MASS EXCHANGE BETWEEN A SOLID AND A GAS–LIQUID MIXTURE, COMPLICATED BY LIBERATION OF THE GASEOUS PHASE

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Mass exchange between a solid and a gas–liquid mixture in a diffusion chemical reaction, accompanied by liberation of the gaseous phase, is investigated experimentally.

We discuss here the mass exchange between a solid and a liquid which occurs in a diffusion chemical reaction and is accompanied by liberation of the gaseous phase. Reactions of this type are widely used in the chemical industry. They include decomposition of carbonates by acids (with the liberation of CO_2), decomposition of fluorapatites by acids (with the liberation of HF), and many reactions between metals and acids (with the liberation of H_2).

The kinetics of these processes has been investigated in a number of papers [1-3]. Liberation of gaseous reaction products accelerates mass exchange. However, the problem of additional intensification arises in many cases, which can be solved either by means of stirring by mechanical mixers or by using an inert-gas flow. Under certain conditions, the latter method is to be preferred [4].

Thus, we shall investigate the mass exchange between a solid and a liquid, accompanied by liberation of the gaseous phase under conditions where agitation is provided by an inert gas.

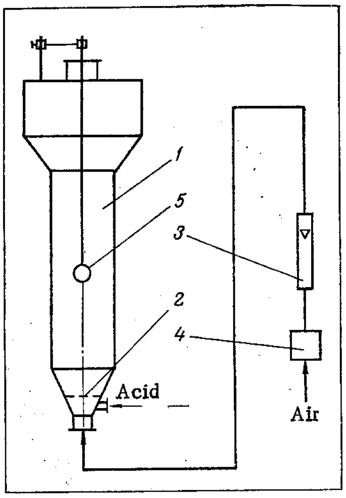

Fig. 1. Schematic diagram of the experimental device. 1) Vertical apparatus; 2) grid; 3) rotameter; 4) gas counter; 5) fixed solid particle.

Fixed spherical magnesium and calcite particles were used as the soluble solids. The liquid phase consisted of solutions of sulfuric, hydrochloric, and nitric acids. Air was used as the agitating gas.

The experimental device (Fig. 1) for investigating mass exchange under the above conditions consists of a vertical cylindrical apparatus, 1, with a diameter of 160 mm, made of a transparent plastic. A gas-distributing grid, 2, with openings 2 mm in diameter is mounted in the lower, conical part of the apparatus. The arrangement of the openings and the mounting height of the grid in the cone are determined on the basis of experimental data in order to provide the most uniform gas distribution over the cross section of the apparatus and to prevent the liquid from running through the grid for a wide range of gas velocities. The gas discharge is recorded by means of a rotameter, 3, while accurate mean discharge values are determined from the readings of counter 4.

Acid in the amount of 10 liters was poured into the apparatus, the gas supply was turned on, and a temperature of 17 ± 1°C was established and kept constant in all experiments. The attached spherical particle 5 was immersed in the reaction volume; it was placed each time in the same fixed position in the apparatus. After a certain measured period of time τ, the particle was taken out, rinsed, and dried

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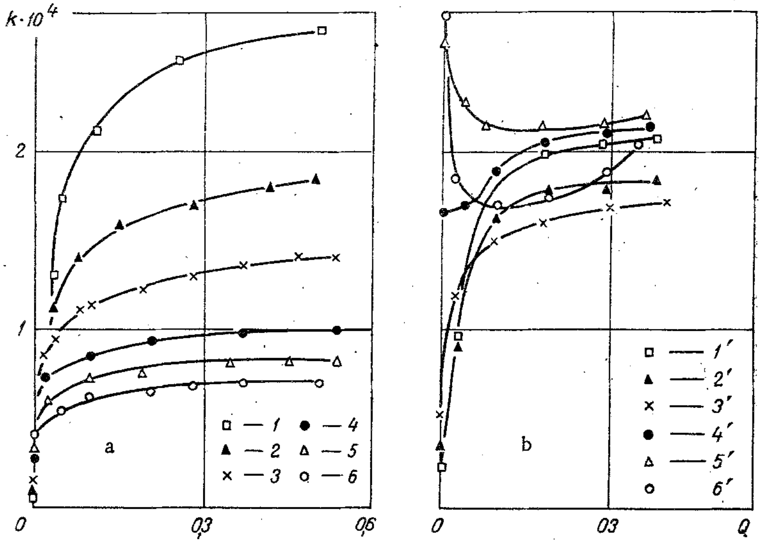

Fig. 2. Mass-transfer coefficient k as a function of the gas discharge Q. a) Interaction between calcite and hydrochloric acid with different concentrations: 1) 0.016; 2) 0.05; 3) 0.1; 4) 0.25; 5) 0.5; 6) 1.0 N; b) interaction between magnesium and sulfuric acid with different concentrations: 1') 0.034; 2') 0.105; 3') 0.72; 4') 1.45; 5') 2.3; 6') 3.15 N; k, m/sec; Q, m³/min.

