EFFECT OF PHYSICAL PROPERTIES OF A SYSTEM ON THE CRITICAL RATE OF JET FORMATION IN SIEVE-PLATE EXTRACTION COLUMNS

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Sieve-plate extraction columns are in widespread use at the present time in the chemical industry and related industries, and offer some major advantages, such as: absence of longitudinal phase intermixing and the possibility of using end effects repeatedly, simplicity and reliability in design, ease of automation, etc. This lends added importance to papers in the literature on hydrodynamics and mass transfer in equipment of this type.

Bussolari, Treybal, and associates [1] noted, on observing dispersion of kerosene in water, that kerosene drops were formed on the surface of the sieve plate at small loads in the dispersed phase, while the drops separated from the resulting jet at higher speeds, the jet height reaching 50 mm at that point. This was called streaming by those authors. The overall picture does not change as the velocity of the continuous phase is varied, but the length of the jet does decrease. Those authors did not determine the rate of efflux of the kerosene at which the streaming began.

S. N. Bulatov [2] discovered three dispersion regimes in a study of the pattern of drop formation in perforated-plate extractors operating on a water—kerosene system: a droplet regime, a transitional regime, and the streaming regime. He suggested a formula for determining the critical velocity of transition to the streaming flow with water as the dispersed phase:

$$\mathrm{Re} = \frac{w_{\mathrm{cr}} d}{\nu_{\mathrm{d}}} = 438.$$

where w_{cr} is the critical velocity or streaming velocity in m/sec, d the hole diameter in m, and ν_{d} the kinematic viscosity of the dispersed phase in $\mathrm{m}^2/\mathrm{sec}$.

It has been demonstrated [3,4] that the streaming flow is the one best suited to mass transfer. However, the problem of what effect the physical properties of the dispersed and continuous phases might have, respectively, on the critical streaming velocity was not discussed in a single one of the papers dealing with hydrodynamics or mass transfer in perforated-plate columns. We address ourselves to that problem in the present article.

Assuming that, at constant hole diameter in the sieve trays, the streaming velocity will be a function of the physical properties of the phases when different liquids are used, we state the following general relationship:

$$w_{\mathrm{cr}} = f_1(\sigma_{cn}, \sigma_{\mathrm{d}}, \nu_{cn}, \nu_{\mathrm{d}}, \gamma_{cn}, \gamma_{\mathrm{d}}),$$

where σ_{d} and σ_{cn} are the surface tensions of the dispersed and continuous phases, respectively, in kg/m; ν_{d} and ν_{cn} are the kinematic viscosities of the dispersed and continuous phases in $\mathrm{m}^2/\mathrm{sec}$; γ_{d} and γ_{cn} are the specific weights of the dispersed and continuous phases in $\mathrm{kg/m}^3$.

Then the relationship between the variables as derived by the method of dimensional analysis may be presented in the form

$$w_{\mathrm{cr}} = A_1 \left(\frac{\sigma_{cn}}{\sigma_{\mathrm{d}}}\right)^a \left(\frac{\gamma_{cn}}{\gamma_{\mathrm{d}}}\right)^b \left(\frac{\nu_{\mathrm{d}}}{\nu_{cn}}\right)^c \left(\frac{\gamma_{\mathrm{d}}^{0,5} \nu_{cn}}{\sigma_{\mathrm{d}}^{0,5}}\right). \tag{1}$$

Experiments were carried out on a special facility (Fig. 1) comprising a column of two glass stills 37 mm in diameter and standing 250 mm in height, for the purpose of determining the values of A, a, b, and c. The dispersed phase was fed from the tank 1 through the receptacle 2 at constant head into the column 3 filled with the continuous phase. The flowrate of the dispersed phase was measured with a rotameter 4 and was monitored by batch weighing. Onset of streaming was recorded photographically in terms of drop size and the appearance of a continuous sector in the jet. A comparison of the values of the streaming velocity as obtained photographically and visually revealed no perceptible discrepancies. The effect of hole diameter of streaming velocity was also investigated in these experiments.

