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INTERRELATION BETWEEN THE KINETIC INDICES OF THE PROCESS OF RECTIFICATION AND MOVING FORCES

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The authors obtained generalized dependences for the heights of transfer units of ideal and actual steps that are expressed by the parameters of an actual tray in the vapor and liquid phases. The particular dependences of the heights of the transfer units equivalent to a theoretical tray that are expressed by the parameters of an actual tray in the vapor phase are presented for four variants of interrelation between the ideal and actual trays, two of which are characteristic of the Murphree model in analyzing the efficiency in the vapor and liquid phases and one of which is characteristic of the Hausen model. The ratio of the heights of the ideal and actual trays in all the variants is equal to the efficiency. It is noted that the expressions of the average moving forces, the mass-transfer coefficients, and the numbers of transfer units are individual for each variant and form of organization of phase motion, but in generalized form they are given by the existing dependences.

In calculations of rectification processes, the height of transfer units H, the mass-transfer coefficient K, and the number of transfer units N are important indices [1, 2]. The first two indices reflect the kinetics of the process if the moving force is expressed in terms of N and the concentration difference, respectively.

The operational height of the step of contact that corresponds to its actual step can be expressed by the following parameters of the vapor and liquid phases:

$$H' = \frac{V(y_n - y_{n-1})}{K_{\text{v}} a S \Delta y_{\text{av}}} , \tag{1}$$

$$H' = \frac{L(x_n - x_{n-1})}{K_{\text{liq}} a S \Delta x_{\text{av}}} . \tag{2}$$

In [3], we analyzed the expressions of the moving force for different forms of organization of flows of interacting phases for four variants of interrelation between the ideal and actual steps of contact. The first variant is distinguished by equality of the compositions of a vapor, arriving at both steps, and of a liquid that leaves them. These conditions are typical of the Murphree model [4, 5] in analyzing the efficiency in the vapor phase. In the second variant, the compositions of the vapor, going out from the ideal and actual steps, and of the liquid, arriving at them, coincide, which is peculiar to the Murphree model in analyzing the efficiency in the liquid [4, 5]. The third variant is distinguished by equality of the compositions of the vapor and the liquid that arrive at the ideal and actual steps of contact, which characterizes the Hausen model [5, 6]. In the fourth variant, the compositions of the vapor and the liquid, leaving the ideal and actual steps, coincide.

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TABLE 1. Magnitudes of the Average Moving Forces Expressed by the Parameters of the Liquid and Vapor Phases

