SECTIONING OF THE LIQUID COLUMN ON A BUBBLE-CAP PLATE

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In designing a plate rectification column with plate model [1-3], we need to know the number of complete-mixing sections S and the relative vapor load of the sections $K_i = G_i/G$, where G_i is the vapor load of the i-th section of a plate, G is the total vapor load of a plate, and

$$i = 1,2 \ldots S, \quad \sum_{i=1}^{S} K_i = 1.$$

In the literature there are indications [4] that, for bubble-cap plates, the number of total-mixing sections can be taken as equal to the number of rows of bubble caps on the plate in the direction of flow of the liquid.

Gautreaux and O'Connell [5] suggested an equation for the Murphy efficiency of a plate in which the number of total-mixing sections is, according to their recommendation, determined from a graph as a function of the path length of the liquid on the plate.

A detailed investigation of this question was made by A. A. Zakharova [6], who determined the number of total-mixing sections from the curve of elution of a dye at the outlet from the plate. The equation for the number of total-mixing sections, S, takes the form

$$S = 0{,}915 \cdot 10^{-2} \mathrm{Re}_{\mathrm{liq}}^{0,6} \left(\frac{D_K}{h_{\mathrm{over}}}\right)^{1,a}, \tag{1}$$

where $\mathrm{Re}_{\mathrm{liq}} = \frac{L' h_{\mathrm{col}}}{\nu}$ is the Reynolds number for the liquid current; L' is the volume load of the plate for liquid, in $m^3/m^2 \cdot sec$; $h_{\mathrm{col}} = \frac{h_{\mathrm{perf}}}{2} + h$ is the level of the liquid on the plate in m; h_{perf} is the height of the bubble-cap perforation to the level of the clear liquid on the plate, in m; ν is the viscosity of the liquid in m^2/sec; and $\frac{D_K}{h_{\mathrm{over}}}$ is the ratio of the column diameter to the height of the overflow baffle.

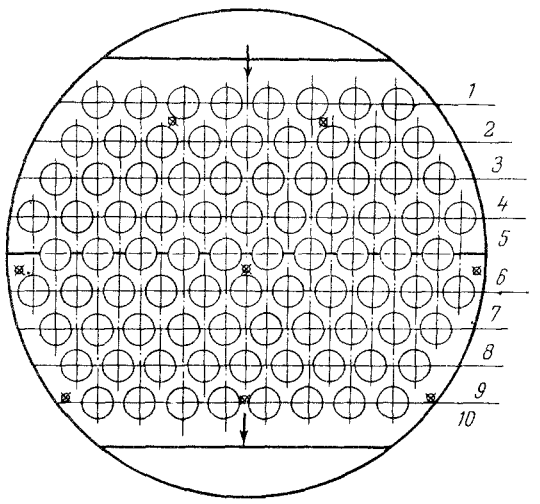

Fig. 1. Sectioning scheme of a bubble-cap plate. ⊠) Points of withdrawal of dye samples. Arrows indicate direction of flow of liquid on plate.

Equation (1) allows for the influence of liquid load and certain constructional elements on liquid mixing. For gas velocities between 0.5-1.0 m/sec (the range under study), the number of total-mixing sections was independent of the gas velocity.

It is of interest to discuss the possibility of sectioning the liquid current at a bubble-cap plate in connection with its construction, using the existing experimental data [6].

Consider a bubble-cap plate (Fig. 1). The rows of caps clearly constitute natural obstacles to the motion of the current of liquid. The most intense interaction of vapor with liquid goes on between the rows of caps, and inside those zones we can with sufficient accuracy assume that the liquid is completely mixed. Starting out from these considerations, we can determine the number of total-mixing sections and the relative vapor load of each section from the equations

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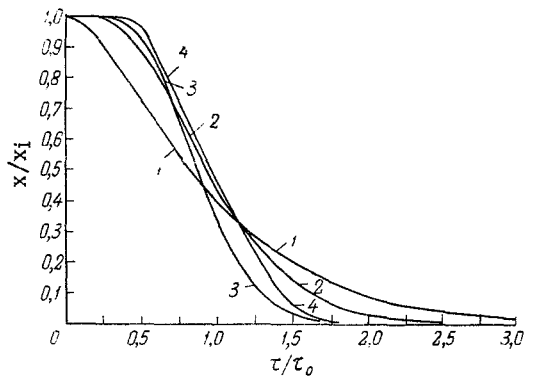

Fig. 2. Comparison of some elution curves with the elution curve at the outlet from the ninth section. 1) S = 2; 2) S = 5; 3) S = 10 (outlet from ninth section); 4) S = 10 (outlet from tenth section).

