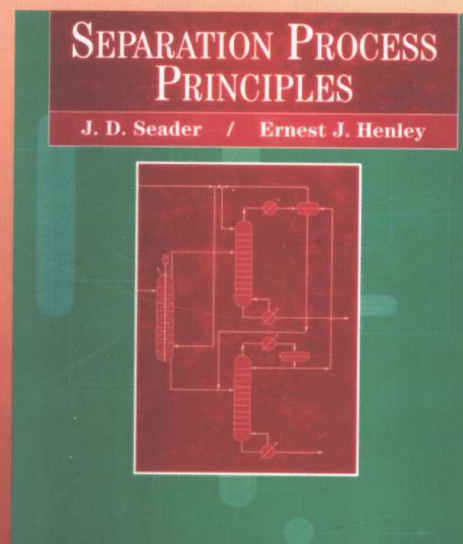


国外名校名著

SEPARATION PROCESS PRINCIPLES

分离过程原理

J.D.Seader, Ernest J.Henley



化学工业出版社

SEPARATION

SEPARATION PROCESS PRINCIPLES

SECOND EDITION

By *Robert Perry* and *Don W. Weaver*



McGraw-Hill

国外名校名著



Separation Process Principles

分离过程原理

J. D. Seader, Ernest J. Henley



化学工业出版社

(京) 新登字 039 号

图书在版编目 (CIP) 数据


分离过程原理: 英文/(美) 塞德 (Seader, J.) 等著. —影印本.
—北京: 化学工业出版社, 2002. 6
书名原文: Separation Process Principles
ISBN 7-5025-2818-0

I. 分… II. 塞… III. 分离-化工过程-高等学校-教材-英文
IV. TQ028

中国版本图书馆 CIP 数据核字 (2002) 第 040066 号

J. D. Seader, Ernest J. Henley
Separation Process Principles
ISBN: 0-471-58626-9
Copyright © 1998 by John Wiley & Sons, Inc. All Rights Reserved.

AUTHORIZED REPRINT OF THE EDITION PUBLISHED BY JOHN
WILEY & SONS, INC., New York, Chichester, Weinheim, Singapore,
Brisbane, Toronto. No part of this book may be reproduced in any form
without the written permission of

 John Wiley & Sons, Inc.

This reprint is for sale in the People's Republic of China only and exclude
Hong Kong and Macau.

本书封面贴有 John Wiley & Sons, Inc. 公司防伪标签, 无标签者不得销售。
北京市版权局著作权合同登记号: 01-2002-4043

Separation Process Principles

分离过程原理

J. D. Seader, Ernest J. Henley

责任编辑: 徐世峰 王丽娜

封面设计: 郑小红

*

化学工业出版社出版发行

(北京市朝阳区惠新里 3 号 邮政编码 100029)

发行电话: (010) 64982530

<http://www.cip.com.cn>

*

新华书店北京发行所经销

北京市彩桥印刷厂印刷

北京市彩桥印刷厂装订

开本 850×1168 毫米 1/16 印张 57¼

2002 年 8 月第 1 版 2002 年 8 月北京第 1 次印刷

ISBN 7-5025-2818-0/G·737

定 价: 89.00 元

版权所有 违者必究

该书如有缺页、倒页、脱页者, 本社发行部负责退换

前 言

随着中国社会主义现代化建设进入新的阶段，以高质量的高等教育培养千百万专门人才，迎接新世纪的挑战，是实现“科教兴国”战略的基础工程，也是完成“十五”计划各项奋斗目标的重要保证。为切实加强高等学校本科教学并提高教学质量，教育部于2001年专门下发文件提出12条意见，对高等学校教学工作从认识、管理、教师队伍到教学方法和教学手段等给予指导。文件强调，按照“教育要面向现代化、面向世界、面向未来”的要求，为适应经济全球化和科技国际化的挑战，本科教育要创造条件使用英语等外语进行公共课和专业课教学。

在文件精神指导下，全国普通高等学校尤其是重点高校中兴起了使用国外教材开展教学活动的潮流。如生物技术与工程、环境科学与工程、材料科学与工程及作为其学科基础理论重要组成部分的化学技术和化学工程技术又是这股潮流中最为活跃的领域之一。在教育部“化工类专业人才培养方案及教学内容体系改革的研究与实践”项目组及“化工类专业创新人才培养模式、教学内容、教学方法和教学改革的研究与实践”项目组和“全国本科化学工程与工艺专业教学指导委员会”的指导和支持下，化学工业出版社及时启动了引进国外名校名著的教材工程。