Mean moving forces	Variants of mass exchange			
	1	2	3	4
		Direct flow		
$\Delta x_{\text{d.f av}}$	$\Delta x_{\text{d.f 1 av}}=\dfrac{\left(\dfrac{L}{mV}+1\right)(x_n-x_{n-1})}{\ln\dfrac{1+\dfrac{mV}{L}E_{\text{d.f 1}}}{1-E_{\text{d.f 1}}}}$	$\Delta x_{\text{d.f 2 av}}=\dfrac{\left(\dfrac{L}{mV}+1\right)(x_n-x_{n-1})}{\ln\dfrac{1+\dfrac{L}{mV}E_{\text{d.f 2}}}{1-E_{\text{d.f 2}}}}$	$\Delta x_{\text{d.f 3 av}}=\dfrac{\left(\dfrac{L}{mV}+1\right)(x_n-x_{n-1})}{\ln\dfrac{1}{1-E_{\text{d.f 3}}}}$	–
$\Delta y_{\text{d.f av}}$	$\Delta y_{\text{d.f 1 av}}=\dfrac{\left(1+\dfrac{mV}{L}\right)(y_n-y_{n-1})}{\ln\dfrac{1+\dfrac{mV}{L}E_{\text{d.f 1}}}{1-E_{\text{d.f 1}}}}$	$\Delta y_{\text{d.f 2 av}}=\dfrac{\left(1+\dfrac{mV}{L}\right)(y_n-y_{n-1})}{\ln\dfrac{1+\dfrac{L}{mV}E_{\text{d.f 2}}}{1-E_{\text{d.f 2}}}}$	$\Delta y_{\text{d.f 3 av}}=\dfrac{\left(1+\dfrac{mV}{L}\right)(y_n-y_{n-1})}{\ln\dfrac{1}{1-E_{\text{d.f 3}}}}$	–
		Counterflow		
$\Delta x_{\text{g av}}$	$\Delta x_{\text{g1 av}}=\dfrac{\left(\dfrac{L}{mV}-1\right)(x_n-x_{n-1})}{\ln\dfrac{1}{1-E_{\text{g1}}}}$	–	$\Delta x_{\text{g3 av}}=\dfrac{\left(\dfrac{L}{mV}-1\right)(x_n-x_{n-1})}{\ln\dfrac{1-\dfrac{mV}{L}E_{\text{g3}}}{1-E_{\text{g3}}}}$	$\Delta x_{\text{g4 av}}=\dfrac{\left(\dfrac{L}{mV}-1\right)(x_n-x_{n-1})}{\ln\dfrac{1-\dfrac{L}{mV}E_{\text{g4}}}{1-E_{\text{g4}}}}$
$\Delta y_{\text{g av}}$	$\Delta y_{\text{g1 av}}=\dfrac{\left(1-\dfrac{mV}{L}\right)(y_n-y_{n-1})}{\ln\dfrac{1}{1-E_{\text{g1}}}}$	–	$\Delta y_{\text{g3 av}}=\dfrac{\left(1-\dfrac{mV}{L}\right)(y_n-y_{n-1})}{\ln\dfrac{1-\dfrac{mV}{L}E_{\text{g3}}}{1-E_{\text{g3}}}}$	$\Delta y_{\text{g4 av}}=\dfrac{\left(1-\dfrac{mV}{L}\right)(y_n-y_{n-1})}{\ln\dfrac{1-\dfrac{L}{mV}E_{\text{g4}}}{1-E_{\text{g4}}}}$
		Cross flow		
$\Delta x_{\text{cr av}}$	$\Delta x_{\text{cr1 av}}=\dfrac{\dfrac{L}{mV}(x_n-x_{n-1})}{\ln\dfrac{\dfrac{2L}{mV}-1+E_{\text{cr1}}}{\left(\dfrac{2L}{mV}-1\right)(1-E_{\text{cr1}})}}$	$\Delta x_{\text{cr2 av}}=\dfrac{\dfrac{L}{mV}(x_n-x_{n-1})}{\ln\dfrac{\dfrac{2L}{mV}E_{\text{cr2}}+1-E_{\text{cr2}}}{1-E_{\text{cr2}}}}$	$\Delta x_{\text{cr3 av}}=\dfrac{\dfrac{L}{mV}(x_n-x_{n-1})}{\ln\dfrac{\dfrac{2L}{mV}+1-E_{\text{cr3}}}{\left(\dfrac{2L}{mV}+1\right)(1-E_{\text{cr3}})}}$	$\Delta x_{\text{cr4 av}}=\dfrac{\dfrac{L}{mV}(x_n-x_{n-1})}{\ln\dfrac{1-E_{\text{cr4}}-\dfrac{2L}{mV}E_{\text{cr4}}}{1-E_{\text{cr4}}}}$
$\Delta y_{\text{cr av}}$	$\Delta y_{\text{cr1 av}}=\dfrac{y_n-y_{n-1}}{\ln\dfrac{\dfrac{2L}{mV}-1+E_{\text{cr1}}}{\left(\dfrac{2L}{mV}-1\right)(1-E_{\text{cr1}})}}$	$\Delta y_{\text{cr2 av}}=\dfrac{y_n-y_{n-1}}{\ln\dfrac{\dfrac{2L}{mV}E_{\text{cr2}}+1-E_{\text{cr2}}}{1-E_{\text{cr2}}}}$	$\Delta y_{\text{cr3 av}}=\dfrac{y_n-y_{n-1}}{\ln\dfrac{\dfrac{2L}{mV}+1-E_{\text{cr3}}}{\left(\dfrac{2L}{mV}+1\right)(1-E_{\text{cr3}})}}$	$\Delta y_{\text{cr4 av}}=\dfrac{y_n-y_{n-1}}{\ln\dfrac{1-E_{\text{cr4}}-\dfrac{2L}{mV}E_{\text{cr4}}}{1-E_{\text{cr4}}}}$

