PROBABILITY FOR THE COLLISION WITH A SOLID SURFACE AS A DROP PASSES THROUGH A PACKED COLUMN

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A method is proposed for determining the probability that a drop will collide with an element of a packed column. The cases of both ordered and disordered packings are treated. Experimental values of the probability are found for a packing of Raschig rings 25 × 25 mm in size.

Collisions of a drop with a column packing greatly accelerate mass transfer to the drop [1]. In order to carry out calculations for the mass transfer in columns with an "industrial" packing* it becomes necessary to determine the probability for collisions of a drop with an element of the packing as the drop passes through a single "layer" of the packing [2, 3] (i.e., as it traverses a distance equal to the height of a single element of the packing).

We denote by ε_d the probability for a collision of a drop of diameter d, and we denote by ω_d the probability that the drop will traverse the layer without undergoing a collision:

$$\varepsilon_d + \omega_d = 1. \tag{2}$$

If a drop is to pass through an aperture of diameter D without colliding with the wall, the center of a drop (of diameter d) must lie within a circle of diameter D − d. On this basis we can determine the values of ε_d and ω_d for a packing of Raschig rings, either ordered or disordered.

The limiting cases of an ordered packing are the square- and rhombic-packing versions. We distinguish a quadrangle with corners at the centers of four adjacent rings. In the case of square packing this quadrangle is obviously a square, while in the case of rhombic packing it is a rhombus. If the ratio D_c/d_e is large and wall effects can be neglected, the probabilities ε_d and ω_d for the entire layer are equal to the corresponding probabilities for a single element. For a single element, ε_d can be calculated as the ratio of the total area of the walls of the rings, increased by an amount d / 2 in both directions, to the total area of the element. For the case $d_e \gg d$ and $d_e \gg \Delta$, we have the following relations:

$$\varepsilon_d \cong \frac{\pi(\Delta + d)}{2d_e}, \tag{3}$$

for square packing and

$$\varepsilon_d \cong \frac{\pi(\Delta + d)}{\sqrt{3}d_e} \tag{4}$$

for rhombic packing.

*In packed columns for liquid – liquid systems the size of an industrial packing (15 × 15 or larger) is generally larger than the critical dimension of the packing, i.e., the dimension determining the transition from the regime of coalescence and redispersion of the drops in each packing layer to the regime in which the drops float in voids in the packing, undergoing periodic collisions. According to the data of [4], this critical packing dimension is

$$d_{cr} = 2.52\left(\frac{\sigma}{g\Delta\rho}\right)^{0.5}. \tag{1}$$

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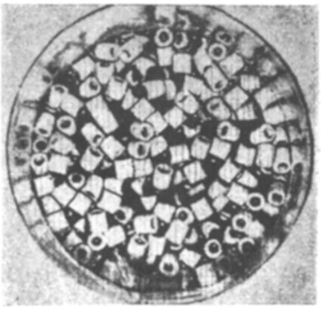

Fig. 1. Photograph of a packing layer.

In the case of a disordered packing we would be dealing with a set of "openings," the projections of the channels onto the base of the layer, instead of channels of regular shape. These openings are characterized by some distribution with respect to size δ, i.e., $f(\delta)$; here

$$\sum_{0}^{\infty} f(\delta)\,\Delta\delta = 1 \quad \text{or} \quad \int_{0}^{\infty} f(\delta)\,d\delta = 1. \tag{5}$$

This distribution of openings, $f(\delta)$, was determined experimentally.

For this purpose a glass vessel is filled with a packing of the necessary size. If wall effects are to be negligible, the ratio of the vessel diameter to the packing size must be at least 12 [5]. Then a dark-colored liquid is poured into the vessel, to a level reaching the middle of the upper layer of the packing. The packing layer is photographed from above. Then the rings of the upper layer are removed, and an amount of the liquid corresponding to the height of one layer is drained off, so that the level of the liquid is now at the middle of the second packing layer. As a control, the volume of the liquid which is drained off is measured and compared with the quantity $Sd_e p$. Then the second layer is photographed, etc. Figure 1 shows an illustrative photograph.

In this procedure the photographs reveal the projections of the channels onto the middle of the layer, while the "openings" are the projections of the channels onto the base of the layer. Let us evaluate the error involved in determining $f(\delta)$ from the projections of the channels onto the middle of the layer instead of from the projections of the channels onto the base of the layer. We consider a single packing element (a Raschig ring). We assume that the angle between the axis of the ring and the base plane is α. The error ΔF is equal to the difference between the areas of the projections of the ring onto the plane passing through the middle of the layer and onto its base. Obviously, for $\alpha = 0$, $\pi/6 < \alpha < \pi/3$, and $\alpha = \pi/2$ these projections are equal, and we have $\Delta F = 0$ (Fig. 2,a–c). An error appears only in the intervals $0 < \alpha < \pi/6$ and $\pi/3 < \alpha < \pi/2$ (Fig. 2d). For a numerical evaluation we consider the difference between the areas of two ellipses with minor semiaxes $d_e/2$ and major semiaxes

$$a' = \frac{d_e}{2}(\cos\alpha + \sin\alpha)$$

for the large ellipse and

$$a = \frac{d_e}{2}[\cos\alpha + \sin\alpha - (0{,}5 - \sin\alpha)\operatorname{tg}\alpha]$$

for the small ellipse. Then we have

$$\Delta F = \frac{\pi d_e^2}{4}(0{,}5 - \sin\alpha)\operatorname{tg}\alpha,$$

and the relative error is

$$\frac{\Delta F}{F'} = \frac{(0{,}5 - \sin\alpha)\operatorname{tg}\alpha}{\sin\alpha + \cos\alpha}. \tag{6}$$

The maximum relative error according to Eq. (6) is $(\Delta F/F')_{max} = 5.3\%$.

