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MASS TRANSFER IN A ROTOR DISPERSION-FILM APPARATUS

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Results of experimental investigations of the desorption of carbon dioxide from water in a rotor dispersion-film apparatus are presented. The main factors influencing the volume mass-transfer coefficient in the liquid phase and the efficiency of mass transfer in this apparatus were determined. A comparative analysis of the apparatus investigated with other analogous apparatus has been carried out.

In the chemical and petrochemical industries as well as in industries closely related to them, absorption is widely used for removal of deleterious substances from the process and combustible gases and for separation of valuable components from these gases. Column apparatuses have found the widest application in the purification of gases. The efficiency of these apparatuses is increased as a rule by increasing their overall dimensions, which increases the capital and current expenditures for the purification process. A promising way of solving this problem is the use of apparatus with interaction of phases in a swirling flow for realization of mass-transfer processes. At present, these apparatus are designed in two crucially different variants [1–4]:

1) apparatus in which rotary motion of both phases or one of them is initiated with the use of guiding devices without mechanical action; these apparatus have garned wide acceptance and the mechanisms of interaction of the phases in them have been studied in sufficient detail [1–5];

2) rotor apparatus, in which rotary motion of both phases or one of them is initiated by a special rotating device — a rotor.

Analysis of the results of investigations and publications [3, 4, 6] shows that the efficiency of mass transfer in apparatuses, to which energy is supplied from the outside substantially exceeds the kinetic characteristics of contact apparatus in which the interaction between phases is realized by traditional methods in a gas–liquid system, which makes it possible to markedly decrease the overall dimensions of the first-mentioned apparatus.

Among the surface, spraying, and barbotage rotor apparatus, dispersion-film apparatus stand out because, in them, the interaction between a gas and a liquid is activated by a dispersion device in the zone of intensive dispergation of the liquid and is accompanied by the interaction of the phases in the zone of liquid-film flow. The initiation of a swirling flow in such apparatus makes it possible to intensify the processes occurring in them and substantially increase the rate of interaction of the phases at a comparatively low hydraulic resistance.

Rotor apparatus, in which widely used absorption and rectification processes are conducted, are at in the developmental stage at present; therefore, the hydrodynamics of the processes and the mass transfer occurring in them are little known.

For realization of the interaction between a gas and a liquid in a swirling flow, a rotor dispersion-film apparatus has been designed (Fig. 1). This apparatus includes a cylindrical body 1 with tangential input 2 and output 3 branch pipes for the gas and a dispersion device 4, mounted on a drive shaft 5 activated by an electric motor 8, for the liquid. The rotational speed of the drive shaft is controlled by regulator 10 (frequency converter). The dispersion device is designed in the form of a hollow perforated cylinder with a flange, in the upper part of which a vane swirler 6 is installed. The diameter of the apparatus is equal to 0.195 m, the diameter of the dispersion device is 0.054 m, and the angle between the input branch pipe and the horizontal is 7^{o}.

The principle of operation of the apparatus proposed is as follows. A gas (air) is introduce at the bottom of the apparatus; then it passes through the input branch pipe 2 set tangentially to the body and is swirled. A liquid (dis-

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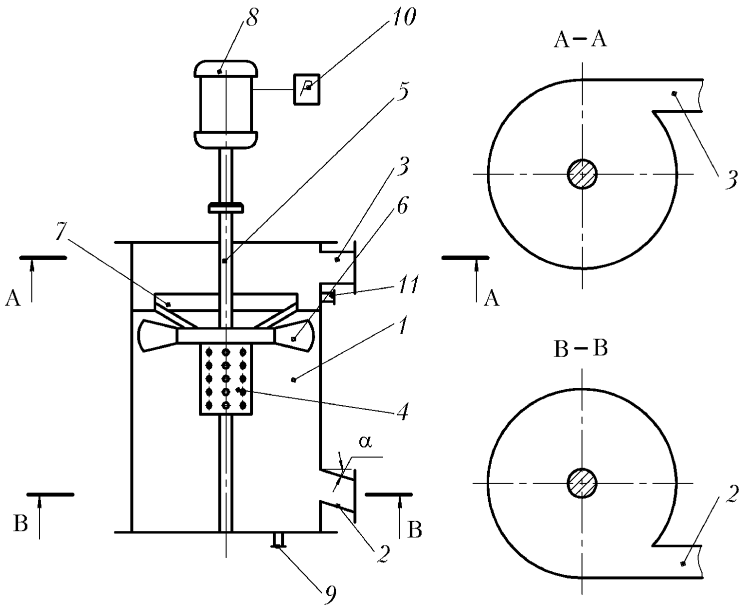


Fig. 1. Scheme of the experimental setup.

tilled water) is saturated with CO_2 and is then transferred through the connection point 11 and the overflow-type device 7 to the rotating device 4, where it is dispergated into drops. Then the water in the form of a film runs down the wall of the apparatus and is removed through the connection point 9. Thus, the gas-liquid interaction in this apparatus is realized in both the dispersion and film regimes.