In particular, in direct flow and under the conditions of the relationship of the ideal and actual trays that correspond to the Murphree model in analyzing the efficiency of mass exchange in the vapor phase, the average moving forces expressed by the parameters of the vapor and liquid phases are, respectively, equal to

$$\Delta y_{\text{d.f 1 av}}=\frac{mx_n-y_{n-1}-mx_{n-1}+y_n}{\ln\dfrac{mx_n-y_{n-1}}{mx_{n-1}-y_n}}=\frac{\left(1+\dfrac{mV}{L}\right)(y_n-y_{n-1})}{\ln\dfrac{1+\dfrac{mV}{L}E_{\text{d.f 1}}}{1-E_{\text{d.f 1}}}}, \tag{3}$$

$$\Delta x_{\text{d.f 1 av}} = \frac{x_n - \dfrac{y_{n-1}}{m} - x_{n-1} + \dfrac{y_n}{m}}{\ln \dfrac{x_n - \dfrac{y_{n-1}}{m}}{x_{n-1} - \dfrac{y_n}{m}}} = \frac{\left(\dfrac{L}{mV} + 1\right)(x_n - x_{n-1})}{\ln \dfrac{1 + \dfrac{mV}{L} E_{\text{d.f 1}}}{1 - E_{\text{d.f 1}}}} \,. \tag{4}$$

Similar dependences are also found in other variants of mass transfer for all forms of organization of the flows (Table 1). The absence of values for the average moving forces in the fourth variant in direct flow and in the second variant in counterflow in this table and the remaining ones is caused by the fact that in these models the efficiency is equal to unity.

Substituting Eq. (3) into Eq. (1) and Eq. (4) into Eq. (2), we obtain, respectively

$$H' = \frac{V \ln \dfrac{1 + \dfrac{mV}{L} E_{\text{d.f 1}}}{1 - E_{\text{d.f 1}}}}{K_{\text{v}} a S \left(1 + \dfrac{mV}{L}\right)} \,, \tag{5}$$

$$H' = \frac{L \ln \dfrac{1 + \dfrac{mV}{L} E_{\text{d.f 1}}}{1 - E_{\text{d.f 1}}}}{K_{\text{liq}} a S \left(1 + \dfrac{mV}{L}\right)} \,. \tag{6}$$

Analogous expressions can also be found in all the variants of mass transfer for all forms of the organization of flows.

As the efficiency approaches unity in the expressions obtained, the denominator of the logarithm number tends to zero, while the value of the logarithm and correspondingly the height of the ideal step tend to infinity, since the difference in the concentrations for a highly volatile component after the ideal step approaches zero and the determination of the mean logarithmic value of the moving force is difficult. Therefore, formulas (5) and (6) can be used only for determining the height of an actual step but they are unsuitable for calculating the height of an ideal step.

Figures 1 and 2 present the concentrations of the highly volatile component in the vapor phase and the liquid and also the corresponding heights of the steps of contact. As is seen from the figures, the height H is proportional to the difference of $(y_n - y_{n-1})$ and $(x_n - x_{n-1})$, whereas the height H'' is proportional to the difference of $(y_n^* - y_{n-1}^*)$ and $(x_n^* - x_{n-1}^*)$. With account for the variants of interrelation between the ideal and actual steps, the indicated proportionalities are somewhat modified.

In [7, 9], we analyzed the models of efficiency of contact steps in direct flow, counterflow, and cross motion of the vapor and liquid phases with account for the special features of the interrelation between the ideal and actual steps. Based on the results of these works, in all the variants and for all forms of organization of the flows it is possible to obtain the following expressions:

$$y_n^* - y_{n-1}^* = \frac{y_n - y_{n-1}}{E} \,, \tag{7}$$

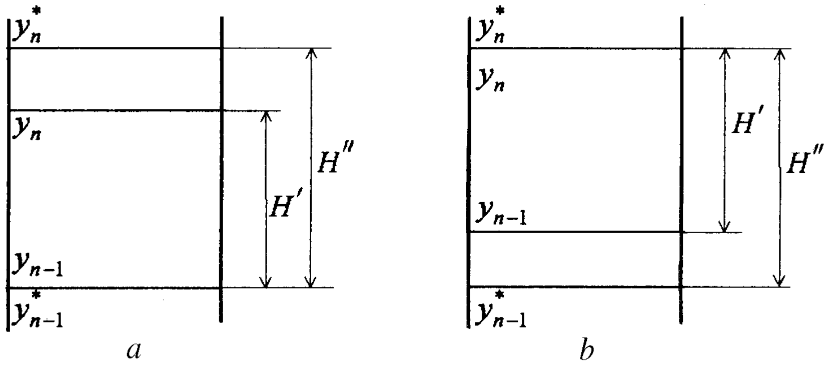

Fig. 1. Concentrations of the highly volatile component in the vapor phase in the first and third variants (a), the second and fourth (b) variants.