The values of p and $f(\delta)$ are determined from photographs of the layers in the following manner: the photographs are covered with a grid of intersecting parallel lines $l_1, l_2, \ldots, l_j, \ldots, l_c$ running in an arbitrary direction. We find the distribution of line segments lying between packing elements, δ_{ji}, which turns out to be approximately a logarithmically normal distribution. Evgrafov [6] has offered a theoretical justification for using the distribution of line segments with respect to length as a characteristic of the size distribution of voids. Bogomolova and Orlova [7] used this method to determine the size distribution of the voids in porous materials.

The fraction of free cross section of a layer is determined from

$$p = \frac{\sum_{j=1}^{k}\sum_{i=1}^{n_j}\delta_{ji}}{\sum_{j=1}^{k} l_j}. \tag{7}$$

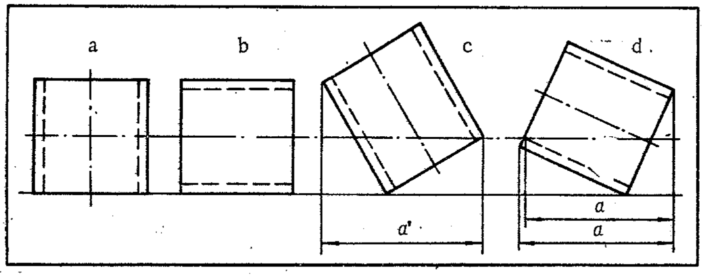

Fig. 2. Difference between the areas of the projections ΔF of a packing element onto the plane passing through the base of the layer and onto a plane passing through the middle of the layer as a function of the inclination angle α: a) $\alpha = \pi/2$; b) $\alpha = 0$; c) $\pi/3 < \alpha < \pi/2$, $0 < \alpha < \pi/6$; d) $\pi/6 < \alpha < \pi/3$.

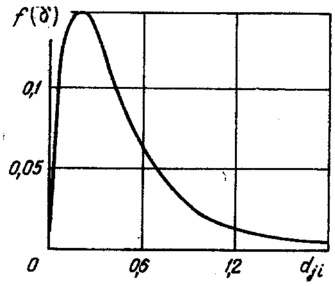

Fig. 3

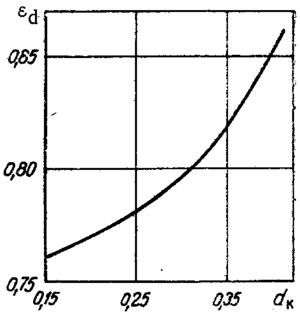

Fig. 4

Fig. 3. Size distribution $f(\delta)$ of the projections of the channels onto a plane. Here d_{ji} is given in cm.

Fig. 4. Probability ε_d for the collision of a drop with a packing element as the drop traverses a layer of Raschig rings 25 × 25 × 3 mm in size as a function of the drop diameter, d (in cm).

If the drop size is negligible, the probability for the passage of a drop through the packing layer without undergoing a collision is equal to this fraction:

$$\omega = p. \tag{8}$$

If the drop size must be taken into account, we would have

$$\omega_d = p \sum_{\delta=d}^{\infty} f(\delta)\,\Delta\delta. \tag{9}$$

In the present experiments we used a packing of Raschig rings 25 × 25 mm in size.

When the distribution curve became reproducible, we conclude that we had carried out a sufficient number of measurements. We found that on the order of 1400 measurements for a single layer were sufficient to obtain reproducible results. The distribution $f(\delta)$ is shown in Fig. 3.

The fraction of free cross section, determined from Eq. (7) and the results of measurement of 28 layers, is 0.27 ± 0.014. Figure 4 shows the collision probability for this particular packing as a function of the drop diameter, determined from Eqs. (7) and (9).

NOTATION

ε_d is the probability for a collision as a drop traverses a single packing layer;
ω_d is the probability for the traversal of a single packing layer by a drop without a collision;
δ is the size of the projection of the channel onto the base of the layer;
$f(\delta)$ is the size distribution of the projections of the channels;

S is the cross-sectional area of the column;
p is the fraction of free cross section of the packing layer;
d is the drop diameter;
d_e is the size of the packing element;
a, a' are the major axes of the ellipse;
F' is the area of an ellipse with a major axis a';
ΔF is the difference between the areas of the projections of the ring onto the base of the layer and onto the center of the layer;
D_c is the column diameters;
Δ is the wall thickness of the Raschig rings;
σ is the surface tension;
$\Delta\rho$ is the difference between the densities of the solid and disperse phases;
j is the index of the intersecting lines;
i is the index of the interval δ on an intersecting line.

LITERATURE CITED

1. A. S. Zheleznyak and E. M. Tarasova, Zh. Prikl. Khim., 45, 1149 (1973).
2. A. M. Landau and A. S. Zheleznyak, Zh. Prikl. Khim., 43, 317 (1970).
3. A. S. Zheleznyak, A. M. Landau, E. M. Tarasova, in: Abstracts of Reports, Ninth All-Republic Intercollegiate Conference on Evaporation, Combustion, and Gasdynamics of Disperse Systems [in Russian], Izd. OGU, Odessa (1969).
4. R. Gayler, N. Roberts, and H. Pratt, Trans. Inst. Ch. Eng., 31, 57 (1953).
5. K. Ridgway and K. Tarbuck, BCE, 12, 384 (1967).
6. V. A. Evgrafov, Inzh.-Fiz. Zh., 7, 121 (1964).
7. A. F. Bolomolova and N. A. Orlova, Zh. Prikl. Mekhan. Tekh. Fiz., No. 4, 77 (1961).