

MIXING OF GAS IN THE SPACE BETWEEN THE PLATES OF A RECTIFYING COLUMN

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This paper gives the results of an experimental investigation of the degree of mixing of the gas passing through the separating space between the plates of a rectifying column in relation to its velocity in the free section of the column, the column diameter, and the distance between the plates.

Owing to the inadequacy of research on the different effects accompanying mass transfer the designers of chemical apparatus have to make assumptions which simplify the picture of the process and, hence, lead to errors in the calculation.

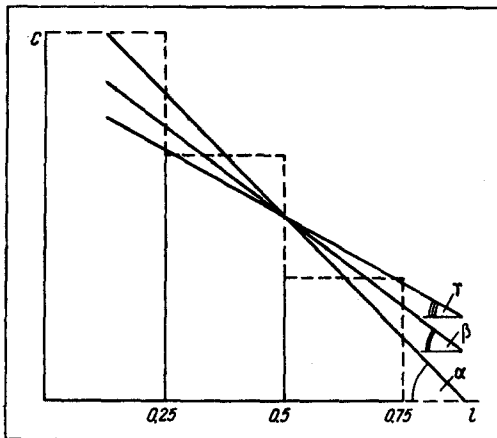


Fig. 1. Change in vapor concentration $C(\%)$ front along length l (rel. units) of path of liquid on plate during passage of vapor through bubbling layer and separating space.

The separation of liquid mixtures on the plate of a rectifying column largely depends on the actual distributions of concentrations of the phases involved in the exchange and these distributions depend on the hydrodynamic conditions.

Mixing of the liquid phase on the plate has now been investigated so well that it can be given due consideration in column design [1-3], but there have been hardly any investigations of the vapor phase in this respect. However, a theoretical estimate and the available experimental data [5, 6] confirm the hypothesis of a concentration gradient in the vapor entering the bubbling layer of the plate.

In view of this the aim of our work was to investigate the mixing of the vapor phase in the space between the plates and to verify the generally accepted assumption of the uniform composition of the vapor arriving at the plate.

The experiments were carried out on a "cold" model. Air was driven by a blower into the bottom section of

the column. The column consisted of a cylinder divided by three vertical partitions into four sections filled with 10×10 mm Raschig rings to even out the air flow over the cross section. The amount of air entering each section was measured with Pitot tubes. Helium, which acted as an indicator substance, was delivered into the first, second, and third sections. On its path to the plate the helium was completely mixed with the air and on entry to the liquid layer its concentration over the whole cross-sectional area was constant. This was verified by the analysis of gas samples taken at the entrance to the plate.

The constancy of the gas concentration over the width of the plate was assumed on the basis of the experimental data of Volland [7] and Dil'man [8]. They showed that the concentration gradient over the width of the plate in the liquid phase can be taken as zero. If we assume that the velocity front of the vapor phase is constant the vapor leaving the liquid must also have the same concentration over the width of the plate. We assumed that the variation of the composition of the arriving vapor along the plate was linear. Hence, on the graph of $C = f(l)$ the line drawn through the concentration values on the axis of each section is a straight line inclined to the axis at some angle α (Fig. 1). The linearity of the relationship between the helium concentration on the axis of the sections and the plate length was established artificially by selection and maintenance of the corresponding value in each section.

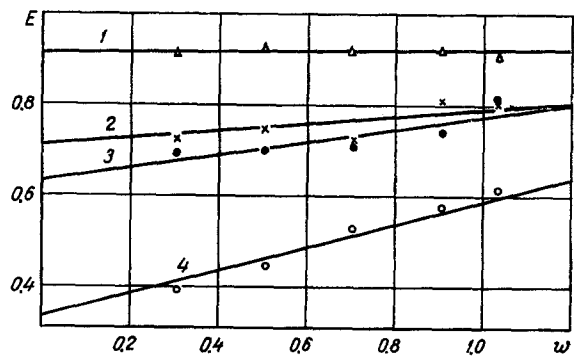


Fig. 2. Degree of mixing E of vapor as a function of air velocity ω (m/sec) in free section of column for $D_c = 218$ mm and different distances between the plates: 1) $H = 161$; 2) 208; 3) 235; 4) 300 mm.

The perforated plate used in the experiments had a free sectional area equal to 7.35% of the area of the plate, an overflow area of 8.5%, hole diameter 2.2 mm, and the thickness of the bottom was 1.5 mm. However,

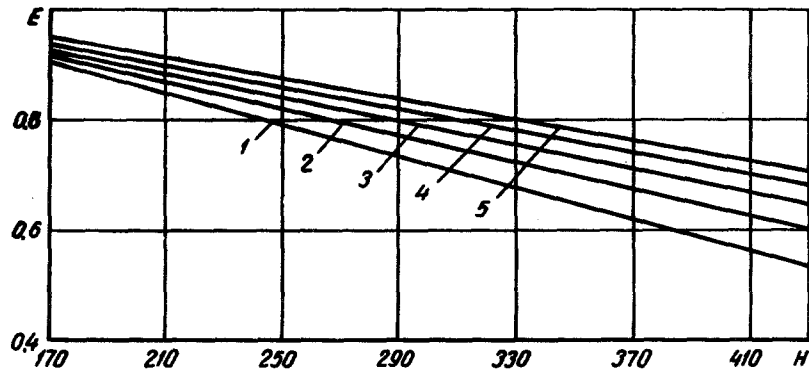


Fig. 3. Degree of mixing E of vapor as a function of distance between plates H (mm) for $D_c = 330$ mm and different air velocities in the free section of the column: 1) $\omega = 0.3$; 2) 0.5; 3) 0.7; 4) 0.9; 5) 1.1 m/sec.