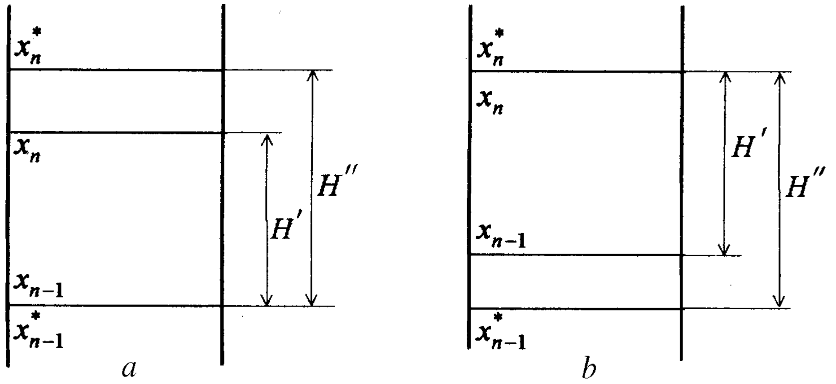

Fig. 2. Concentrations of the highly volatile component in the liquid in the first and fourth variants (a), the second and third (b) variants.

$$x_n^* - x_{n-1}^* = \frac{x_n - x_{n-1}}{E}, \tag{8}$$

which are also modified depending on the specific features of the variants.

With Eqs. (7) and (8) taken into account, we represent the height H'' for direct flow in the first variant of interrelation between the ideal and actual steps of contact as

$$H'' = \frac{H'}{E_{\text{d.f}\,1}} = \frac{V \ln \dfrac{1 + \dfrac{mV}{L} E_{\text{d.f}\,1}}{1 - E_{\text{d.f}\,1}}}{E_{\text{d.f}\,1} K_{\text{v}} a S \left(1 + \dfrac{mV}{L}\right)}, \tag{9}$$

$$H'' = \frac{H'}{E_{\text{d.f}\,1}} = \frac{L \ln \dfrac{1 + \dfrac{mV}{L} E_{\text{d.f}\,1}}{1 - E_{\text{d.f}\,1}}}{E_{\text{d.f}\,1} K_{\text{liq}} a S \left(1 + \dfrac{mV}{L}\right)}. \tag{10}$$

Similar expressions are derived for other variants and forms of organization of the flows; using them it is possible to determine the height of a theoretical tray from the parameters of an actual tray. Just as formulas (5) and (6), these expressions are of little use for values of the efficiency equal to unity.

Since on the step of contact of height H'' one obtains concentrations of the highly volatile component identical to those obtained under ideal conditions, H'' is the height of an actual step that is equivalent to a theoretical tray (HETT), i.e.,

$$\mathrm{HETT} = H'' . \tag{11}$$

The height of a theoretical tray must be smaller than the HETT due to the higher intensity of the processes of mass exchange. It can be expressed by formulas (9) and (10) in which the efficiency is equal to unity. However, as has been mentioned above, for this efficiency the value of the height is not specified.