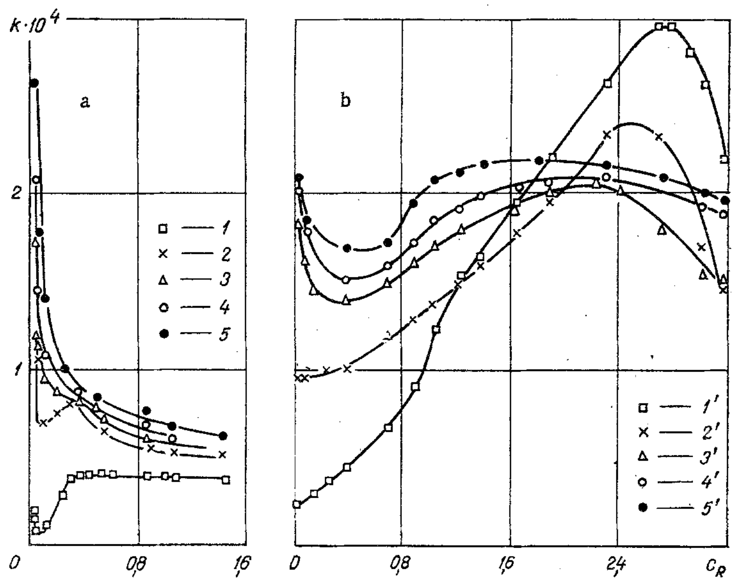

Fig. 3. Mass-transfer coefficient k as a function of the acid concentration c_R for different values of the gas discharge Q. a) Interaction between calcite and hydrochloric acid: 1) 0; 2) 0.02; 3) 0.05; 4) 0.1; 5) 0.51 m³/min; b) interaction between magnesium and sulfuric acid: 1') 0; 2') 0.03; 3') 0.1; 4') 0.18; 5') 0.38 m³/min; k, m/sec; c_R, N.

until its weight remained constant. The amount of the solid substance that had reacted ΔG was determined by weighing. The mass-transfer coefficient k was found by means of the expression

$$k = \frac{\Delta G}{\alpha F c_R \tau},$$

where c_R is the acid concentration, F is the surface area of the particle, and α is the stoichiometric coefficient.

The experimental conditions were such that the concentration c_R and the surface area of the particle F remained virtually constant. This simplified the processing of the results.

In view of the complexity of the process in question, where the liquid is agitated by gaseous phases of different origins and with different chemical compositions, it is extremely difficult to provide any quantitative estimates, and, therefore, the experimental results given here are chiefly qualitative in character.

The primary data obtained in these experiments are given in Fig. 2 in the form of dependences of the mass-transfer coefficient k on the gas discharge Q for different concentrations.

As was found earlier [1, 5], mass exchange with liberation of the gaseous phase is similar to the heat-exchange process in boiling. Therefore, by analogy with heat exchange, we shall represent the mass-transfer coefficient as a function of the driving force, i.e., the acid concentration (Fig. 3).

The chemical reaction rate increases with the acid concentration, as a result of which the amount of gas liberated per unit time increases, which leads to an increase in the mass-transfer coefficient. However, a higher concentration of the acid results in partial insulation of the solid's surface from the liquid reagent. As a result of the combined effect of these two factors, we observe extremum values of the mass-transfer coefficient (Fig. 3, curves 1 and 1').

On the one hand, introduction of an inert gas into the system intensifies the mixing, which enhances mass transfer, while, on the other hand, it increases the degree of insulation of solid particles from the liquid reagent, which reduces the mass-transfer coefficient.

Formally, the effect of either of the gaseous phases on mass transfer is of the same type. However, these actions are essentially different in character, since bubbles of the gas liberated during the reaction process create turbulence in the boundary layer, while the gas introduced for the purpose of mixing increases the liquid velocity relative to the solid particles.

Differentiation between the relative contributions of each gas to the mass exchange is not possible at present. Thus, in interaction between a solid and a gas–liquid mixture, accompanied by liberation of the gaseous phase, we can separate the following factors that materially affect the process: a) mixing; b) screening.

The curves 2-5 and 2'-5', obtained as a result of combined action of the above factors, indicate the regions where gas supply is most efficient. These are regions of low concentrations of the liquid, which are often encountered in industrial practice.

In the range of high-concentrations (up to the critical values), the process occurs at a sufficiently high rate due to the evolution of bubbles, while additional agitation by an inert gas even reduces somewhat the mass-transfer coefficient.

It is impractical to carry out mass-exchange (or heat-exchange) processes in the supercritical region.

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