出版社组织编辑人员多次赴国外学习考察，通过国外出版研究机构对国外著名的高等学校进行调查研究，搜集了一大批国际知名院校的现用教材选题。他们还联络国内重点高校的专家学者组建了“国外名校名著评价委员会”，对国外和国内高等本科教学进行比较研究，对教材内容质量进行审查评议，然后决定是否引进。他们与国外许多著名的出版机构建立了联系，有的还建立了长期合作关系，以掌握世界范围内优秀教材的出版动态。

以其化学化工专业领域的优势资源为基础，化学工业出版社的教材引进主要涉及化学、化学工程与工艺、环境科学与工程、生物技术与工程、材料科学与工程、制药工程等专业，对过程装备与控制工程、自动化等传统专业教材的引进也在规划之中。

他们在影印、翻译出版国外教材的过程中，注意学习国外教材出版的经验，提高编辑素质，密切编读联系，整合课程体系，更新教材内容，科学设计版面，提高印装质量，更好地为教育服务。

在化工版“国外名校名著”系列教材即将问世之际，我们不仅感谢化学工业出版社为高等教育所做的努力，更应赞赏他们严谨认真的工作作风。

中国科学院院士，天津大学教授

余国琮

2002年8月

About the Authors

J. D. Seader is Professor of Chemical Engineering at the University of Utah. He received B.S. and M.S. degrees from the University of California at Berkeley and a Ph.D. from the University of Wisconsin. From 1952 to 1959, Seader designed processes for Chevron Research, and from 1959 to 1965, he conducted rocket engine research for Rocketdyne. Before joining the faculty at the University of Utah, he was a professor at the University of Idaho. Combined, he has authored or coauthored 102 technical articles, six books, and four patents, and also coauthored the section on distillation in the 6th and 7th editions of *Perry's Chemical Engineers' Handbook*. Seader has been a trustee of CACHE for 26 years, serving as an executive officer from 1980 to 1984. For 20 years, he directed the use and distribution of Monsanto's FLOWTRAN process simulation computer program for various universities. Seader also served as a director of AIChE from 1983 to 1985. In 1983, he presented the 35th Annual Institute Lecture of AIChE, and in 1988, received the Computing in Chemical Engineering Award of the CAST Division of AIChE.

Ernest J. Henley is Professor of Chemical Engineering at the University of Houston. He received his B.S. degree from the University of Delaware and his Dr. Eng. Sci. from Columbia University, where he served as a professor from 1953 to 1959. Henley also has held professorships at the Stevens Institute of Technology, the University of Brazil, Stanford University, Cambridge University, and the City University of New York. He has authored or coauthored 72 technical articles and 12 books, the most recent one being *Probabilistic Risk Management for Scientists and Engineers*. For 17 years, he was a trustee of CACHE, serving as President from 1975 to 1976 and directing the efforts that produced the seven-volume set of "Computer Programs for Chemical Engineering Education" and the five-volume set, "AIChE Modular Instruction." An active consultant, Henley holds nine patents and serves on the Board of Directors of Maxxim Medical, Inc., Procedyne, Inc., Lasermedics, Inc., and Nanodyne, Inc.

Preface

This textbook is intended for use in undergraduate chemical engineering curriculums. The material is suitable for courses in equilibrium-stage processes, stagewise separation processes, mass transfer operations, separation processes, and rate-controlled separations. Those schools that teach a two-semester sequence in equilibrium stages and mass transfer may find that this textbook satisfies all the needs of that sequence. Some schools may find some of the material suitable for graduate courses in separations.