Let us determine the difference of the heights

$$H'' - H' = H' \frac{1 - E_{\text{d.f}\,1}}{E_{\text{d.f}\,1}} = \frac{V \ln \dfrac{1 + \dfrac{mV}{L} E_{\text{d.f}\,1}}{1 - E_{\text{d.f}\,1}}}{K_{\text{v}} aS \left(1 + \dfrac{mV}{L}\right) \dfrac{E_{\text{d.f}\,1}}{1 - E_{\text{d.f}\,1}}} . \tag{12}$$

Since expression (12) represents an indeterminate form (indeterminancy), for it to be evaluated we will find a limit following the l'Hospital rule and having taken the derivatives of the numerator and the denominator:

$$\lim_{E_{\text{d.f}\,1} \to 1} (H'' - H') = \lim_{E_{\text{d.f}\,1} \to 1} \frac{V \ln \dfrac{1 + \dfrac{mV}{L} E_{\text{d.f}\,1}}{1 - E_{\text{d.f}\,1}}}{K_{\text{v}} aS \left(1 + \dfrac{mV}{L}\right) \dfrac{E_{\text{d.f}\,1}}{1 - E_{\text{d.f}\,1}}} = \lim_{E_{\text{d.}f1} \to 1} \frac{V}{K_{\text{v}} aS \left(1 + \dfrac{mV}{L}\right)} \frac{\left(\ln \dfrac{1 + \dfrac{mV}{L} E_{\text{d.}f1}}{1 - E_{\text{d.}f1}}\right)'}{\left(\dfrac{E_{\text{d.}f1}}{1 - E_{\text{d.}f1}}\right)'} =$$

$$= \lim_{E_{\text{d.f}\,1} \to 1} \frac{V}{K_{\text{v}} aS \left(1 + \dfrac{mV}{L}\right)} \frac{\left(1 + \dfrac{mV}{L}\right)(1 - E_{\text{d.f}\,1})}{1 + \dfrac{mV}{L} E_{\text{d.f}\,1}} = \lim_{E_{\text{d.f}\,1} \to 1} \frac{V}{K_{\text{v}} aS} \frac{1 - E_{\text{d.f}\,1}}{1 + \dfrac{mV}{L} E_{\text{d.f}\,1}} = 0 .$$

The proof that the difference of the heights of the ideal and actual trays for $E_{\text{d.f}\,1} \to 1$ is equal to zero confirms that H' is the height of the theoretical step.

In a similar manner, we can obtain analogous dependences in all the variants of mass transfer for all forms of organization of the flows, which makes it possible to express the height of the ideal step by the corresponding relations (Table 2) and to represent it in generalized form by the formulas

$$H_{\text{th.t}} = \frac{V (y_n - y_{n-1})}{E K_{\text{v}} aS \Delta y_{\text{av}}} , \tag{13}$$

TABLE 2. Values of the Heights of an Actual Tray Equivalent to the Heights of a Theoretical Tray

Height of actual tray	Variants of mass exchange			
	1	2	3	4
Direct flow				
$(\text{HETT})_{\text{d.f}}$	$\dfrac{V \ln \dfrac{1+\dfrac{mV}{L}E_{\text{d.f}1}}{1-E_{\text{d.f}1}}}{E_{\text{d.f}1}K_{\text{v}}aS\left(1+\dfrac{mV}{L}\right)}$	$\dfrac{V \ln \dfrac{1+\dfrac{L}{mV}E_{\text{d.f}2}}{1-E_{\text{d.f}2}}}{E_{\text{d.f}2}K_{\text{v}}aS\left(1+\dfrac{mV}{L}\right)}$	$\dfrac{V \ln \dfrac{1}{1-E_{\text{d.f}3}}}{E_{\text{d.f}3}K_{\text{v}}aS\left(1+\dfrac{mV}{L}\right)}$	–
Counterflow				
$(\text{HETT})_{\text{g}}$	$\dfrac{V \ln \dfrac{1}{1-E_{\text{g}1}}}{E_{\text{g}1}K_{\text{v}}aS\left(1-\dfrac{mV}{L}\right)}$	–	$\dfrac{V \ln \dfrac{1-\dfrac{mV}{L}E_{\text{g}3}}{1-E_{\text{g}3}}}{E_{\text{g}3}K_{\text{v}}aS\left(1-\dfrac{mV}{L}\right)}$	$\dfrac{V \ln \dfrac{1-\dfrac{L}{mV}E_{\text{g}4}}{1-E_{\text{g}4}}}{E_{\text{g}4}K_{\text{v}}aS\left(1-\dfrac{mV}{L}\right)}$
Cross flow				
$(\text{HETT})_{\text{cr}}$	$\dfrac{V \ln \dfrac{\dfrac{2L}{mV}-1+E_{\text{cr}1}}{\left(\dfrac{2L}{mV}-1\right)(1-E_{\text{cr}1})}}{E_{\text{cr}1}K_{\text{v}}aS}$	$\dfrac{V \ln \dfrac{\dfrac{2L}{mV}E_{\text{cr}2}+1-E_{\text{cr}2}}{1-E_{\text{cr}2}}}{E_{\text{cr}2}K_{\text{v}}aS}$	$\dfrac{V \ln \dfrac{\dfrac{2L}{mV}+1-E_{\text{cr}3}}{\left(\dfrac{2L}{mV}+1\right)(1-E_{\text{cr}3})}}{E_{\text{cr}3}K_{\text{v}}aS}$	$\dfrac{V \ln \dfrac{1-E_{\text{cr}4}-\dfrac{2L}{mV}E_{\text{cr}4}}{1-E_{\text{cr}4}}}{E_{\text{cr}4}K_{\text{v}}aS}$

