Journal of Engineering Physics and Thermophysics, Vol. 74, No. 3, 2001

COMPLEX MODEL OF THE EFFICIENCY OF RECTIFICATION PLATES.
6. SOME FEATURES OF APPLICABILITY OF CALCULATIONAL DEPENDENCES

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UDC 66.048.375

The author assumes the interrelation of the distances from the site of injection of a vapor h and a liquid h_1 to the surface of equality of the concentrations on ideal and real plates with a degree of deviation from the Raoult law that is characterized by the activity coefficient γ. If the activities of the components of ideal and real solutions coincide ($\gamma = 1$), then $h = 0.5$ and $h_1 = 0.5$. With a positive deviation of a highly volatile component from the Raoult law ($\gamma > 1$), $h > 0.5$ and $h_1 > 0.5$ with a negative deviation ($\gamma < 1$) – $h < 0.5$ and $h_1 < 0.5$. The influence of the activity of a poorly volatile component and of both components on the indicated distances is also analyzed. In order to eliminate the negative values of the efficiency in calculational procedures, especially in countercurrent flow, it is proposed that the coefficient of equilibrium be found from the slope of a tangent to an equilibrium line to the X axis and that the length of a segment cut off by this tangent on the Y axis be taken into account. Some modifications of new dependences for concurrent flow, countercurrent flow, and cross flow with mixing and without it are given.

The distances from the site of injection of a vapor h and a liquid h_1 to the surface that is characterized by equality of the corresponding compositions on ideal and real plates are given in all general calculational dependences of the considered schemes of organization of the flows of the interacting phases [1–5]. The magnitudes of the indicated distances can be represented as the degree of approximation of a real solution to an ideal one. In the particular case the vapor and the liquid are considered as the components of an ideal solution; they show the corresponding properties in mass transfer on ideal and real plates, and in this case $h = h_1 = 0.5$.

A decrease in h or h_1, as has been noted in [1–5], improves the efficiency, which can be attributed to a deviation of real solutions from the Raoult law, which is formalized in the form [6]

$$p = Px\gamma \,. \tag{1}$$

With a positive deviation from the Raoult law ($\gamma > 1$) of, for example, a highly volatile component its partial pressure increases according to formula (1). In accordance with the first Konovalov law the vapor is enriched with the component whose partial mole pressure is higher [6]. An increase in the content of the highly volatile component in the vapor phase improves the efficiency of mass transfer. However this improvement in the operating efficiency of equipment is fictitious. In fact, all other things being equal, it remains the same as in rectification of an ideal solution. Therefore, in order to reduce the efficiency to its true value, we should increase h or h_1.

Let us assume that an ideal solution arrives at an ideal plate and a real solution, i.e., a solution with a negative deviation of a poorly volatile component from the Raoult law, arrives at an actual plate. The com-

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Belarusian State Technological University, Minsk, Belarus. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 74, No. 3, pp. 181–183. Original article submitted January 26, 2000; revision submitted September 14, 2000.

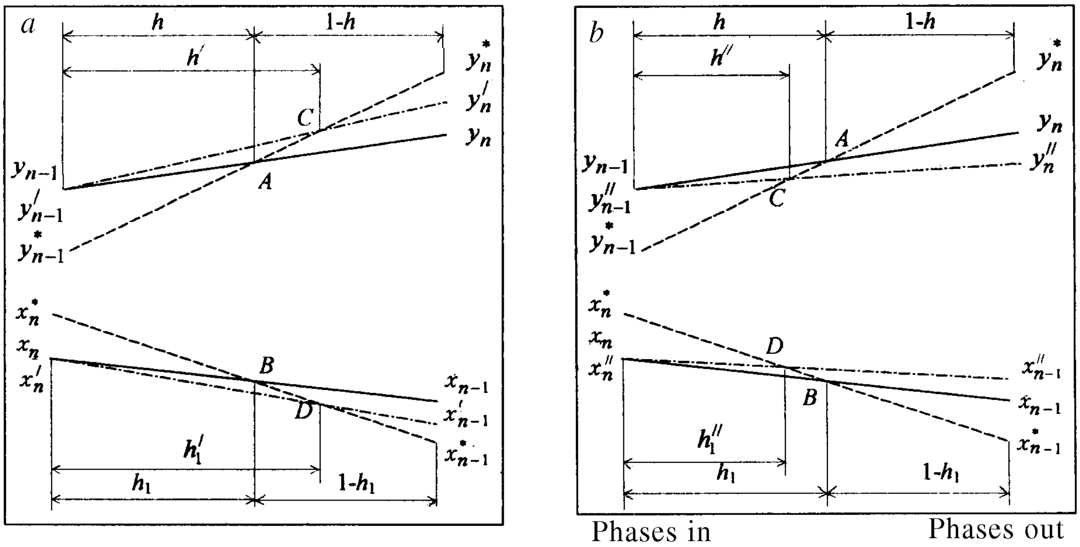

Fig. 1. Change in the concentrations on real (solid lines) and ideal (dashed lines) plates with allowance for the activity of a poorly volatile component (dot-dash lines): a) $\gamma < 1$; b) $\gamma > 1$.

positions of a vapor on the ideal and real plates coincide at point C rather than at point A, as is observed for an ideal solution (Fig. 1a). The distance h increases and becomes equal to h'. The final concentration of the highly volatile component in the vapor phase increases to y'_n. The composition of the liquid on the real plate is depleted of the highly volatile component more intensely than in rectification of an ideal solution, is equated with the composition of the liquid on the ideal plate at point D, and attains the final content on the step x'_{n-1} (Fig. 1a). The distance h_1 also increases to h'_1. In the general case, $h' \neq h'_1$.