In 1963, E. J. Henley and H. K. Staffin authored a book, entitled *Stagewise Process Design*, that introduced chemical engineering students to nondiffusional aspects of material and energy balances under phase equilibria constraints, using mainly graphical methods. Most of that book was incorporated, in 1981, into a greatly expanded textbook, *Equilibrium-Stage Separation Operations in Chemical Engineering*, by E. J. Henley and J. D. Seader. The objective of this expanded book was to enhance the 1963 book by adding material on the mathematics and science associated with staged calculations as implemented in commercial, steady-state process simulation computer programs, which were becoming widely available and relied on numeric, rather than graphical, methods of solution. Today, the use of simulation programs is taught to undergraduate students in virtually every chemical engineering department. These programs are easy to use, but, to avoid convergence problems and impossible specifications, the user must have a firm understanding of the fundamentals of chemical engineering. Hopefully, the 1981 textbook provided that understanding.

Since publication of our 1981 textbook, interest in the design and simulation of separation operations using mass transfer (rate-based) principles has increased considerably. This resulted from the availability of improved packings for packed columns used in absorption, distillation, and stripping, and also from the development of theory and applications for the less mature separation operations of adsorption, crystallization, and membrane separations. At the same time, batch distillation, for which rigorous, computer-based calculation methods have been developed, has found wider application. Also, greatly improved procedures for the development of separation processes using enhanced distillation (azeotropic, extractive, pressure-swing, and reactive) have been published, and new applications of supercritical-fluid extraction and chromatography have been commercialized. Our 1981 textbook contained little material on these topics; however, this new textbook contains substantial material on these important topics, as well as those covered in the 1981 textbook. Both equilibrium-based and rate-based methods are covered extensively.

This textbook is organized and divided into four parts. Part one, which consists of five chapters, presents introductory concepts. Chapter 1 describes the many ways in which chemical mixtures are separated industrially. Chapter 2 reviews solution thermodynamics, for both equilibrium-based and rate-based approaches to separation operations. This chapter can be omitted and used only for reference if students have completed or are taking concurrently a course in chemical engineering thermodynamics. Chapter 3 covers the basic principles of diffusion and mass transfer required for the rate-based approach to separation operations. The use of phase equilibrium and material-balance equations to solve a wide range of single equilibrium-stage separations is covered in Chapter 4, while Chapter 5 introduces the student to cascades of equilibrium stages.

The remaining three parts of the textbook are organized according to the method of separation. In Part two, separations achieved by phase creation or addition are presented. Chapters 6 through 8 cover absorption and stripping of dilute solutions, binary distillation, and ternary liquid–liquid extraction. Chapters 9 through 11 detail computer-based methods used in simulation programs for vapor–liquid and liquid–liquid separations. Chapter 12 presents new rate-based methods for multicomponent, multistage separations, while Chapter 13 focuses on batch distillation.

Separations by barriers and solid agents are presented in Part three, with membrane separations in Chapter 14 and adsorption, ion exchange, and chromatography in Chapter 15. This first edition of *Separation Process Principles* does not include Part four, which consists of three chapters on separations that involve a solid phase: leaching and washing; crystallization, desublimation, and evaporation; and drying. These chapters may be obtained from the senior author. If there is sufficient demand for these three chapters, they will be included in the next edition of this textbook.

Almost every topic in this textbook is illustrated by a detailed example and is accompanied by at least three homework exercises. There are a total of 157 examples and 538 homework exercises, and solutions to most homework exercises are included in an instructor's manual. In addition, the authors plan to add examples and exercises to a web site located at www.wiley.com/college/seader.

An attempt has been made to present the development of industrial equipment and the accompanying theory for each separation operation, together with pertinent references to the literature, in an historical context. To assist students in gaining a suitable understanding of this descriptive material, the authors have prepared extensive sets of questions for each chapter (available on the Web site).

The authors wish to acknowledge Professors Vincent Van Brunt of the University of South Carolina, William L. Conger of Virginia Polytechnic Institute and State University, William A. Heenan of Texas A&M University–Kingsville, James H. McMicking of Wayne State University, and Ross Taylor of Clarkson University, who provided advice and detailed reviews for many of the chapters. The draft of the manuscript was typed by Anna Zoe Simmons and Christie J. Perry of the University of Utah, with the effort facilitated by Vickie S. Jones. Chemical engineering students at the University of Utah and the University of Houston, who used early drafts of many of the chapters in their undergraduate courses in equilibrium-stage calculations, mass transfer, and separations, also provided valuable suggestions that improved the presentations of this material. Finally, we are indebted to A. Wayne Anderson of John Wiley & Sons, who provided valuable guidance from a publisher's perspective.