The aim of the present work is to investigate the influence of the operating conditions of the rotor dispersion-film apparatus described above on the efficiency of mass transfer in it and to compare the characteristics of this apparatus and its efficiency with the characteristics and efficiency of other analogous apparatus. It is often difficult to investigate the characteristics of mass-transfer in actual systems because of their complex design and the aggressiveness and toxicity of gases and liquids interacting in them. For this reason, such investigations are carried out under laboratory conditions with the use of model media, and the results obtained are then extended to a large number of actual systems.

The number of stages and the height of a mass-transfer apparatus are determined by the efficiency of the contact stage and the coefficient of mass transfer occurring in it. When difficultly-soluble gases are absorbed in such an apparatus, the main resistance to the mass transfer in it is set up in the liquid. In this case, the resistance of the gas can be disregarded and it can be assumed that the total mass-transfer coefficient is equal to the mass-transfer coefficient in the liquid $K = \beta_{\text{liq}}$, whose value is usually determined experimentally by the absorption of oxygen and carbon dioxide by water.

Since the largest number of data on the mass transfer in the liquid phase has been accumulated for the desorption of carbon dioxide from an aqueous solution saturated with air, we conducted our experiment in this system. The content of CO_2 was determined by the change in the acidity of the medium, measured with the use of a standard pH meter. On the basis of processing of the experimental data obtained, we determined the dependence of the concentration of CO_2 in an aqueous solution on the acidity of this solution. For pH 5–7, this concentration was calculated by the formula [7]

$$C = 2.69 \cdot 10^{5-\text{pH}} . \tag{1}$$

In the process of experiments, the initial acidity of the solution was changed by no more than 0.03. The temperatures of the gas and the liquid changed in the range 15–18°C. The irrigation-density range was 3–8 $m^3/(m^2 \cdot h)$. The mean flow rate of the gas in the apparatus changed from 2 to 3.6 m/sec. For each operating parameter of the apparatus, the initial and finite concentrations of CO_2 in water were measured and the efficiency of mass transfer was cal-

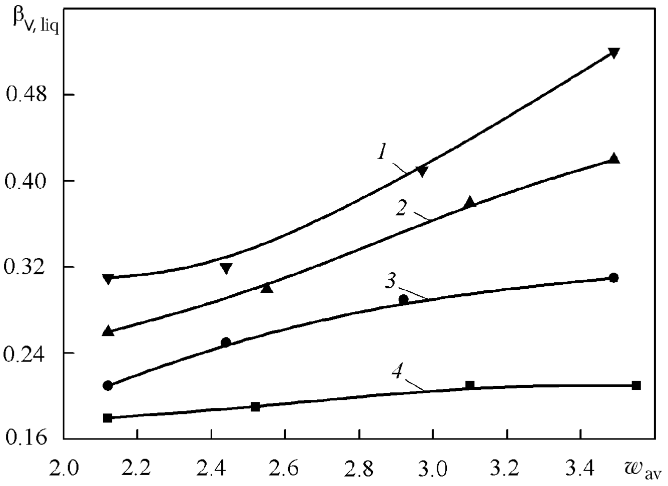


Fig. 2. Dependence of the volume mass-transfer coefficient on the velocity of the gas in a rotor dispersion-film apparatus at n = 1400 rpm: q = 3.266 (1), 4.803 (2), 6.404 (3), and 7.941 $m^3/(m^2 \cdot h)$ (4). $\beta_{v,liq}$, 1/sec; w_{av}, m/sec.

culated. In the case of desorption of CO_2 from water by air, the mass-transfer efficiency was determined by the formula [8, 9]

$$E_{liq} = \frac{C_{in} - C_f}{C_{in}} = 1 - \frac{C_f}{C_{in}} . \tag{2}$$

The mass-transfer coefficient in the liquid phase, related to the working volume of the apparatus, was determined by the formula