$$H_{\text{th.t}} = \frac{L\,(x_n - x_{n-1})}{EK_{\text{liq}}aS\Delta x_{\text{av}}}\,. \tag{14}$$

Thus, in direct flow, the HETT is determined by formulas (9) and (10), while the height of the ideal step is determined by formulas (5) and (6). These formulas are applicable on substitution into them of the parameters of the actual step of contact of the vapor phase and the liquid.

The amount of highly volatile component that changes from the liquid to a vapor is expressed [1, 2] in terms of the parameters of the vapor phase

$$M = K_{\text{v}}aSH\Delta y_{\text{av}} \tag{15}$$

or the parameters of the liquid

$$M = K_{\text{liq}}aSH\Delta x_{\text{av}}\,, \tag{16}$$

By equating formulas (15) and (16) we can obtain the relation

$$K_{\text{v}}\Delta y_{\text{av}} = K_{\text{liq}}\Delta x_{\text{av}}\,. \tag{17}$$

For direct flow on condition that there is a relationship between the ideal and actual trays that correspond to the Murphree model in analyzing the efficiency in the vapor phase, the average moving forces expressed by the parameters of the vapor and liquid phases are determined by formulas (3) and (4).

Division of the left- and right-hand sides of Eqs. (3) and (4) gives the dependence

$$\frac{\Delta y_{\text{d.f 1 av}}}{\Delta x_{\text{d.f 1 av}}} = m\,, \tag{18}$$

which in generalized form in all the variants of mass transfer for all forms of organization of the flows is represented as

$$\frac{\Delta y_{\text{av}}}{\Delta x_{\text{av}}} = m\,. \tag{19}$$

By substituting Eq. (19) into Eq. (17) we obtain the relation of the mass-transfer coefficients expressed by means of the concentrations of the highly volatile component in the vapor and liquid phases:

$$K_{\text{liq}} = mK_{\text{v}}\,. \tag{20}$$

Relations similar to Eqs. (19) and (20) can be derived in other forms of organization of flows in all the variants of mass exchange. They correspond to the existing dependences [1, 2], which confirms the validity of the data in Table 1.

Thus, the ratio of the average moving forces in the vapor phase and the liquid is proportional to the equilibrium coefficient, whereas the ratio of the mass-transfer coefficients in the vapor and the liquid is inversely proportional to this quantity.

Proceeding from the material-balance equation for the highly volatile component, its amount, changing from the liquid to a vapor, is equal to

$$M = V\,(y_n - y_{n-1}) = L\,(x_n - x_{n-1})\,. \tag{21}$$

The numbers of transfer units, N_{v} and N_{liq}, are a result of simultaneous solution of the equilibrium equations and the operating line of the process prescribed by the initial and final concentrations [2]. These numbers expressed by the parameters of the vapor and liquid phases in the first variant in direct flow are determined by the corresponding dependences

$$N_{\text{d.f 1}} = \frac{y_n - y_{n-1}}{\Delta y_{\text{d.f 1 av}}} = \frac{K_{\text{v}} aSH}{V}\,, \tag{22}$$

$$N_{\text{d.f 1liq}} = \frac{x_n - x_{n-1}}{\Delta x_{\text{d.f 1 av}}} = \frac{K_{\text{liq}} aSH}{L}\,. \tag{23}$$

