MASS TRANSFER DURING EXTRACTION OF SULFUR
FROM A LAYER OF SULFUR ORE

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A rather simple method has been developed for determining the process time of almost complete (98%) sulfur extraction from a layer of sulfur ore, as a function of the ore properties and of the layer length.

The extraction method of separating soluble components from solid porous particles is used in various industries, which include, for example, sulfur mining [2].

When extracting sulfur from its ores, one encounters several problems in handling so-called difficult-to-enrich ores.

In our earlier tests we have explored the mechanism of sulfur mass transfer from an ore particle to a liquid solvent (kerosene). It has been established that, in character, this process is one of internal diffusion, i.e., the limiting stage of the process is the diffusion of sulfur through a porous structure of an ore particle filled with kerosene. We have performed experiments, which will be described here, with the purpose of explaining the characteristics of mass transfer during sulfur extraction from a layer of ore particles.

According to [1], two stages must be distinguished in the extraction of a substance from a layer of porous particles. The first stage is characterized by the presence of the substance to be extracted in the porous particles and it lasts until the soluble substance has been entirely extracted from a particle at the beginning of the layer (along the path of solvent flow). The duration of the first stage is determined from the equations:

$$\frac{Dt_1}{R^2} = \frac{1}{6} \cdot \frac{\gamma}{c_s - c_i}. \tag{1}$$

During the second stage there appear two zones in the layer. One zone does not contain any of the substance to be extracted, in the other zone some of that substance is still retained. Beginning at time t_1, the boundary between both zones shifts in the direction of solvent flow at a constant velocity:

$$v = \frac{c_s - c_i}{\gamma} \cdot \frac{U\gamma_0}{\eta m}. \tag{2}$$

The duration of the second stage is

$$t_2 = \frac{\eta \gamma m L}{\gamma_0 (c_s - c_i) U}. \tag{3}$$

In some cases [1], when the porous particles are small (1-2 mm), the length of the first stage is negligible. During the processing of sulfur ores after the last comminution cycle, however, there remain 8-10% of 35-60 mm large particles. The time of duration of the first extraction stage will in this case be considerable and must be taken into account.

Thus, the total time of extraction from a layer of porous particles is
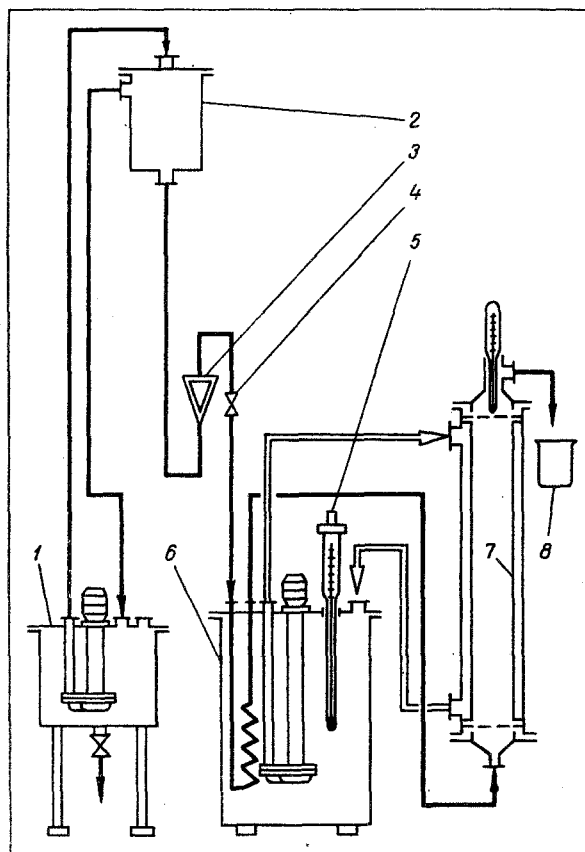
$$t = t_1 + t_2. \tag{4}$$

Fig. 1. Schematic diagram of the test apparatus.

The porosity of sulfur ore is determined predominantly by its sulfur content alone. All pores are taken to be filled with sulfur. In fact, only 2-3% of all pores are not filled with sulfur. Disregarding this fraction, we have

$$m = \beta \, \frac{\gamma_0}{\gamma} . \tag{5}$$

Inserting the value of t_2 from (3) into (4) and taking into account (5) together with the condition $c_i = 0$, we will then obtain

$$t = t_1 + \frac{\eta \beta}{c_s U} \, L. \tag{6}$$

Equation (6) is represented by a straight line having an intercept t_1 on the axis of ordinates t (at $L \to 0$) and a tangent (with respect to the axis of abscissas L)

$$\mathrm{tg}\, \alpha = \eta \beta / c_s U. \tag{7}$$

Inserting (2) into (7) gives

$$\mathrm{tg}\, \alpha = 1/v. \tag{8}$$

It follows from (8) and (7) that tan α represents the time spent on extracting the soluble substance from a unit length of the layer.

