INVESTIGATION AND CALCULATION OF THERMOCHEMICAL PROCESSES

CALCULATION OF THE NUMBER OF THEORETICAL AND ACTUAL PLATES IN RECTIFICATION COLUMNS
BY MEANS OF THE ENTHALPY DIAGRAM

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In Russian and foreign literature [1,4], the method of determining the number of theoretical plates in rectification columns—making use of the I-x, y diagram—is the one that is preferred in the great majority of cases, since it gives the best accuracy. The enthalpy diagram, in addition to giving a clear picture of the thermodynamics of the process, makes it possible to see what effect the various factors have on the rectification process, such as the change in the ratio between the amount of reflux and the amount of vapor, the amount of heat transferred during evaporation of the high-boiling and condensation of the low-boiling components, and the way the concentrations of the components change. However, making the calculations and plotting the enthalpy diagram is very complicated and takes a lot of work. There are a number of cases in which it becomes impossible to use it because the physicochemical constants required for plotting the diagram are not available.

This paper makes a comparison between the results of calculations made from I-t-x and y-x diagrams. The physicochemical constants taken from the handbook literature were used to calculate the number of theoretical plates for a number of mixtures (Table 1). Two methods were used in the calculation: the familiar method of plotting the enthalpy diagram and calculating the number of plates from the diagram, and the method suggested by N. I. Gel'perin and V. L. Pebalk in [3]. The results of the calculations made by these two methods were compared with the results obtained from the y-x diagram. An interesting modification of the method of calculating the number of plates from the I-x, y diagram is to use the equilibrium y=f(x) curve, and a working line plotted from the variable molar fluxes along the length of the column. This method was also used as a check.

The working line was plotted in the following way. First, the enthalpy and y-x diagrams that go together were constructed (see Fig.1). The operating concentration line for the concentration part of the column passes through the point K lying on the diagonal. The abscissa and the ordinate of this point

| Mixtures                  | r_a Cal/kg | r_b Cal/kg | r_a Cal/kmol | r_b Cal/kmol | t_a °C | t_b °C | M_a | M_b | p, mm Hg | \( \frac{r_a}{r_b} \) | \( \frac{r_b}{r_a} \) | \( \frac{I_a}{I_b} \) | \( \frac{I_b}{I_a} \) | \( \frac{t_b}{t_a} \) |
|--------------------------|------------|------------|---------------|---------------|--------|--------|------|------|----------|----------------|----------------|----------------|----------------|----------------|----------------|
| Water-ethanol            | 204.0      | 539.0      | 11 720        | 11 500        | 2300   | 1800   | 78.3 | 100.0| 760      | 0.378          | 1.02            | 1.28            | 0.277          | 4.31          |
| Oxygen-nitrogen          | 197.7      | 51.0       | 10 940        | 10 650        | 2055   | 1600   | 70.0 | 100.0| 750      | 0.935          | 0.532           | 1.92            | 0.357          | 5.59          |
| Ammonia-water            | 260.0      | 483.1      | 12 000        | 11 700        | 2300   | 1800   | 32.4 | 179.0| 7000     | 0.58            | 0.552           | 1.57            | 0.577          | 4.52          |
| Propane-n-butane         | 71.0       | 61.0       | 4 330         | 7 302         | 1190   | 3800   | 42.5 | 103.0| 7000     | 1.16            | 0.303           | 1.34            | 0.314          | 12.2          |
| Acetone-water            | 125.0      | 589.0      | 9 630         | 11 500        | 1780   | 1800   | 56.1 | 100.0| 7000     | 0.292          | 0.785           | 0.99            | 0.784          | 32.3          |
| Chloroform-methanol      | 539.0      | 97.0       | 11 500        | 9 480         | 1800   | 3680   | 100.0| 118.1| 7000     | 5.55            | 1.21            | 0.49            | 0.181          | 1.7           |

Note: r is the specific heat of evaporation. \( l^1 \) is the vapor enthalpy of a pure component. \( l^2 \) is the liquid enthalpy of the pure component. \( t \) is the boiling point. M is the molecular weight. p is the pressure in the system. \( \alpha \) is the relative volatility factor for the feed plate, and the subscripts a and b designate the components that can be volatilized easily and with difficulty, respectively.

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give the concentration of the distillate. The operating concentration line for the distillation part of the column passes through the point M, which also lies on the diagonal. The abscissa and the ordinate of this point give the composition of the residue. To find the other points that the operating line passes through, we draw an arbitrary number of lines out from the point P, thus P-1-2, P-3-4, etc. From point P, we also draw a number of arbitrary lines P-1'-2', P-3'-4' etc. On the enthalpy diagram, the points of intersection of these arbitrary lines with the vapor and liquid lines give the composition y of the vapor, and x of the liquid in the countercurrent streams in the column, and represent the points that go together on the working concentration line. If the concentrations y and x thus found are transferred to the y-x diagram, and are joined together, we get the operating line.

This method was used to plot the operating lines on the y-x diagram for all the mixtures used in the calculations. These operating lines are only slightly curved, and, for practical purposes, differ very little from the operating lines plotted on a y-x diagram for the condition where the molar fluxes are equal along the length of the column. Calculations of the operating lines made by the method suggested by N. I. Gel'perin and V. L. Pebałk give results which are in complete agreement with the results found by the method described above.

In addition to finding the curvature of the operating lines graphically, an analytic calculation was made. As we know, the equation of the operating line for the concentration part of the column with the molar fluxes equal along the length is:

\[ y = \frac{R}{R+1} x + \frac{x_p}{R+1}, \]

where \( R \) is the reflux ratio, and \( x_p \) is the amount of the easily volatilized component in the distillate in mole fractions. The equation is linear.

If the molar fluxes vary along the column, with \( R \neq \text{const} \), the equation of the operating line will be of a different form, namely:

\[ y = \frac{R^*}{R^*+1} x + \frac{x_p}{R^*+1}, \]

where \( R^* \) is the reflux ratio for any arbitrary cross section of the column, as found from the \( I-x, y \) diagram.

To find the change in slope of the operating line plotted on the y-x diagram by means of the \( I-x, y \) diagram, as compared with the operating line plotted from Eq. (1), the following equation may be used:

\[ \Delta \varphi = \arctg \frac{R}{R+1} - \arctg \frac{R^*}{R^*+1}, \]

where \( \Delta \varphi \) is the change in inclination of the operating line in degrees.

The enthalpy diagram makes it possible to find the reflux ratio at any cross section of the column. What was put into Eq. (2) was the value of the reflux ratio \( R^* \) in the concentration part of the column, where the concentration of the liquid is equal to \( x \). The value of the reflux ratio for this cross section differs to the greatest possible extent from the value of the reflux ratio for a cross section where the concentration of the liquid is \( x_p \), which serves to explain why the curvature of the operating line is so large. For this reason, precisely these cross sections were chosen for making a comparison of the slopes of the operating lines.

The minimum values of the reflux ratios found from the y-x and I-x, y diagrams are slightly different, but this has nothing to do with the operating reflux ratio, and is of no importance in making practical calculations, since the operating reflux ratio is not determined by multiplying \( R_{\min} \).