ABSORPTION FUNDAMENTALS & APPLICATIONS

ABSORPTION

Fundamentals & Applications

Roman Zarzycki and Andrzej Chacuk

Faculty of Process & Environmental Engineering
Technical University of Lodz

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NOTATION

a - specific surface of packing, m^2/m^3

a - mass transfer area in unit volume of equipment, m^2/m^3

b - mass fraction, dimensionless

C - molar concentration, $kmol/m^3$

c_p - heat capacity at constant pressure, J/(kg K)

C_p - molar heat capacity at constant pressure, J/(kmol K)

CF - capacity factor, m/s

d - diameter, m

D - multicomponent diffusion coefficient, m^2/s

$\mathcal{D}$ - binary diffusion coefficient, m^2/s

Đ - generalized Stefan-Maxwell diffusion coefficient, m^2/s

D_D - dispersion coefficient, m^2/s

D^T - binary thermal diffusion coefficient, m^2/s

E - enhancement factor, dimensionless

E_∞ - enhancement factor for instantaneous reaction, dimensionless

E - point efficiency, dimensionless

E_o - overall plate efficiency, dimensionless

E_M - Murphree plate efficiency, dimensionless

FP - flow parameter, dimensionless

g - mass rate of gas, kg/s

g_z - acceleration of gravity, m/s^2

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G - molar rate of gas, kmol/s
h - enthalpy per unit mass, J/kg
H - enthalpy per unit kilomole, J/kmol, kJ/lmol
He - Henry's law constant, Pa
H - Henry's law constant, $(\text{Pa m})^3/\text{kmol}$
H' - Henry's law constant, Pa^{-1}
I - mass transfer rate, kmol/s
k - binary mass transfer coefficient, m/s
k_x - binary liquid mass transfer coefficient, $\text{kmol}/(\text{m}^2\text{s})$
k_y - binary gas mass transfer coefficient, $\text{kmol}/(\text{m}^2\text{s})$
k_X - binary liquid mass transfer coefficient, $\text{kmol}/(\text{m}^2\text{s})$
k_Y - binary gas mass transfer coefficient, $\text{kmol}/(\text{m}^2\text{s})$
k - chemical reaction rate constant, different dimensions
K - overall mass transfer coefficient, m/s
l - liquid mass rate, kg/s
L - liquid molar rate, kmol/s
m - molarity, kmol/kg
m - slope of equilibrium line, dimensionless
M - molecular weight, kg/kmol
M - reaction factor, dimensionless
n - number of components in fluid
n - mass flux with respect to stationary coordinates, $\text{kg}/(\text{m}^2\text{s})$
N - Avogadro's number, 1/kmol
N - molar flux with respect to stationary coordinates, $\text{kmol}/(\text{m}^2\text{s})$
p - number of plates in plate column
P - pressure, Pa
q - heat flux, W/m^2
q - mass transfer factor, dimensionless
Q - heat rate, W
r - number of chemical reaction
R - molar rate of chemical reaction, $\text{kmol}/(\text{m}^2\text{s})$
R - universal gas constant, J/(kmol K)
S - cross-sectional area, m^2
t - time, s
T - temperature, K
u - superficial fluid velocity in equipment, m/s
v - volumetric flow rate, m^3/s
V - molar volume, m^3/kmol
w - superficial mass fluid velocity, $\text{kg}/(\text{m}^2\text{s})$

W - superficial molar fluid velocity, kmol/(m^2s)
x - rectangular coordinate, m
x_i - mole fraction of component i in liquid phase, dimensionless
y - rectangular coordinate, m
y_i - mole fraction of component i in the gas phase, dimensionless
z - rectangular coordinate, m
Z - height of the equipment, m

α - heat transfer coefficient, W/(m^2K)
α - gas hold-up, m^3/m^3
β - volumetric fraction, dimensionless
β - liquid hold-up, m^3/m^3
γ - solid volumetric fraction, m^3/m^3
δ - film thickness, m
ε - voidage of bed, dimensionless
ε - energy flux, W/m^2
η - viscosity, kg/(m s)
λ - conductivity, W/(mK)
υ - kinematic viscosity, m^2/s
υ - stoichiometry coefficient, dimensionless
ρ - density, kg/m^3
σ - surface tension, N/m
σ_c - critical surface tension, N/m
Ξ_H - correction factor for the effect of high fluxes on heat transfer coefficient, dimensionless
Φ_H - dimensionless heat transfer factor, dimensionless

Subscripts

A, B, C - components in multicomponent systems
av - average
c - at critical point
d - dynamic quantity
G - gas phase
i, j, k, l - components in multicomponent system
ij - pair i-j in multicomponent system
in - inert

k - column
l - laboratory
L - liquid phase
m - logarithmic mean value
p - bubble, element of packing
r - reduced relative to critical value
s - static quantity
t - total mass (molar) flux
0 - reference state
1 - quantity evaluated at lower cross section of equipment
2 - quantity evaluated at upper cross section of equipment

Superscripts

ef - effective
r - equilibrium value
* - gas-liquid interface
** - liquid-solid interface
‾ - mean value
~ - partial value
o - at infinite dilution
● - for finite mass-transfer flux
▼ - relative to the molar average velocity of fluid
■ - relative to the volumetric average velocity of fluid
δ - in the bulk of fluid

Vectors and Matrices

$\mathbf{d}_i = [d_{ix}, d_{iy}, d_{iz}]$ - vector of driving forces for diffusion, m^{-1}

$\mathbf{f}_i = [f_{ix}, f_{iy}, f_{iz}]$ - vector of external force on unit mass of component i, N/m