J. D. Seader
Ernest J. Henley

Contents

Chapter 1

Separation Processes 1

- 1.1 Industrial Chemical Processes 1
- 1.2 Mechanism of Separation 5
- 1.3 Separation by Phase Addition or Creation 7
- 1.4 Separation by Barrier 14
- 1.5 Separation by Solid Agent 16
- 1.6 Separation by External Field or Gradient 18
- 1.7 Component Recoveries and Product Purities 19
- 1.8 Separation Power 22
- 1.9 Selection of Feasible Separation Processes 23
- Summary 27 References 28 Exercises 28

Chapter 2

Thermodynamics of Separation Operations 31

- 2.1 Energy, Entropy, and Availability Balances 31
- 2.2 Phase Equilibria 36
 - Fugacities and Activity Coefficients 37
 - K -Values 38
- 2.3 Ideal Gas, Ideal Liquid Solution Model 42
- 2.4 Graphical Correlations of Thermodynamic Properties 47
- 2.5 Nonideal Thermodynamic Property Models 51
 - P - v - T Equation-of-State Models 54
 - Derived Thermodynamic Properties from P - v - T Models 58
- 2.6 Activity Coefficient Models for the Liquid Phase 63
 - Activity Coefficients from Gibbs Free Energy 63
 - Regular Solution Model 64
 - Chao-Seader Correlation 66
 - Nonideal Liquid Solutions 68
 - Margules Equations 72
 - van Laar Equation 72
 - Local Composition Concept and Wilson Equation 74
 - NRTL Equation 78
 - UNIQUAC Equation 79
 - UNIFAC Equation 80
 - Liquid-Liquid Equilibria 82
- Summary 83 References 83 Exercises 84

Chapter 3

Mass Transfer and Diffusion 90

- 3.1 Steady-State Ordinary Molecular Diffusion 91
 - Fick's Law of Diffusion 92
 - Velocities in Mass Transfer 92
 - Equimolar Counterdiffusion 93
 - Unimolecular Diffusion 95
- 3.2 Diffusion Coefficients 99
 - Diffusivity in Gas Mixtures 99
 - Diffusivity in Liquid Mixtures 101
 - Diffusivity in Solids 109
- 3.3 One-Dimensional Steady-State and Unsteady-State Molecular Diffusion 117
 - Steady State 117
 - Unsteady State 118
- 3.4 Molecular Diffusion in Laminar Flow 126
 - Falling Liquid Film 127
 - Boundary-Layer Flow on a Flat Plate 133
 - Fully Developed Flow in a Straight, Circular Tube 136
- 3.5 Mass Transfer in Turbulent Flow 140
 - Reynolds Analogy 141
 - Chilton-Colburn Analogy 142
 - Prandtl Analogy 143
- 3.6 Models for Mass Transfer at a Fluid-Fluid Interface 144
 - Film Theory 145
 - Penetration Theory 146
 - Surface Renewal Theory 147
 - Film-Penetration Theory 149
- 3.7 Two-Film Theory and Overall Mass Transfer Coefficients 150
 - Gas-Liquid Case 150
 - Liquid-Liquid Case 153
 - Case of Large Driving Forces for Mass Transfer 154
- Summary 157 References 158 Exercises 159

Chapter 4

Single Equilibrium Stages and Flash Calculations 163

- 4.1 The Gibbs Phase Rule and Degrees of Freedom 163
 - Degrees-of-Freedom Analysis 164
- 4.2 Binary Vapor-Liquid Systems 166
- 4.3 Azeotropic Systems 173
- 4.4 Multicomponent Flash, Bubble-Point, and Dew-Point Calculations 176
 - Isothermal Flash 178
 - Bubble and Dew Points 181
 - Adiabatic Flash 184
- 4.5 Ternary Liquid-Liquid Systems 186
- 4.6 Multicomponent Liquid-Liquid Systems 195

4.7	Solid-Liquid Systems	198
	Leaching	198
	Crystallization	201
	Liquid Adsorption	204
4.8	Gas-Liquid Systems	207
4.9	Gas-Solid Systems	211
	Sublimation and Desublimation	211
	Gas Adsorption	212
4.10	Multiphase Systems	213
	Approximate Method for a Vapor-Liquid-Solid System	214
	Approximate Method for a Vapor-Liquid-Liquid System	215
	Rigorous Method for a Vapor-Liquid-Liquid System	218
	Summary	220
	References	221
	Exercises	222

