle size of porous medium.

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2. G. A. Aksel'rud, Theory of Diffusion Extraction of Materials from Porous Media [in Russian], MVO, L'vov, 1959.

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