Mass transfer effects in distillation
Springer, P.A.M.

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**Notation**

\( A_i \)  
area for component \( i \), \( \text{m}^2 \)

\( a' \)  
interfacial area per unit volume of vapour bubbles, \( \text{m}^2/\text{m}^3 \)

\( a_b \)  
vapour-liquid interfacial area per unit volume of dispersion, \( \text{m}^2/\text{m}^3 \)

\( a_d \)  
liquid-liquid interfacial area per unit volume of dispersion, \( \text{m}^2/\text{m}^3 \)

\( B_{ij} \)  
NRTL parameters; see Table 3.3, K

\( c_i \)  
molar concentration of species \( i \), \( \text{mol}/\text{m}^3 \)

\( c_i \)  
mixture molar density, \( \text{mol}/\text{m}^3 \)

\( c_{iL} \)  
mixture molar density of the liquid phase, \( \text{mol}/\text{m}^3 \)

\( c_{iV} \)  
mixture molar density of the vapour phase, \( \text{mol}/\text{m}^3 \)

\( d_b \)  
bubble diameter, m

\( d_d \)  
droplet diameter, m

\( D_{ij} \)  
Fick diffusivity in binary mixture, \( \text{m}^2/\text{s} \)

\( D_{x,ij} \)  
Maxwell-Stefan diffusivity for pair i-j, \( \text{m}^2/\text{s} \)

\( D_{x,ij} \)  
Maxwell-Stefan diffusivity for pair i-j for the liquid phase, \( \text{m}^2/\text{s} \)

\( D_{y,ij} \)  
Maxwell-Stefan diffusivity for pair i-j for the vapour phase, \( \text{m}^2/\text{s} \)

\( E_i \)  
component Murphree stage efficiency, dimensionless

\( E_{MV} \)  
component Murphree point efficiency, dimensionless

\( F_0 \)  
Fourier number, dimensionless

\( G_{ij} \)  
NRTL parameters; see Table 3.3, dimensionless

\( g \)  
acceleration due to gravity, \( \text{m}/\text{s}^2 \)

\( h \)  
distance along froth height, m

\( h_f \)  
height of dispersion, m

\( i \)  
component index

\( [I] \)  
identity matrix, dimensionless

\( j \)  
component index

\( J_i \)  
molar diffusion flux of species \( i \) relative to the molar average reference velocity \( u \), \( \text{mol}/\text{m}^2 \text{s} \)

\( k_{ij} \)  
element for matrix of multicomponent mass transfer coefficient, \( \text{m}/\text{s} \)

\( [k] \)  
matrix of multicomponent mass transfer coefficients, \( \text{m}/\text{s} \)

\( [k_x] \)  
matrix of multicomponent liquid mass transfer coefficients, \( \text{m}/\text{s} \)

\( [k_y] \)  
matrix of multicomponent vapour mass transfer coefficients, \( \text{m}/\text{s} \)

\( K_i \)  
concentration factor for component \( i \), \( \text{kg}^{-1} \)

\( [K_{eq}] \)  
diagonal matrix of K-values, dimensionless

\( [K_{OV}] \)  
matrix of multicomponent overall mass transfer coefficients, \( \text{m}/\text{s} \)

\( [K_{OV}] \)  
matrix of multicomponent overall mass transfer coefficients, \( \text{m}/\text{s} \)

\( m \)  
mass (of molecule), kg

\( N_i \)  
molar flux of species \( i \), \( \text{mol}/\text{m}^2 \text{s} \)

\( N_i \)  
mixture molar flux, \( \text{mol}/\text{m}^2 \text{s} \)

\( [N_{TV}] \)  
matrix of overall number of vapour phase transfer units, dimensionless

\( [N_{TL}] \)  
matrix of overall number of liquid phase transfer units, dimensionless

\( [N_{TV}] \)  
matrix of overall number of vapour phase transfer units, dimensionless

