PETROLEUM REFINING EQUIPMENT

APPROXIMATE CALCULATION OF CONTINUOUS RECTIFICATION

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Despite the wide application of electronic computers to calculate multicomponent rectification [1-3], there are three reasons why the approximate methods of calculation retain (and, apparently, will retain in future) their importance. They are:

a) the need for choosing a sufficiently good first approximation for calculation on computers, since the calculation programs utilize iteration methods, which may not generally converge, as is known, if the first approximation is not satisfactory; a simple and sufficiently accurate approximate method of calculation accelerates the convergence of the iteration process;

b) the need for a reliable and, at the same time, simple and rapid method for use, for example, in the stage of working up the designing assignments, etc.,

c) the need for applying such a method to the cases where calculations cannot be performed on a computer.

A number of approximate methods of calculating multicomponent rectification [4-8] were analyzed in order to choose a satisfactory method. It was established that though all the methods considered have some advantages or other, none of these can be accepted as a whole. This required the development of a complex method without the disadvantages of the well-known methods.

The proposed method is based on V. V. Popov's method of calculating the number of theoretical plates for multicomponent rectification [5, 6].

Since this method does not give recommendations for calculating the minimum reflux ratio, the minimum number of theoretical plates, and the position of the feed plate, investigations were conducted to clarify these processes, the accuracy of the method was verified, and the ways of its utilization have been proposed.

While working out the method, we simplified it by accepting Mikhailovskii's postulate [7] that the operating reflux ratio (R) and the number of plates in the column (N\textsubscript{tot}) are mutually compensated during multicomponent rectification, and that the end-product compositions thereby remain constant.

The minimum reflux ratio (R\textsubscript{min}) was calculated by the Underwood method [8] and the minimum number of theoretical plates in the column (N\textsubscript{min tot}) and in the rectifying section of the column (N\textsubscript{r min}) by the Underwood-Fenske equation.

The verification of the basic equation used [6]

\[ N_{\text{tot}} = \frac{\sigma N_{\text{min tot}}}{\frac{1}{2} \left( 8.2 + \frac{a_k}{a_{k+1}} \right) - 0.36 E_r E_s} \] (1)

(where \( \sigma \) is excess reflux; R is operating reflux ratio; \( a_k \) is relative volatility of the k-th component; \( a_{k+1} \) is number of the light boundary-component; \( E_r \) is separating efficiency in the rectifying section, and \( E_s \) is separating efficiency in the stripping section of the column) showed that though the equation has fully satisfactory accuracy, it gives a certain systematic error.

To reduce this error, it is necessary to add a multiplier, which depends only on the excess of reflux, and then the equation assumes the form:
where

\[ N_{\text{tot}} = \frac{\alpha N_{\text{min}, \text{tot}}}{\sigma - B} \cdot \frac{\sigma - 0.984}{\sigma - 1}, \]

and

\[ B = 1.5 \left( \frac{a_k}{a_{k+1}} + 8.2 \right) - 0.36E_f E_s \]

The fractionating efficiency \([5, 6]\) was calculated by the equations

\[ E_f = \frac{1 - z_d - \sum_{i=1}^{\kappa} x_{iF}}{1 - \sum_{i=1}^{\kappa} x_{iF}} \]

\[ E_s = \frac{1 - z_w - \sum_{i=k+1}^{t} x_{iF}}{1 - \sum_{i=k+1}^{t} x_{iF}} \]

where \(z_d\) is total content of heavy components in the distillate (mole fractions); \(z_w\) is total content of light components in the still bottoms (mole fractions); \(x_{iF}\) is concentration of the \(i\)-th component in the feed (mole fractions), components being numbered from light to heavy components; and \(t\) is the number of components in the mixture.

It is known that the position of the feed plate is not critical \([8, 9]\) and depends on the reflux ratio. It was assumed that the number of plates in the rectifying section is proportional to \((R + 1)/R N_{\text{min}}\) and in the stripping section to \((S + 1)/S N_{\text{min}}\) (\(S\) is still number). Therefore:

\[ \frac{N_r}{N_s} = \frac{N_r}{N_{\text{min}, \text{tot}}} \left( \frac{R}{R + 1} \right) \frac{S}{S + 1} \]

where \(N_r\) and \(N_s\) are number of theoretical plates in the rectifying and stripping sections of the column, respectively.

At the same time, we can write

\[ N_{\text{tot}} = N_r + N_s \]

\[ N_{\text{min}, \text{tot}} = N_{\text{min}, r} + N_{\text{min}, s} \]

The combined solution of Eqs. (5), (6), and (7) with respect to \(N_r\) gives

\[ N_r = N_{\text{min}, \text{tot}} \left( \frac{R + 1}{R} \right) \frac{S}{S + 1} N_{\text{min}, r} \]

The composition of the still bottoms and the distillate are calculated in terms of the division factor \(H\), which is the ratio of the streams of still bottoms \((W)\) and the distillate \((D)\) \([5, 10] \):

\[ H = \frac{W}{D} = \frac{x_{ID} - x_{IF}}{x_{IF} - x_{IW}} = \frac{\sum_{i=1}^{\kappa} x_{iD} - \sum_{i=1}^{\kappa} x_{iF}}{\sum_{i=1}^{\kappa} x_{iF} - \sum_{i=1}^{\kappa} x_{iW}} \]