S. N. Bulatov reported the following relationship based on a water–kerosene system: $w_{cr}d$ = const. This relationship was checked and confirmed on kerosene–water, benzene–water, carbon tetrachloride–water systems. A family of curves of hyperbolic type shifted relative to each other (Fig. 2) and described by the general equation

$$w_{cr}=\frac{A''}{d}$$

was obtained.

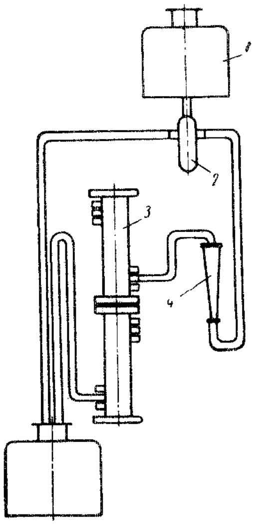

Fig. 1. Layout of experimental arrangement.

Mixtures of kerosene and spindle oil of varying concentration and viscosity over the range of $(1.27\text{-}19.9)\cdot 10^{-6}$ m²/sec were utilized to throw some light on the effect of the dispersed-phase viscosity in our experiments. Water was the continuous phase in all cases. The experimental results, when processed (Fig. 3), revealed no change in the streaming velocity accompanying a change in the viscosity of the dispersed phase.

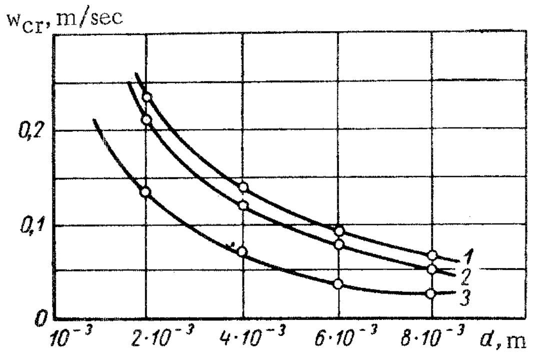

Fig. 2. Dependence of streaming velocity on diameter of sieve-tray holes, for the system: 1) kerosene–water; 2) benzene–water; 3) carbon tetrachloride–water.

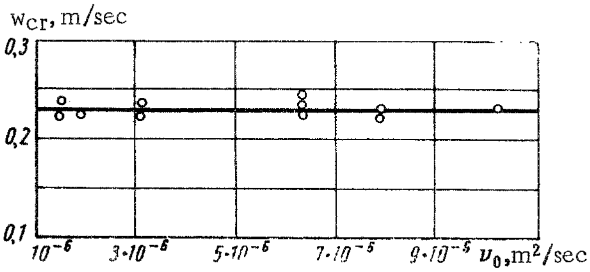

Fig. 3. Dependence of critical streaming velocity on viscosity of dispersed phase.

On the basis of the experimental data, the assumption is warranted that ν_d/ν_{cn} will have no effect on w_{cr} and may be eliminated from Eq. (1) on that account. In order to throw some light on the effect of the surface tension of the phases, the surface tension of the water was altered with the addition of the surfactant OP-10 and the water was then dispersed in kerosene.

For the case of organic substances dispersed in water, we derived the formula

$$w_{cr}=0.146\left(\frac{\sigma_{cn}}{\sigma_d}\right)^{0.5}.$$

Then, once the relationship between w_{cr} and σ_{cn}/σ_d is known and we have at our disposal experimental values of the streaming velocities, we can determine the relationship

$$\frac{w_{cr}}{\left(\frac{\sigma_{cn}}{\sigma_d}\right)^{0.5}}=f\left(\frac{\gamma_{cn}}{\gamma_d}\right). \tag{2}$$

The power exponent attached to γ_{cn}/γ_d and derived from least-squares processing of the experimental data is 0.475. Consequently,

$$w_{cr}=A_3\left(\frac{\sigma_{cn}}{\sigma_d}\right)^{0.5}\left(\frac{\gamma_{cn}}{\gamma_d}\right)^{0.475}.$$