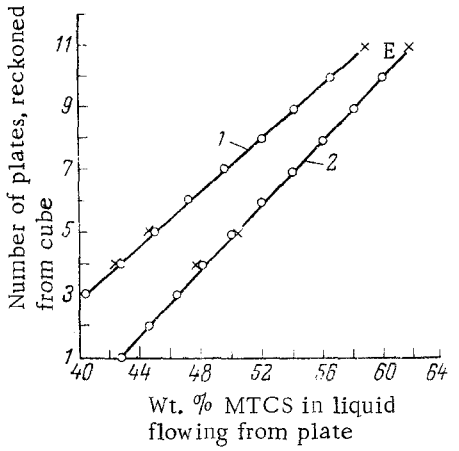

Fig. 3. Distributions of concentration up the column, calculated by means of (2) and (3), for sectioned liquid current: Φ is the ratio by weight of the liquid and vapor currents; E is the local efficiency; 1) Φ = 1 with x_D = 58.70 wt. %; x_W = 33.45 wt. %; E = 0.61; 2) Φ = 0.982 with x_D = 61.83 wt. %; x_W = 40.24 wt. %; E = 0.55. ×—Experimental points; ○—calculated points.

$$S = n_K + 1, \tag{2}$$

$$K_i = \frac{n^0_{Ki}}{n^0_K}, \quad i = 1,2,\ldots, S, \tag{3}$$

where n_K is the number of rows of caps on the plate, n_K^0 is the number of half-caps on the plate, i.e., twice the number of plates, and n_{Ki}^0 is the number of half caps in the i-th section of the plate.

For the plate scheme shown in Fig. 1, we shall have n_K^0 = 172, n_K = 9, S = 10.

Section no.	n°_{Ki}	K_i	Section no.	n°_{Ki}	K_i
1	8	8/172	6	21	21/172
2	17	17/172	7	21	21/172
3	19	19/172	8	19	19/172
4	21	21/172	9	17	17/172
5	21	21/172	10	8	8/172

Equation (1) was derived by superimposing the experimental elution curves on to the theoretical curves for various gas and liquid loads. The equation of the theoretical elution curves [6, 7] is

$$C = \frac{x}{x_i} = \left\{ \sum_{i=1}^{S} \frac{\left(S\frac{V}{V_0}\tau\right)^{i-1}}{(i-1)!} \right\} \exp\left(-S\frac{V}{V_0}\tau\right), \tag{4}$$

where C is the relative concentration x of eluted substance (dye) in the liquid at the outlet from the plate of S sections at time τ, divided by the initial dye concentration x_i at $\tau = 0$; V is the volumetric liquid flow rate in m^3/sec; V_0 is the volume of liquid on the plate in m^3; and τ is the time in sec. The ratio $(V_0/V) = \tau_0$ is the mean time for renewal of the whole of the liquid on the plate. Figure 2 shows some of the curves corresponding to Eq. (1), for $S \geq 2$. It will be seen from Fig. 2 that the curves for different values of S have approximately the same configuration and intersect at points with abscissae $(\tau/\tau_0) \simeq 1$. In this region the elution curves differ little among themselves. On analyzing the data of [6] we find that for 89% of the series of experiments the number of total-mixing sections $S \geq 4$, and for 76% of the series $S \geq 5$. Here we must observe that for the series of experiments in which S < 4 the liquid flow rates were very small (1-2 $m^3/m \cdot h$), which is not typical of industrial apparatus.

Owing to the arrangement of the samples on the plate (see Fig. 1), the liquid samples were taken, not at the outlet from the plate, but a little upstream of it. In conformity with the above-recommended method of sectioning the bubble-cap plate we can assert that if S = 10 the samples were taken at the outlet from the ninth, i.e., the (S−1)-th section. In this case we write (4) in the following form:

$$C_9 = \frac{x_9}{x_i} = \left\{ \sum_{i=1}^{9} \frac{\left[(S-1)\frac{V}{V_0'}\tau\right]^{i-1}}{(i-1)} \right\} \exp\left(-(S-1)\frac{V}{V_0'}\tau\right) \tag{4,a}$$

The curve constructed from (4a) is shown in Fig. 2. The curves in Fig. 2 show that, although the hydraulics of the plate exert some influence on the number of total-mixing sections, the curve $C_9 = f(\tau)$ nevertheless lies in the same region, between the elution curves for S = 2 and S = 10, as most of the series of experimental points. On analyzing the position of the curve $C_9 = f(\tau)$ relative to the experimental series by the method of least squares, we find that this curve is in satisfactory agreement with many of the experimental series, in some cases even better than the corresponding curves constructed from (4) (experimental series Nos. 5, 8, 9, 13, 19-21, 23, 29, 41, 76-80).

If we remember that when $S \geq 5$ the calculated results of the rectification process are close to those obtained for $S \rightarrow \infty$ [8], we can regard as vindicated the suggested method of sectioning the liquid current at a bubble-cap plate by means of (2) and (3).

This method of sectioning the liquid current was used to calculate the concentration distribution up the column by means of the equations given in [3]. Figure 3 gives the calculated and experimental concentration distribution curves for a mixture of methyltrichlorosilane and dimethyldichlorosilane (MTCS-DDCS).

Take the column diameter as 800 mm, the number of plates as 10; for an MTCS-DDCS mixture $\alpha = 1.125$; $K_1 = K_6 = 0.0958$; $K_2 = K_3 = K_4 = K_5 = 0.2021$. It will be seen that for corresponding plates the calculated and experimental concentrations are in excellent agreement.

Our investigation revealed that for plates with circular (capsule) bubble-caps we can section the liquid current by starting out from the plate construction. Using (2) and (3) we can determine the number of total-mixing sections and also the relative vapor loads of the sections.

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