\( n \)  
number of diffusing species, dimensionless

\( n \)  
number of species in the mixture, dimensionless

\( [Q] \)  
\( = \exp[-(N_{TV})] \), dimensionless

\( r_i \)  
response factor of the GC for component \( i \), \( \text{m}^2/\text{kg} \)
Notation

$[R_{ij}]$ matrix of inverse mass transfer coefficients, m$^{-1}$ s

$S$ parameter defined in Eq. (4.13), m/s

$Sh$ Sherwood number, dimensionless

$t_b$ liquid-bubble contact time, s

$t_c$ liquid-bubble contact time, s

$T$ temperature, K

$u_i$ velocity of the diffusing species $i$, m/s

$u$ molar average mixture velocity, m/s

$V$ volume, m$^3$

$V_b$ single bubble rise velocity, m/s

$V_{injection}$ injection volume taken by the GC automatically, m$^3$

$x_i$ liquid composition for component $i$, dimensionless

$y_i$ vapour composition for component $i$, dimensionless

$z_i$ mole fraction of component $i$ of the appropriate phase, dimensionless

Greek letters

$\alpha_{ij}$ non-randomness parameter in NRTL equation; see Table 3.3, dimensionless

$\alpha_{ij}$ hold-up of vapour, dimensionless

$\alpha_d$ hold-up of drops, dimensionless

$\kappa_{ij}$ binary Maxwell-Stefan mass transfer coefficients, m/s

$\kappa_{s,ij}$ binary Maxwell-Stefan liquid mass transfer coefficients, m/s

$\kappa_{v,ij}$ binary Maxwell-Stefan vapour mass transfer coefficients, m/s

$\rho_L$ density of the liquid, kg/m$^3$

$\mu_L$ liquid viscosity, Pa s

$\mu_i$ molar chemical potential, J/mol

$\sigma$ surface tension, N/m

$\tau_V$ vapour phase residence time, s

$\tau_V$ vapour phase residence time, s

$\tau_{ij}$ NRTL parameters; see Table 3.3, dimensionless

$\xi$ dimensionless distance along dispersion or column height, dimensionless

Subscript

b referring to a bubble

cal referring to calibration solution

cs referring to calibration sample (for GC)

E referring to conditions entering a specified stage

eq referring to equilibrium

f referring to the froth

$i$ component index

$j$ component index, stage index

$k$ component index

L referring to conditions leaving a specified stage

$L_c$ referring to the continuous liquid phase
Ld referring to the dispersed liquid phase
mix referring to withdrawn column samples
n component index
OV overall parameter referred to the vapour phase
Oy overall parameter referred to the vapour phase
ref referring to reference solution/component
s referring to sample solution (for GC)
solvent referring to solvent to dissolve in
t referring to total mixture
V referring to the vapour phase
x referring to the liquid phase / component index
y referring to the vapour phase

Superscript
L referring to the liquid phase
Lc referring to the continuous liquid phase
Lc,b referring to the continuous liquid phase next to bubble
Lc,d referring to the continuous liquid phase next to drop
Ld referring to dispersed liquid droplet phase
M referring to Murphree
V referring to the vapour phase
* referring to equilibrium state

Dimensionless criteria

\[ Sh = \frac{\kappa_{Lc} d_{b}}{D} = \frac{2}{3} \pi^2 \left( \frac{\sum_{m=1}^{\infty} \exp\left(-m^2 \pi^2 Fo\right)}{\sum_{m=1}^{\infty} \frac{1}{m^2} \exp\left(-m^2 \pi^2 Fo\right)} \right) \]

\[ Sh_{ij} = \frac{\kappa_{y,ij} d_{b}}{D_{y,ij}} = \frac{2}{3} \pi^2 \left( \frac{\sum_{m=1}^{\infty} \exp\left(-m^2 \pi^2 Fo_{y}\right)}{\sum_{m=1}^{\infty} \frac{1}{m^2} \exp\left(-m^2 \pi^2 Fo_{y}\right)} \right) \]

\[ Fo = \frac{4D t}{d_b^2} \]

\[ Fo_{ij} = \frac{4D_{y,ij} \pi^2}{d_b^2} \]