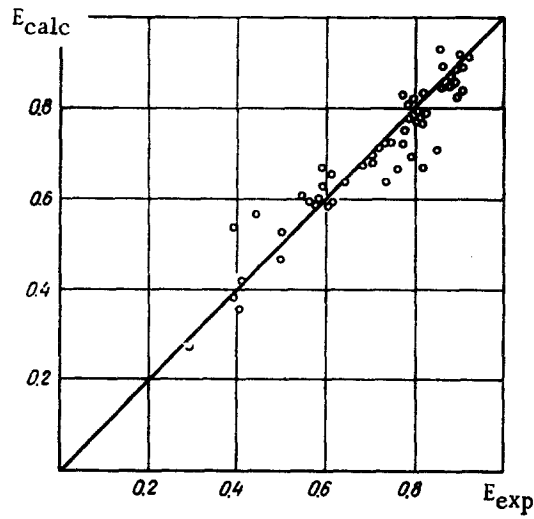


Fig. 4. Correlation graph of E_{calc} against E_{exp} .

in the investigation of the mixing of the vapor in the separating space the plate did not operate continuously, since the velocity of ascent of the vapor was much greater than the liquid flow velocity and, hence, the latter could not have an appreciable effect on the mixing of the vapor in the space between the plates.

We used water as the liquid phase. The height of the layer of clear liquid in all the experiments was 30 mm.

The percentage content of helium in the samples was determined from the thermal conductivity of the mixture in a gas analyzer operating on the principle described in [9]. The gas samples were taken at 48 points immediately above the surface of the liquid and under the overlying plate. The analysis of the samples showed that in passing through the liquid layer the gas was mixed and the line of the concentration front was rotated in the direction of equalization and on emergence from the bubbling layer was inclined at an angle β to the x axis (Fig. 1). At the entrance to the overlying plate the concentration gradient in the vapor was reduced even more and the inclination to the horizontal here was at an angle $\gamma < \beta$.

In the treatment of the experimental data the index of the degree of mixing E of the gas phase in the separating space was taken as the ratio of the tangent of the angle of inclination of the concentration front under the overlying plate ($\text{tg } \gamma$) to the tangent of the angle of inclination of the concentration line on emergence from the bubbling layer ($\text{tg } \beta$):

$$E = \text{tg } \gamma / \text{tg } \beta. \quad (1)$$

The range of variation of E lies between 0 and 1. If the vapor in its passage across the distance between the plates is ideally displaced, then under the top plate $\text{tg } \gamma = \text{tg } \beta$ and $E = 1$. If mixing is ideal, then at the entrance to the overlying plate $\text{tg } \gamma = 0$ and $E = 0$. In all other cases partial mixing of the vapor occurs and $0 < E < 1$.

In the course of the investigation we studied the degree of mixing in relation to the gas velocity in the free section of the column, the distance between the plates, and the diameter of the column. The air velocity was varied from 0.3 to 1.1 m/sec.

The experiments were conducted in columns of the following dimensions: 1) diameter $D_c = 175$ mm, distance between plates $H = 170, 190, 240,$ and 345 mm; 2) diameter $D_c = 218$ mm, distance between plates $160, 210, 235,$ and 300 mm; and 3) diameter $D_c = 330$ mm, distance between plates $180, 240, 280,$ and 415 mm.

Graphic treatment of the experimental data showed that the mixing rate decreased linearly with increase in air velocity, with reduction in the distance between the plates, and with increase in the column diameter (Figs. 2, 3). A mathematical relationship connecting the degree of mixing E with $\omega, H,$ and D_c was sought in the form

$$E = f(\omega, H/D_c).$$

The reason for the choice of the functional relationship in this form, rather than

$$E = f(\omega, H, D_c)$$

was as follows. Since the relationship $E = f(D_c)$ was investigated for only three different column diameters, we decided to improve the accuracy of the proposed formula by representing the degree of mixing E of the gas as a function of the ratio of the distance between the plates and the column diameter.

The empirical formula obtained from the treatment of the experimental data had the form

$$E = 1.14 - (0.47 - 0.115\omega) (H/D_c). \quad (2)$$

The satisfactory nature of the results obtained from this formula can be estimated from the correlation graph of E_{calc} against E_{exp} , where the experimental values of the degree of mixing are compared with the values of E_{calc} obtained from expression (2) for the same values of $\omega, H,$ and D_c (Fig. 4). It should be noted that the points where the deviations were greatest were obtained in the vast majority of cases at an air velocity of 0.3 m/sec, i. e., at low Reynolds numbers. Hence, the spread can be attributed to the presence of a velocity gradient over the free cross section of the column.

From the obtained relationship for the degree of mixing of the gas in its ascent in the space between the plates we can make a more accurate calculation of the number of plates in rectifying columns by the method based on a pseudo-sectional model of mixing of the liquid.

NOTATION

C is the helium content of air mixture, m^3/m^3 ; l is the length of path of liquid on plate in relative units; E is the degree of mixing of gas on passage between plates; D_c is the column diameter, m; H is the distance between plates; ω is the gas velocity in free section of column, m/sec.

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