Chapter 5

Cascades 232

5.1	Cascade Configurations	232
5.2	Solid-Liquid Cascades	234
5.3	Single-Section Liquid-Liquid Extraction Cascades	237
	Cocurrent Cascade	238
	Crosscurrent Cascade	239
	Countercurrent Cascade	239
5.4	Multicomponent Vapor-Liquid Cascades	241
	Single-Section Cascades by Group Methods	242
	Two-Section Cascades	246
5.5	Degrees of Freedom and Specifications for Countercurrent Cascades	253
	Stream Variables	254
	Adiabatic or Nonadiabatic Equilibrium Stage	254
	Single-Section Countercurrent Cascade	255
	Two-Section Countercurrent Cascades	257
	Summary	263
	References	264
	Exercises	264

Chapter 6

Absorption and Stripping of Dilute Mixtures 270

6.1	Equipment	273
6.2	General Design Considerations	281
6.3	Graphical Equilibrium-Stage Method for Trayed Towers	282
	Minimum Absorbent Flow Rate	284
	Number of Equilibrium Stages	285
6.4	Algebraic Method for Determining the Number of Equilibrium Stages	289
6.5	Stage Efficiency	292
	Performance Data	293
	Empirical Correlations	294
	Semitheoretical Models	299
	Scale-up from Laboratory Data	303

6.6	Tray Capacity, Pressure Drop, and Mass Transfer	305
	Tray Diameter	306
	Tray Vapor Pressure Drop	310
	Mass Transfer Coefficients and Transfer Units	312
	Weeping, Entrainment, and Downcomer Backup	315
6.7	Rate-Based Method for Packed Columns	317
6.8	Packed Column Efficiency, Capacity, and Pressure Drop	325
	Liquid Holdup	325
	Capacity and Pressure Drop	330
	Mass Transfer Efficiency	335
6.9	Concentrated Solutions in Packed Columns	342
	Summary	346
	References	347
	Exercises	348

Chapter 7

	Distillation of Binary Mixtures	355
7.1	Equipment and Design Considerations	358
7.2	McCabe–Thiele Graphical Equilibrium-Stage Method for Trayed Towers	359
	Rectifying Section	362
	Stripping Section	365
	Feed-Stage Considerations	366
	Determination of Number of Equilibrium Stages and Feed-Stage Location	369
	Limiting Conditions	369
	Column Operating Pressure and Condenser Type	374
	Subcooled Reflux	376
	Reboiler Type	380
	Condenser and Reboiler Duties	381
	Feed Preheat	382
	Optimal Reflux Ratio	382
	Large Number of Stages	384
	Use of Murphree Efficiency	386
	Multiple Feeds, Side Streams, and Open Steam	387
7.3	Estimation of Stage Efficiency	391
	Performance Data	391
	Empirical Correlations	392
	Semitheoretical Models	395
	Scale-up from Laboratory Data	396
7.4	Capacity of Trayed Towers and Reflux Drums	397
	Reflux Drums	397
7.5	Rate-Based Method for Packed Columns	398
	HETP Method	399
	HTU Method	400
7.6	Ponchon–Savarit Graphical Equilibrium-Stage Method for Trayed Towers	404
	Summary	406
	References	407
	Exercises	408

Chapter 8**Liquid-Liquid Extraction with Ternary Systems 419**

- 8.1 Equipment 423
 - Mixer-Settlers 424
 - Spray Columns 426
 - Packed Columns 426
 - Plate Columns 426
 - Columns with Mechanically Assisted Agitation 427
- 8.2 General Design Considerations 432
- 8.3 Hunter and Nash Graphical Equilibrium-Stage Method 438
 - Number of Equilibrium Stages 440
 - Minimum and Maximum Solvent-to-Feed Flow-Rate Ratios 444
 - Use of Right-Triangle Diagrams 448
 - Use of an Auxiliary Distribution Curve 451
 - Extract and Raffinate Reflux 453
- 8.4 Maloney and Schubert Graphical Equilibrium-Stage Method 459
- 8.5 Theory and Scale-up of Extractor Performance 465
 - Mixer-Settler Units 465
 - Multicompartment Columns 475
 - Axial Dispersion 480
- Summary 484 References 485 Exercises 486