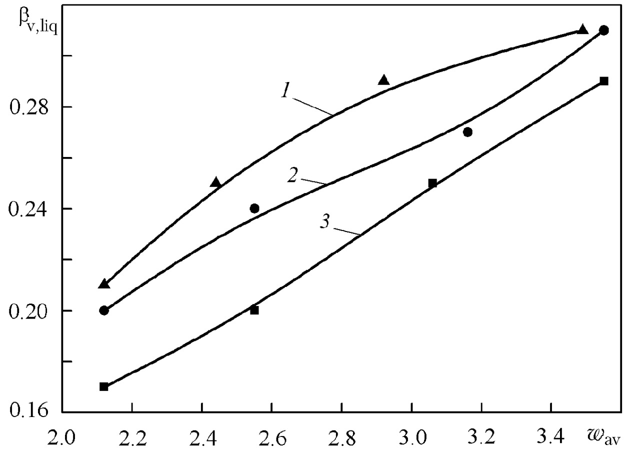
$$\beta_{v,liq} = \frac{L}{V} \ln \frac{C_{in}}{C_f} . \tag{3}$$

The mass-transfer efficiency is defined in terms of $\beta_{v,liq}$ as

$$E_{liq} = 1 - \frac{1}{\exp\left(\frac{\beta_{v,liq} V}{L}\right)} . \tag{4}$$

Figure 2 presents the dependences of the volume mass-transfer coefficient in the liquid phase on the velocity of the gas in the apparatus, determined for different irrigation densities. As is seen from the graph presented, the volume mass-transfer coefficient increases with increase in w_{av}. This is explained by the following facts. An increase in the velocity of the gas in the apparatus leads to an increase in the shear stresses at the interphase boundary; in this case, the liquid film is swirled at the wall of the apparatus. This leads to an increase in the time of residence of the liquid phase in the apparatus and, accordingly, to an increase in $\beta_{v,liq}$. An increase in the irrigation density decreases the volume mass-transfer coefficient because the thickness of the liquid film becomes larger, which aids in increasing the rate of its running down the wall of the apparatus. Since the rotation frequency is one of the most important operating parameters of a rotor apparatus influencing the dispersion composition of the liquid phase, we investigated the influence of the rotation frequency on the volume mass-transfer coefficient in the liquid phase.

Figure 3 presents the dependence of the volume mass-transfer coefficient in the liquid phase on the average flow rate of the gas at different revolutions of the rotor. The increase in the mass-transfer coefficient with increase in the number of revolutions of the rotor can be due to the increase in the peripheral velocity of the dispersion cylinder and, consequently, the increase in the rate of motion of the liquid drops. The dimensions of the drops, formed as a



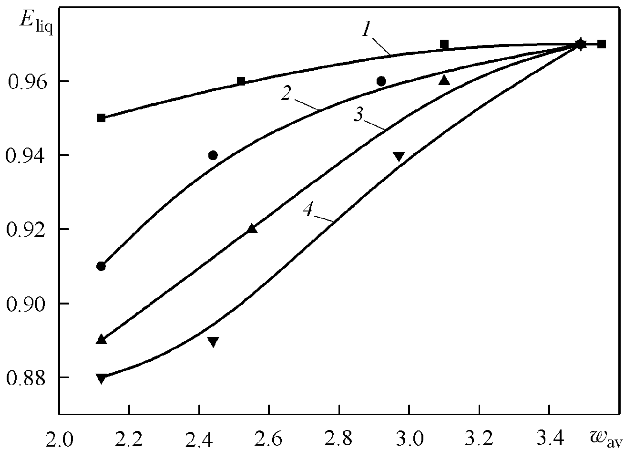


Fig. 3. Dependence of the volume mass-transfer coefficient on the gas velocity in the apparatus at q = 4.803 $m^3/(m^2 \cdot h)$: n = 1400 (1), 1000 (2), and 600 rpm (3). $\beta_{v,liq}$, 1/sec; w_{av}, m/sec.

Fig. 4. Dependence of the efficiency of mass transfer in the apparatus on the gas velocity at n = 1400 rpm: q = 3.266 (1), 4.803 (2), 4.976 (3), and 7.941 $m^3/(m^2 \cdot h)$ (4). w_{av}, m/sec.

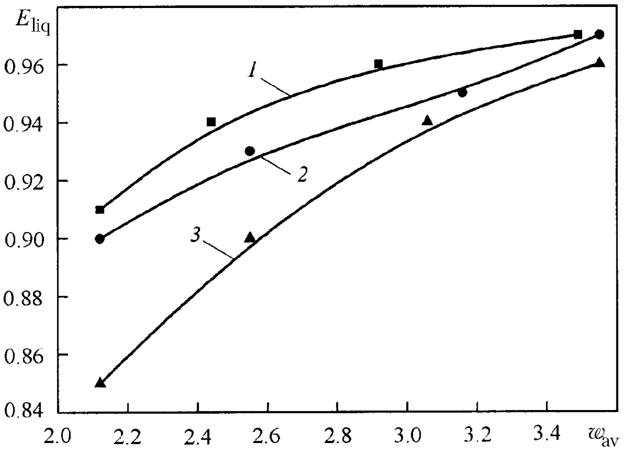


Fig. 5. Dependence of the efficiency of mass transfer in the apparatus on the gas velocity at q = 4.803 $m^3/(m^2 \cdot h)$: n = 1400 (1), 1000 (2), and 600 rpm (3). w_{av}, m/sec.

result of the dispergation of the liquid in the process of its passage through the holes in the wall of the hollow rotating cylinder, decrease and the number of these drops increase with increase in the angular velocity of the rotor. In this case, the surface of the interphase boundary becomes larger. The above-listed factors as a whole serve to intensify the mass transfer.