$\mathbf{J}^{▼} = [J^{▼}_1,\ldots,J^{▼}_{n-1}]^T$ - vector of molar diffusion flux, $kmol/(m^2 s)$

$\mathbf{J}^{\omega}_i = [J^{\omega}_{ix}, J^{\omega}_{iy}, J^{\omega}_{iz}]$ - vector of molar diffusion flux of component i relative to velocity ω, $kmol/(m^2 s)$

$\mathbf{j}^{\omega}_i = [j^{\omega}_{ix}, j^{\omega}_{iy}, j^{\omega}_{iz}]$ - vector of mass diffusion flux of compoent i relative to velocity ω, $kg/(m^2 s)$

$\mathbf{k} = (k_{ij})_{i,j \leq n-1}$ - matrix of multicomponent mass transfer coefficients for "zero" mass transfer flux, m/s

$k^{\bullet} = (k^{\bullet}_{ij})_{i,j \leq n-1}$ - matrix of multicomponent mass transfer coefficients for finite mass transfer flux, m/s

$N = [N_1,\ldots,N_{n-1}]^T$ - vector of molar flux, $kmol/(m^2 s)$

$N_i = [N_{ix}, N_{iy}, N_{iz}]$ - vector of molar flux of component i, $kmol/(m^2 s)$

$n_i = [n_{ix}, n_{iy}, n_{iz}]$ - vector of mass flux of component i, $kg/(m^2 s)$

$q = [q_x, q_y, q_z]$ - vector of heat flux, W/m

$u = [u_x, u_y, u_z]$ - vector of mass average velocity, m/s

$u^{\blacktriangledown} = [u^{\blacktriangledown}_x, u^{\blacktriangledown}_y, u^{\blacktriangledown}_z]$ - vector of molar average velocity, m/s

$u^{E} = [u^{E}_x, u^{E}_y, u^{E}_z]$ - vector of volume average velocity, m/s

$u_i = [u_{ix}, u_{iy}, u_{iz}]$ - vector of macroscopic velocity of component i, m/s

$w_i^{(\alpha)} = [w_{ix}^{(\alpha)}, w_{iy}^{(\alpha)}, w_{iz}^{(\alpha)}]$ - vector of mass flow velocity of gas phase in absorber, $kg/(m^2 s)$

$w_i^{(\beta)} = [w_{ix}^{(\beta)}, w_{iy}^{(\beta)}, w_{iz}^{(\beta)}]$ - vector of mass flow velocity of liquid phase in absorber, $kg/(m^2 s)$

$W_i^{(\alpha)} = [W_{ix}^{(\alpha)}, W_{iy}^{(\alpha)}, W_{iz}^{(\alpha)}]$ - vector of molar flow velocity of gas phase in absorber, $kmol/(m^2 s)$

$W_i^{(\beta)} = [W_{ix}^{(\beta)}, W_{iy}^{(\beta)}, W_{iz}^{(\beta)}]$ - vector of molar flow velocity of liquid phase in absorber, $kmol/(m^2 s)$

$x = [x_1,\ldots,x_{n-1}]^T$ - vector of mole fraction in liquid phase, dimensionless

$y = [y_1,\ldots,y_{n-1}]^T$ - vector of mole fraction in gas phase, dimensionless

$\Gamma = (\Gamma_{ij})_{i,j \leq n-1}$ - matrix of thermodynamic factors, dimensionless

$\Phi = (\Phi_{ij})_{i,j \leq n-1}$ - matrix of mass transfer factor, dimensionless

Dimensionless Groups

$$\mathrm{Bo} = \frac{g_z \, d_p \, \rho_L}{\sigma}$$ - Bond number

$$\mathrm{De} = \frac{u \, \lambda}{d_p}$$ - Deborah number

$$\mathrm{Ga} = \frac{g_z \, d_k^3}{\upsilon_L^3}$$ - Galillei number

$$\mathrm{Fr} = \frac{u_G}{(g_z d_k)^{1/2}}$$ - Froude number

$$\mathrm{Re} = \frac{u \, d \, \rho}{\eta}$$ - Reynolds number

$$\mathrm{Sc} = \frac{\eta}{\rho \, \mathcal{D}}$$ - Schmidt number

$$\mathrm{Sh} = \frac{k \, d}{\mathcal{D}}$$ - Sherwood number

CONTENTS

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Chapter 1

INTRODUCTION

Since the foundation of modern industry until the present time, absorption of gases in liquids has been of interest to practitioners and theoreticians of chemical and process engineering. This reflects the fact that it is one of the basic operations in many technological processes. The fertilizer industry provides a good example of the role of absorption processes. Absorption is also very important in gas and crude oil processing. Many intermediate and final products in the manufacture of organic chemicals are obtained as a result of the absorption of gases with their simultaneous reaction in the liquid phase. Recently, environmental protection has emerged as a significant problem. One of the basic operations of use in the solution of these problems is absorption.

The theory of absorption initially concentrated on kinetics and the design of absorbers for the case of physical absorption of one component in a liquid. Theoretical and experimental studies were also carried out on absorption accompanied by a simple chemical reaction. The culmination of these studies was the classical monograph by Sherwood and Pigford, "Absorption and Extraction", the second edition of which was published in 1952.

In the 1960s studies on absorption accompanied by a chemical reaction developed. Of particular importance were the investigations carried out by Astarita and Danckwerts. The results of many of these studies found practical applications. Until now these studies have represented one of the most quickly developing branches of chemical engineering. Another branch is multicomponent absorption, with special reference to multicomponent diffusion, which was initiated by Standard and Krishna in the 1970s. The

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