The L−t diagram has been plotted from test data so that by extrapolating the straight line t = f(L) to its intersection with the t-axis, one can determine the duration of the first extraction stage t_1 and then from Eq. (9), which is derived directly from Eq. (1), the diffusivity:

$$D = \frac{1}{6} \cdot \frac{\gamma R^2}{c_s t_1} . \tag{9}$$

For studying the kinetics of sulfur extraction from a layer of ore by means of kerosene, we performed tests in an apparatus (Fig. 1) consisting of an extractor filled with a given ore and a solvent preparation and feed system including a storage tank 1 with an immersed pump, a pressure tank 2, a rotameter 3, a regulator valve 4, and a contact thermometer 5 installed inside a thermostat 6.
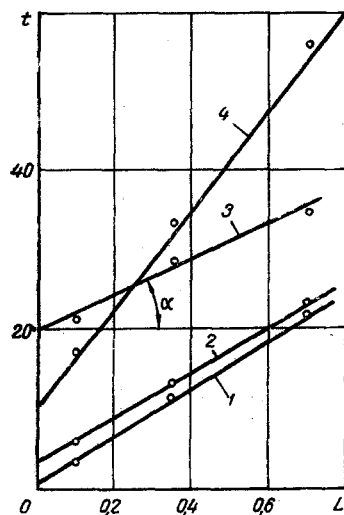
Fig. 2. Kinetics of sulfur extraction from a layer of sulfur ore particles, t = f(L): 1–4) theoretical t = f(L) curves plotted according to Eqs. (6) and (7). Test temperature and particle size: 140°C and 0.375 mm (1), 140°C and 1.5 mm (2), 140°C and 4 mm (3); 100°C and 1.5 mm (4). The slope angle of the t = f(L) line is α: the dots indicate test points.

The extractor 7 was made up of a metallic vertical container enclosed by a jacket for heating by means of oil pumped from the thermostat 6. Removable filters were installed at the top and at the bottom of the extractor. The extractor was 70 cm high and had a 10 cm² cross section.

The tests were performed on sulfur ore with a fine-dispersion texture, coming from the Podorozhnensk sector of the Rozdol'sk deposits. After comminution, the ore was passed through sieves for segregation into a 0.375 mm (0.25–0.50 mm), a 1.5 mm (1-2 mm), and a 4 mm (3-5 mm) fraction. The sulfur content in these separate fractions was determined by the sulfite method and found to be 29.9%, 24.3%, and 19.4% respectively. The sulfur content in the tailings (ore residue) fluctuated between 0.16 and 0.8%.

Lamp kerosene (GOST 4753–49) was used as the solvent.

The test procedure was as follows. Kerosene was pumped from the storage tank 1 into the pressure tank 2, from where it proceeded, under gravity, through the coil of thermostat 6 into extractor 7. Here the kerosene filtered through an ore layer while dissolving the sulfur contained in it. The solution was collected in the beaker 8. The test temperature was preset and regulated by means of the contact thermometer 5; the flow rate of kerosene was measured and regulated by means of the rotameter 3 and the regulating valve 4. The solution which had been collected in beaker 8 was then cooled to 20°C. Crystalline sulfur which had precipitated was then filtered, dried, and weighed. A test was considered completed when the concentration of the solute leaving extractor 7 had been reduced to approximately 0.02cs.

The tests were performed at a temperature of 140°C and at a constant filtering velocity $U = 1.5 \cdot 10^{-3}$ m/sec. Three tests were performed for each fraction with three different lengths of the ore layer: 0.1, 0.35, and 0.7 m.

Only ore particles of the 1.5 mm fraction were tested also at a 100°C temperature, with all other test conditions remaining the same.

The test results are shown in Fig. 2 in the form of t = f(L) curves. Theoretical curves based on Eqs. (7) and (6) are also shown here. A comparison of both indicates a close agreement between tested and calculated values.

The values of diffusivity, as determined by our proposed method at 100°C and 140°C, were $5 \cdot 10^{-9}$ and $7.9 \cdot 10^{-9}$ m²/sec respectively.

At 140°C the slope tan α for 0.375 mm, 1.5 mm, and 4 mm particles was 30.2, 27.9, and 21.7 min/m respectively. For the 1.5 mm particles at 100°C the slope was tan α = 54 min/m.

Thus, a rather simple method has been developed for determining the process time of almost complete (98%) extraction of sulfur from a layer of sulfur ore, as a function of the ore properties and of the layer length.

NOTATION

R   is the radius of an ore particle;
γ_0 is the density of the ore;

γ is the density of the medium;

η is the mass of ore particles per unit volume;

β is the sulfur content per unit mass of ore;

m   is the porosity of the ore particles;

t   is the total time of extraction;

t_1 is the duration of the first stage;

t_2 is the duration of the second stage;

L   is the length of the ore layer;

U   is the filtering velocity of the solvent;

c_s is the saturation concentration;

c_i is the initial concentration;

D   is the diffusivity;

α is the slope angle of the straight line $t = f(L)$;

v   is the velocity of the interzonal boundary shaft.

LITERATURE CITED

1. G. A. Aksel'rud and E. M. Semenishin, Vestn. L'vovsk. Politekh. Inst., No. 10 (1968).
2. Sulphur, No. 74 (1968).