The dependence of the efficiency of mass transfer in the apparatus on the velocity of the gas in it, obtained for a rotational frequency of the rotor n = 1400 rpm and different irrigation densities, is presented in Fig. 4. As is seen from this graph, the efficiency of the mass transfer increases with increase in the gas velocity and in the irrigation density. This is explained by the following facts. At large irrigation densities, a large amount of a liquid is contained in the volume of the mass-transfer apparatus at any instant of time and, consequently, a large number of new drops with sizes equal approximately to the sizes of the drops at a low irrigation density are formed. As a result, the flows of the interacting phases are turbulized.

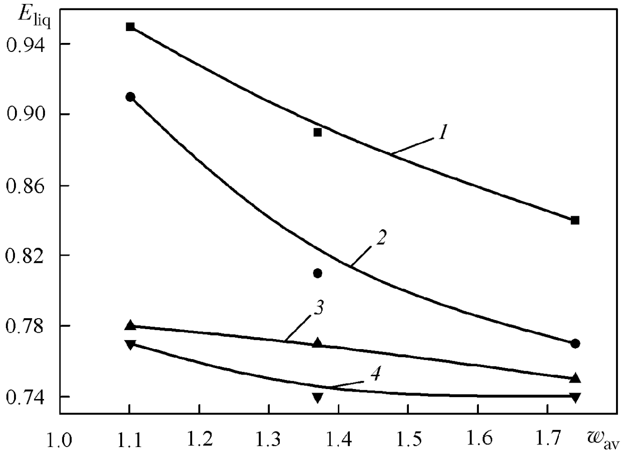


Fig. 6. Dependence of the efficiency of mass transfer in a sievelike tray on the gas velocity: q = 2.538 (1), 3.732 (2), 4.976 (3), and 6.17 $m^3/(m^2 \cdot h)$ (4). w_{av}, m/sec.

An increase in the number of revolutions of the rotor leads to an increase in the efficiency of mass transfer in it due to the above-indicated factors (Fig. 5).

For the purpose of comparative analysis of the apparatus proposed with other analogous apparatus, we investigated the desorption of carbon dioxide from water in a sievelike tray having the following parameters: the diameter of the holes in the tray is equal to 3 mm, the step between the holes is equal to 8 mm, the height of the overflow threshold is 20 mm, and the relative free cross section of the tray is 13.6%. The range of change in the load on the liquid was 2.5–6.2 $m^3/(m^2 \cdot h)$. The average flow rate of the gas in the cross section of the apparatus changed from 1.1 to 1.8 m/sec.

Analysis of the dependences presented in Fig. 6 shows that the efficiency of mass transfer in the sievelike tray being considered decreases with increase in the irrigation density. As is known [2], such trays work well in the foamy regime at definite velocities of the gas. An increase in the velocity of the gas (1.3 m/sec and more) in the sievelike tray being investigated led to a change in the foamy regime of its operation and to a carry-over of liquids drops, which decreased the efficiency of mass transfer in this tray.

Thus, our investigations of the mass transfer in the process of desorption of CO_2 have shown that the efficiency of mass transfer in a rotor dispersion-film apparatus is higher than the efficiency of mass transfer in a sievelike tray. In this case, the limit operating velocities of the gas in the rotor dispersion-film apparatus are fairly higher, which makes it possible to decrease its overall dimensions.

NOTATION

C, C_{in}, C_f, concentrations, %; E_{liq}, efficiency of mass transfer; K, mass-transfer coefficient, 1/sec; L, flow rate of the liquid phase, m^3/sec; n, number of revolutions of the rotor, rpm; q, irrigation density, $m^3/(m^2 \cdot h)$; V, working volume of an apparatus, m^3; w_{av}, average flow rate of a gas in the apparatus, m/sec; β_{liq}, mass-transfer coefficient in the liquid phase, 1/sec; $\beta_{v,liq}$, volume mass-transfer coefficient in the liquid phase, 1/sec. Subscripts: liq, liquid; f, finite; in, initial; av, average; v, volume.

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