Chapter 9**Approximate Methods for Multicomponent, Multistage Separations 492**

- 9.1 Fenske-Underwood-Gilliland Method 492
 - Selection of Two Key Components 493
 - Column Operating Pressure 495
 - Fenske Equation for Minimum Equilibrium Stages 497
 - Distribution of Nonkey Components at Total Reflux 500
 - Underwood Equations for Minimum Reflux 501
 - Gilliland Correlation for Actual Reflux Ratio and Theoretical Stages 508
 - Feed-Stage Location 511
 - Distribution of Nonkey Components at Actual Reflux 512
- 9.2 Kremser Group Method 514
 - Strippers 514
 - Liquid-Liquid Extraction 518
- Summary 521 References 521 Exercises 522

Chapter 10**Equilibrium-Based Methods for Multicomponent Absorption, Stripping, Distillation, and Extraction 526**

- 10.1 Theoretical Model for an Equilibrium Stage 526
- 10.2 General Strategy of Mathematical Solution 530
- 10.3 Equation-Tearing Procedures 531
 - Tridiagonal Matrix Algorithm 531

Bubble-Point Method for Distillation	534
Sum-Rates Method for Absorption and Stripping	544
Isothermal Sum-Rates Method for Liquid-Liquid Extraction	551
10.4 Simultaneous Correction Procedures	555
10.5 Inside-Out Method	569
MESH Equations	571
Rigorous and Complex Thermodynamic Property Models	571
Approximate Thermodynamic Property Models	572
Inside-Out Algorithm	573
Summary	577
References	578
Exercises	579

Chapter 11

Enhanced Distillation and Supercritical Extraction 586

11.1 Use of Triangular Graphs	587
Residue-Curve Maps	591
Distillation-Curve Maps	599
Product-Composition Regions at Total Reflux	602
11.2 Extractive Distillation	604
11.3 Salt Distillation	611
11.4 Pressure-Swing Distillation	612
11.5 Homogeneous Azeotropic Distillation	616
11.6 Heterogeneous Azeotropic Distillation	621
Multiplicity	627
11.7 Reactive Distillation	631
11.8 Supercritical-Fluid Extraction	641
Summary	650
References	651
Exercises	653

Chapter 12

Rate-Based Models for Distillation 655

12.1 Rate-Based Model	658
12.2 Thermodynamic Properties and Transport-Rate Expressions	662
12.3 Methods for Estimating Transport Coefficients and Interfacial Area	667
12.4 Vapor and Liquid Flow Patterns	668
12.5 Method of Calculation	668
ChemSep Program	668
RATEFRAC Program	674
Summary	677
References	677
Exercises	677

Chapter 13

Batch Distillation 681

13.1 Differential Distillation	681
13.2 Binary Batch Rectification with Constant Reflux and Variable Distillate Composition	685
13.3 Binary Batch Rectification with Constant Distillate Composition and Variable Reflux	688
13.4 Batch Stripping and Complex Batch Distillation	689
13.5 Effect of Liquid Holdup	691

13.6	Shortcut Method for Multicomponent Batch Rectification with Constant Reflux	691
13.7	Stage-by-Stage Methods for Multicomponent Batch Rectification	695
	Rigorous Model	695
	Rigorous Integration Method	698
	Rapid Solution Method	705
	Summary	708
	References	708
	Exercises	709

Chapter 14

Membrane Separations 713

14.1	Membrane Materials	718
14.2	Membrane Modules	722
14.3	Transport in Membranes	725
	Porous Membranes	725
	Bulk Flow	726
	Liquid Diffusion	728
	Gas Diffusion	729
	Nonporous Membranes	731
	Solution-Diffusion for Liquid Mixtures	731
	Solution-Diffusion for Gas Mixtures	733
	Module Flow Patterns	738
	Cascades	741
	Concentration Polarization	745
14.4	Dialysis and Electrodialysis	747
	Electrodialysis	750
14.5	Reverse Osmosis	755
14.6	Gas Permeation	761
14.7	Pervaporation	765
	Summary	771
	References	773
	Exercises	773