With a positive deviation of a poorly volatile component from the Raoult law ($\gamma > 1$), the partial pressure and the concentration of a highly volatile component in the vapor phase decrease as compared to an ideal solution and the concentration after the plate attains a value of y''_n (Fig. 1b). The distance h decreases to h''. The compositions of the vapor on the ideal and real plates are equated at point C. The liquid is depleted of the highly volatile component less intensely as compared to an ideal solution and attains a value of x''_{n-1} at the outlet from the plate. The distance h_1 decreases to h''_1.

The parameters of a real solution change similarly with deviation of a highly volatile component from the Raoult law. For the activity of the highly volatile component $\gamma < 1$, the distances h and h_1 must be more than 0.5, while for $\gamma > 1$ they must be less than 0.5. With corresponding deviations of a poorly volatile component – conversely. When both components of the solution deviate from the Raoult law a comparative analysis of their activities is required.

The deviation of real mixtures from the Raoult law is mainly allowed for by the coefficient of equilibrium m. However, when m is used one takes into account only the relative activity of the components, whereas by changing the distances h and h_1 one can prescribe the values of the activity coefficients of real solutions, especially of multicomponent mixtures.

In a number of calculational dependences, especially in countercurrent flow [5], use is made of expressions of the type

$$E_{\mathrm{g,m}} = \left(\frac{L}{mV} - 1\right) \Bigg/ \left(\frac{x_n + x_{n-1} - 2\dfrac{y_{n-1}}{m}}{x_n - x_{n-1}} - \frac{L}{mV}\right),$$

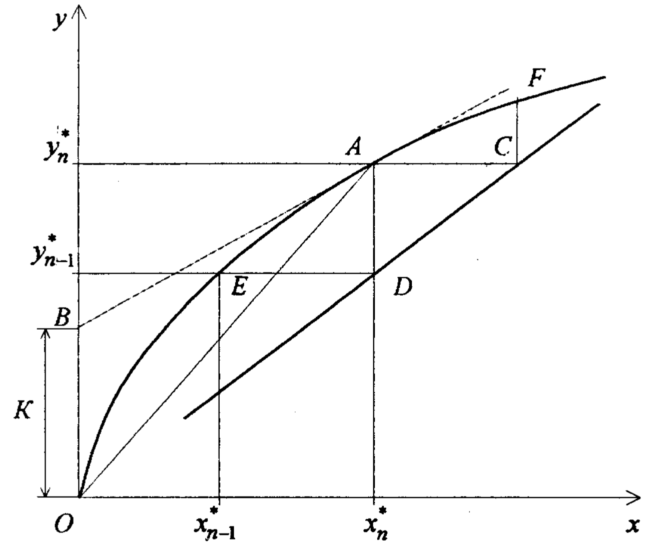

Fig. 2. Representation of the process on the *y*–*x* diagram.

involving the difference $(L/mV-1)$, which must be a positive quantity. This means that the tangent of the slope of a working straight line to the *X* axis must be larger than in an equilibrium line. However the conditions shown schematically in Fig. 2 are possible in practice. The slope of the working straight line *CD* is smaller than the corresponding angle of the equilibrium line *OA*. In this case, the efficiency calculated from the above formula can be negative.

In order to eliminate a similar situation, we propose the following modification of the calculational dependences. Instead of using an equation of an equilibrium line of the type $y^* = mx^*$, we must use the formula [7]

$$y^* = mx^* + K, \tag{2}$$

which is shown in Fig. 2 in the form of the tangent *AB* to the equilibrium line *OEA*. The magnitude of *K* is equal to the magnitude of the segment *OB* cut off by the tangent on the *Y* axis. The slope of the straight line *AB* to the *X* axis is smaller than in the straight line *CD*; consequently, the difference $(L/mV-1)$ and its expressions used will have positive values. Formula (2) can also be used not only in countercurrent flow but for other forms of organization of the phase flows as well. In these cases, instead of the difference $(x_{n-1}-y_{n-1}/m)$, one should substitute $[x_{n-1}-(y_{n-1}-K)/m]$ into the dependences corrected with account for (2). For example, the differences of the concentrations of the highly volatile component in a liquid before and after the plate will take the following form:

for concurrent flow

$$x_n - x_{n-1} = \left(x_{n-1} - \frac{y_{n-1}-K}{m}\right)E_{\text{con}} \Bigg/ \left[L\,(1-E_{\text{con}})\left(\frac{1-h}{mV} - \frac{1-h_1}{L}\right) + \frac{L}{mV}E_{\text{con}}\right], \tag{3}$$