Simultaneous solution of Eqs. (3) and (22) and (4) and (23) with account for Eq. (21) leads to the known formula

$$\frac{N_{\text{d.f 1}}}{N_{\text{d.f 1 liq}}} = \frac{L}{mV}\,. \tag{24}$$

Dependences similar to Eqs. (22)–(24) are also obtained in other variants for all forms of organization of the phase flows and in generalized form are represented by the following relations:

$$N_{\text{v}} = \frac{y_n - y_{n-1}}{\Delta y_{\text{av}}}\,, \tag{25}$$

TABLE 3. Expressions of the Numbers of Transfer Units

Numbers of transfer units, N	Variants of mass exchange			
	1	2	3	4
		Direct flow		
$N_{\text{d.f v}}$	$\frac{\ln\frac{1+\frac{mV}{L}E_{\text{d.f 1}}}{1-E_{\text{d.f 1}}}}{1+\frac{mV}{L}}$	$\frac{\ln\frac{1+\frac{L}{mV}E_{\text{d.f 2}}}{1-E_{\text{d.f 2}}}}{1+\frac{mV}{L}}$	$\frac{\ln\frac{1}{1-E_{\text{d.f 3}}}}{1+\frac{mV}{L}}$	–
		Counterflow		
$N_{\text{g v}}$	$\frac{\ln\frac{1}{1-E_{\text{g1}}}}{1-\frac{mV}{L}}$	–	$\frac{\ln\frac{1-\frac{mV}{L}E_{\text{g3}}}{1-E_{\text{g3}}}}{1-\frac{mV}{L}}$	$\frac{\ln\frac{1-\frac{L}{mV}E_{\text{g4}}}{1-E_{\text{g4}}}}{1-\frac{mV}{L}}$
		Cross flow		
$N_{\text{cr v}}$	$\ln\frac{\frac{2L}{mV}-1+E_{\text{cr1}}}{\left(\frac{2L}{mV}-1\right)(1-E_{\text{cr1}})}$	$\ln\frac{\frac{2L}{mV}E_{\text{cr2}}+1-E_{\text{cr2}}}{1-E_{\text{cr2}}}$	$\ln\frac{\frac{2L}{mV}+1-E_{\text{cr3}}}{\left(\frac{2L}{mV}+1\right)(1-E_{\text{cr3}})}$	$\ln\frac{1-E_{\text{cr4}}-\frac{2L}{mV}E_{\text{cr4}}}{1-E_{\text{cr4}}}$

$$N_{\text{liq}}=\frac{x_n-x_{n-1}}{\Delta x_{\text{av}}}\,, \tag{26}$$

$$\frac{N_{\text{v}}}{N_{\text{liq}}}=\frac{L}{mV}\,. \tag{27}$$

Certain particular dependences of the numbers of transfer units are given in Table 3.

It should be noted that the values of the average forces expressed in terms of the concentration difference, the values of the numbers of transfer units, and mass-transfer coefficients hold only within the limits of individual variants and forms of organization of the flows, i.e., the parameters obtained, for example, for the first variant of interrelation between the ideal and actual trays in direct flow are adequate only for these conditions and differ from the corresponding quantities obtained under other conditions. However, their ratios in conformity with formulas (19), (20), and (27) remain constant for any cases.

NOTATION

a, specific surface of the phase contact per unit volume of the tray, m^2/m^3; *E*, efficiency of the tray; *H*, tray height, *m*; *K*, mass-transfer coefficient, mole/(m^2·sec·mole/m^3); *L*, molar liquid flow, mole/sec; *m*, equilibrium coefficient; *M*, amount of the substance changing from liquid to vapor, mole/sec; *N*, number of transfer units; *S*, tray surface, m^2; *V*, molar flow of the vapor phase, mole/sec; *x* and *y*, concentration of the highly volatile component in the liquid and the vapor, respectively, mole/m^3. Subscripts and superscripts: g, counterflow; cr, cross flow; liq, liquid phase; *n*, number of the tray considered; *n*–1, number of the preceding tray in the direction of vapor motion; d.f, direct flow; av, average value; th.t, theoretical (ideal) tray; v, vapor phase; 1–4, numbers of the variants considered; $'$, theoretical tray; $''$, actual tray that is equivalent to the theoretical one; *, ideal conditions.

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