Chapter 15

Adsorption, Ion Exchange, and Chromatography 778

15.1	Sorbents	781
	Adsorbents	782
	Ion Exchangers	789
	Sorbents for Chromatography	792
15.2	Equilibrium Considerations	794
	Pure Gas Adsorption	794
	Liquid Adsorption	802
	Ion Exchange Equilibria	806
	Equilibria in Chromatography	810
15.3	Kinetic and Transport Considerations	811
	External Transport	812
	Internal Transport	816
	Mass Transfer in Ion Exchange and Chromatography	818

15.4 Sorption Systems	820
Adsorption	820
Ion Exchange	824
Chromatography	825
Slurry Adsorption (Contact Filtration)	827
Fixed-Bed Adsorption (Percolation)	831
Thermal-Swing Adsorption	843
Pressure-Swing Adsorption	848
Continuous Countercurrent Adsorption Systems	856
Ion-Exchange Cycle	861
Chromatographic Separations	863
Summary	870
References	872
Exercises	873
Index	881

Nomenclature

Latin Capital and Lowercase Letters

A	constant in equations of state; constant in Margules equation; area for mass transfer; area for heat transfer; area; coefficient in Freundlich equation; absorption factor= L/KV ; total area of a tray; frequency factor	C_2	constant in (6-116)
A_a	active area of a sieve tray	C_D	drag coefficient
A_b	active bubbling area of a tray	C_G	constant in (6-122) and Table 6.8
A_d	downcomer cross-sectional area of a tray	C_L	constant in (6-121) and Table 6.8
A_{du}	area for liquid flow under downcomer	C_F	entrainment flooding factor in Fig. 6.24 and (6-42)
A_h	hole area of a sieve tray	C_h	packing constant in Table 6.8
A_{ij}	binary interaction parameter in van Laar equation	C_o	orifice coefficient
\bar{A}_{ij}	binary interaction parameter in Margules two-constant equation	C_P	specific heat at constant pressure; packing constant in Table 6.8
A_j, B_j, C_j, D_j	material-balance parameters defined by (10-7) to (10-11)	$C_{P_v}^o$	ideal gas heat capacity at constant pressure
A_M	membrane surface area	c	concentration; constant in the BET equation; speed of light
A_p	pre-exponential (frequency) factor	c^*	liquid concentration in equilibrium with gas at its bulk partial pressure
A_w	specific surface area of a particle	c'	concentration in liquid adjacent to a membrane surface
a	activity; constants in the ideal-gas heat capacity equation; constant in equations of state; interfacial area per unit volume; surface area; characteristic dimension of a solid particle; equivalents exchanged in ion exchange; interfacial area per stage	c_m	metastable limiting solubility of crystals
\bar{a}	interfacial area per unit volume of equivalent clear liquid on a tray	c_s	humid heat; normal solubility of crystals
a_h	specific hydraulic area of packing	c_t	total molar concentration
a_{mk}	group interaction parameter in UNIFAC method	Δc_{limit}	limiting supersaturation
a_v	surface area per unit volume	D	diffusivity; distillate flow rate; amount of distillate; desorbent (purge) flow rate; discrepancy functions in inside-out method of Chapter 10.
B	constant in equations of state, bottoms flow rate; number of binary azeotropes	D_B	bubble diameter
B^0	rate of nucleation per unit volume of solution	D_E	eddy diffusion coefficient in (6-36)
b	molar availability function = $h - T_0s$; constant in equations of state; component flow rate in bottoms; surface perimeter	D_e, D_{eff}	effective diffusivity
C	general composition variable such as concentration, mass fraction, mole fraction, or volume fraction; number of components; constant; capacity parameter in (6-40); constant in tray liquid holdup expression given by (6-50); rate of production of crystals	D_H	diameter of perforation for a sieve tray
C_1	constant in (6-115)	D_i	impeller diameter
		D_{ij}	mutual diffusion coefficient of i in j
		D_K	Knudsen diffusivity
		D_L	longitudinal eddy diffusivity
		\bar{D}_N	arithmetic-mean diameter
		D_0	diffusion constant in (3-57)
		D_P, D_p	effective packing diameter; particle diameter
		\bar{D}_P	average of apertures of two successive screen sizes
		D_s	surface diffusivity
		\bar{D}_s	surface (Sauter) mean diameter
		D_T	tower or vessel diameter