for countercurrent flow

$$x_n - x_{n-1} = \left(x_{n-1} - \frac{y_{n-1}-K}{m}\right)E_{\text{g}} \Bigg/ \left[L\,(1-E_{\text{g}})\left(\frac{1-h}{mV} - \frac{1-h_1}{L}\right) + \frac{L}{mV}E_{\text{g}} - 1\right], \tag{4}$$

for countercurrent flow with mixing of the liquid

$$x_n - x_{n-1} = \left(x_{n-1} - \frac{y_{n-1} - K}{m}\right) E_{\mathrm{g},\varphi} \Big/ \left[L\,(1 - E_{\mathrm{g},\varphi}) \left(\frac{1-h}{mV} - \frac{1-h_1}{L}\right) + \frac{L}{mV} E_{\mathrm{g},\varphi} - 1 + \varphi\right], \tag{5}$$

for cross flow

$$x_n - x_{n-1} = \left(x_{n-1} - \frac{y_{n-1} - K}{m}\right) E_{\mathrm{k}} \Big/ \left[L\,(1 - E_{\mathrm{k}}) \left(\frac{1-h}{mV} - \frac{1-h_1}{L}\right) + \frac{L}{mV} E_{\mathrm{k}} - \frac{1}{2}\right], \tag{6}$$

for cross flow with mixing of the liquid

$$x_n - x_{n-1} = \left(x_{n-1} - \frac{y_{n-1} - K}{m}\right) E_{\mathrm{k},\varphi} \Big/ \left[L\,(1 - E_{\mathrm{k},\varphi}) \left(\frac{1-h}{mV} - \frac{1-h_1}{L}\right) + \frac{L}{mV} E_{\mathrm{k},\varphi} - \frac{1}{2} + \frac{\varphi}{2}\right]. \tag{7}$$

All other things being equal, the largest amount of the highly volatile component extracted from the liquid can be produced in countercurrent motion of the vapor and liquid phases, since of all the above dependences the denominator is minimum in formula (4). The smallest amount of the highly volatile component can be produced in concurrent motion of the phases, since the denominator has a maximum value in (3). Cross motion of the phases should be considered as the average between concurrent flow and countercurrent flow.

Mixing of a liquid reduces mass transfer, since the increase in the amount of a totally mixed liquid φ in concurrent and cross motions of the phases increases the denominator in formulas (5) and (7), respectively, and reduces the two formulas to (1) when $\varphi = 1$. It should be noted that the influence of mixing is more significant in countercurrent flow of the vapor and the liquid and is less significant in cross flow. This is, probably, due to allowance for the content of the highly volatile component in the liquid in the latter form of organization of the motion of flows that envisions the average between its input and output compositions, which can be considered as mixing of a sort.

Equation (2) improves the accuracy of calculations but complicates them somewhat since, in using it, the first is provided by a more accurate characteristic of the considered portion of the equilibrium line, while the second is caused by the necessity of correcting the values of m and K for each step of contact in plate-by-plate calculation of the column, which can affect the efficiency and change it from step to step. However, the latter creates no special difficulties in the presence of a computer.

Thus, formulas (3)–(7), which reflect the complex model of mass exchange in rectification, are mainly of the same character since they are expressed by essentially identical parameters and differ only in the forms of organization of flows.

NOTATION

E, efficiency of the plate; φ, amount of the totally mixed liquid on the plate; γ, activity coefficient of the component of the real solution; h and h_1, dimensionless distance from the site of injection of the vapor and the liquid, respectively, to the surface of equality of the concentrations of the phases on ideal and real plates; K, portion of the Y axis cut off by the tangent to the equilibrium line; L, molar flow of the liquid; m, coefficient of equilibrium; p, partial pressure of the vapor of the highly volatile component of the solution; P, pressure of the pure vapor above the liquid; V, molar flow of the vapor; x and y, concentration of the highly volatile component in the liquid and the vapor, respectively. Subscripts: φ, allowance for the mixing of the liquid; g, countercurrent flow; k, cross motion of the phases; liq, liquid phase; m, values of the parameters for $h = h_1 = 0.5$; n, number of the considered plate; n–1, number of the preceding plate in the direction of vapor motion; con, concurrent flow; v, vapor phase. Superscript: *, ideal conditions.

REFERENCES

1. V. N. Pavlechko, *Inzh.-Fiz Zh.*, **74**, No. 1, 50–56 (2001).
2. V. N. Pavlechko, *Inzh.-Fiz Zh.*, **74**, No. 1, 57–61 (2001).
3. V. N. Pavlechko, *Inzh.-Fiz Zh.*, **74**, No. 2, 38–42 (2001).
4. V. N. Pavlechko, *Inzh.-Fiz Zh.*, **74**, No. 2, 43–47 (2001).
5. V. N. Pavlechko, *Inzh.-Fiz Zh.*, **74**, No. 3, 177–180 (2001).
6. A. G. Kasatkin, in: *Basic Processes and Apparatuses of Chemical Engineering* [in Russian], Moscow (1971), pp. 496–501.
7. V. V. Kafarov, in: *Principles of Mass Transfer* [in Russian], Moscow (1972), p. 218.