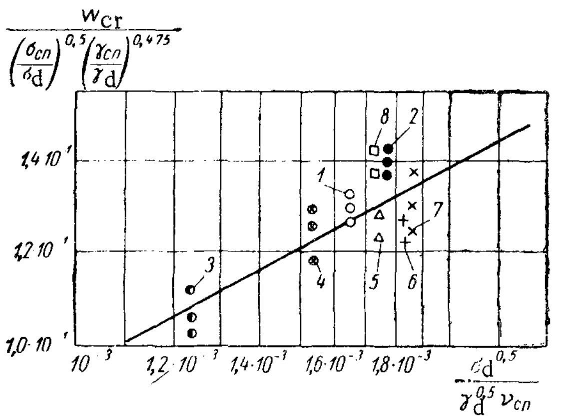

Fig. 4. Dependence of the streaming velocity on physical properties of liquids in the systems: 1) kerosene—water; 2) benzene—water; 3) carbon tetrachloride—water; 4) dichloroethane—water; 5) toluene—water; 6) oleic acid—water; 7) dimethylaniline—water; 8) xylene—water.

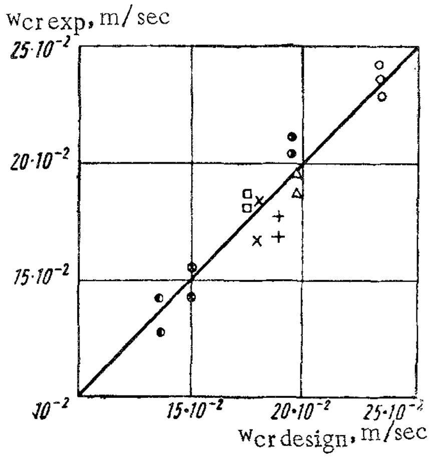

Fig. 5. Comparison of experimental and design data on streaming velocity. Legend for data points same as in Fig. 4.

The relation

$$\frac{w_{cr}}{\left(\frac{\sigma_{cn}}{\sigma_d}\right)^{0.5}\left(\frac{\gamma_{cn}}{\gamma_d}\right)^{0.475}} = f_3\left(\frac{\gamma_d^{0,5}\nu_{cn}}{\sigma_d^{0,5}}\right)$$

is shown graphed in Fig. 4.

As a result of the treatment of the experimental data plotted on the graph (for tray holes 2 mm in diameter), we derived the equation

$$w_{cr} = 2.5\cdot 10^{-3}\left(\frac{\sigma_{cn}}{\sigma_d}\right)^{0.5}\left(\frac{\gamma_{cn}}{\gamma_d}\right)^{0.475}\left(\frac{\sigma_d}{\gamma_d^{0.5}\nu_{cn}}\right)^{0.53}. \qquad (3)$$

Taking into account $w_{cr}d_{hole}$ = const, we have

$$w_{cr\,str}d_{st} = w_{cr}d_{hole}$$

where $w_{cr\,str}$ is the critical streaming velocity for holes 2 mm in diameter, in m/sec and d_{st} the standard hole diameter of $2\cdot 10^{-3}$ m.

Substituting the value of $w_{cr\,str}$ into Eq. (3), we thereby obtain the value of the streaming velocity for holes in the 1-8 mm range:

$$w_{cr} = 2{,}5\cdot 10^{-3}\left(\frac{\sigma_{cn}}{\sigma_d}\right)^{0.5}\left(\frac{\gamma_{cn}}{\gamma_d}\right)^{0.475}\left(\frac{\sigma_d}{\gamma_d^{0.5}\nu_{cn}}\right)\frac{d_{st}}{d_{hole}}. \qquad (4)$$

Figure 5 provides a comparison of design values and experimentally derived values of the streaming velocity; the discrepancy found stays within 13%. The resulting Eq. (4) thus enables us to compute the streaming velocity for liquids of different physical properties to within satisfactory precision.

LITERATURE CITED

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