660.2842 HEN 3rd ed.

Contact "Library Services" : info@dss.go.th

Contents

About the Authors iii

Preface v

Nomenclature xvii

Dimensions and Units xxvii

PART 1
FUNDAMENTAL CONCEPTS

1. Basic Separation Concepts 2

1.1* Industrial Chemical Processes 2
1.2* Basic Separation Techniques 5
1.3O Separations by Phase Addition or Creation 7
1.4O Separations by Barriers 12
1.5O Separations by Solid Agents 13
1.6O Separations by External Field or Gradient 15
1.7* Component Recoveries and Product Purities 15
1.8* Separation Factor 19
1.9B Introduction to Bioseparations 20
1.10* Selection of Feasible Separations 30
Summary, References, Exercises

2. Thermodynamics 37

2.1* Energy, Entropy, and Availability Balances 37
2.2* Phase Equilibria 40
2.3O Ideal Models 44
2.4O Graphical Correlations 47
2.5O Nonideal Models 50
2.6O Liquid Activity-Coefficient Models 56
2.7O Difficult Mixtures 67
2.8* Selecting an Appropriate Model 68
2.9B Thermodynamics of Biological Species 68
Summary, References, Exercises

3. Mass Transfer 91

3.1* Steady-State Molecular Diffusion 92
3.2* Diffusivities 96
3.3* Mass Transfer Through Stationary Media 108
3.4* Mass Transfer in Laminar Flow 114
3.5* Mass Transfer in Turbulent Flow 122
3.6* Models for Mass Transfer in Fluids with a Fluid–Fluid Interface 128
3.7* Two-Film Theory and Overall Mass-Transfer Coefficients 132
3.8B Driving Forces for Molecular Mass Transfer 137
Summary, References, Exercises

4. Single Equilibrium Stages 150

4.1* Degrees of Freedom 150
4.2* Zeotropic Vapor–Liquid Systems 152
4.3* Azeotropic Systems 155
4.4* Multicomponent Flash Calculations 157
4.5* Ternary Liquid–Liquid Systems 163
4.6O Multicomponent Liquid–Liquid Systems 169
4.7* Solid–Liquid Systems 171
4.8* Gas–Liquid Systems 177
4.9* Gas–Solid Systems 178
4.10• Multiphase Systems 180
Summary, References, Exercises

5. Cascades and Hybrid Systems 195

5.1* Cascade Configurations 195
5.2O Solid–Liquid Cascades 196
5.3* Single-Section, Extraction Cascades 198
5.4* Multicomponent Vapor–Liquid Cascades 200
5.5O Membrane Cascades 204

5.6^{O} Hybrid Systems 206
5.7* Degrees of Freedom for Cascades 208
Summary, References, Exercises

PART 2
SEPARATIONS BY PHASE ADDITION OR CREATION

6. Absorption and Stripping 223
6.1^{O} Equipment 225
6.2^{O} Design Considerations 229
6.3* Graphical Equilibrium-Stage Methods 231
6.4* Algebraic Methods 235
6.5^{O} Stage Efficiency 237
6.6^{O} Flooding, Pressure Drop, and Mass Transfer for Trayed Columns 244
6.7* Rate-Based Method for Packed Columns 252
6.8^{O} Liquid Holdup, Flooding, Pressure Drop, and Mass-Transfer for Packed Columns 256
6.9$^{\bullet}$ Concentrated Solutions 270
Summary, References, Exercises

7. Binary Distillation 280
7.1^{O} Design Considerations 281
7.2* McCabe–Thiele Method 283
7.3^{O} Extensions of the McCabe–Thiele Method 293
7.4^{O} Stage Efficiency 303
7.5^{O} Column Diameter 306
7.6* Rate-Based Method for Packed Columns 307
7.7^{O} Introduction to the Ponchon–Savarit Method 310
Summary, References, Exercises

8. Liquid–Liquid Extraction 323
8.1^{O} Equipment 326
8.2^{O} Design Considerations 333
8.3* Hunter–Nash Graphical Method 337
8.4^{O} Maloney–Schubert Graphical Method 351
8.5^{O} Theory and Scale-up of Extractor Performance 354
8.6^{B} Extraction of Bioproducts 368
Summary, References, Exercises

9. Approximate Multicomponent Methods 389
9.1* Fenske–Underwood–Gilliland (FUG) Method 389
9.2* Kremser Method 402
Summary, References, Exercises

10. Computer-Aided Equilibrium-Based Methods 410
10.1$^{\bullet}$ Theoretical Model 410
10.2$^{\bullet}$ Strategy of Mathematical Solution 412
10.3$^{\bullet}$ Equation-Tearing Procedures 413
10.4$^{\bullet}$ Newton–Raphson (NR) Method 427
10.5$^{\bullet}$ Inside-Out Method 434
Summary, References, Exercises

11. Enhanced Distillation and Supercritical Extraction 448
11.1* Triangular Graphs 449
11.2* Extractive Distillation 460
11.3$^{\bullet}$ Salt Distillation 464
11.4$^{\bullet}$ Pressure-Swing Distillation 466
11.5$^{\bullet}$ Homogeneous Azeotropic Distillation 468
11.6* Heterogeneous Azeotropic Distillation 472
11.7$^{\bullet}$ Reactive Distillation 479
11.8$^{\bullet}$ Supercritical-Fluid Extraction 485
Summary, References, Exercises

12. Rate-Based Models 496
12.1$^{\bullet}$ Rate-Based Model 498
12.2$^{\bullet}$ Thermodynamics and Transport 500
12.3$^{\bullet}$ Transport Coefficients and Interfacial Area 503
12.4$^{\bullet}$ Flow Patterns 503
12.5$^{\bullet}$ Calculation Methods 504
Summary, References, Exercises

13. Batch Distillation 514
13.1* Rayleigh Distillation 514
13.2* Batch Rectification 517
13.3$^{\bullet}$ Batch Stripping 519
13.4$^{\bullet}$ Liquid Holdup 520
13.5$^{\bullet}$ Shortcut Method 520
13.6$^{\bullet}$ Stage-by-Stage Methods 522
13.7$^{\bullet}$ Intermediate-Cut Strategy 531
13.8$^{\bullet}$ Optimal Control 532
Summary, References, Exercises

PART 3
SEPARATIONS BY BARRIERS AND SOLID AGENTS

14. Membrane Separations 542
14.1* Materials 545
14.2* Modules 548
14.3* Mass Transfer 551
14.4* Dialysis 570
14.5° Electrodialysis 572
14.6* Reverse Osmosis 575
14.7° Gas Permeation 579
14.8° Pervaporation 581
14.9[B] Membranes in Bioprocessing 585
Summary, References, Exercises

15. Adsorption, Ion Exchange, Chromatography, and Electrophoresis 617
15.1* Sorbents 619
15.2* Equilibrium 628
15.3* Kinetics and Transport 638
15.4° Equipment 662
15.5* Slurry and Fixed-Bed Adsorption Systems 667
15.6[B] Continuous Adsorption Systems 676
15.7° Ion-Exchange Cycle 687
15.8[B] Electrophoresis 688
Summary, References, Exercises

PART 4
SEPARATIONS THAT INVOLVE A SOLID PHASE

16. Leaching 708
16.1° Equipment 709
16.2° Equilibrium-Stage Model 716
16.3° Rate-Based Model 721
Summary, References, Exercises

17. Crystallization, Desublimation, and Evaporation 729
17.1* Crystal Geometry 732
17.2* Thermodynamics 738
17.3* Kinetics and Mass Transfer 743
17.4° Equipment 748
17.5• MSMPR Crystallization Model 752
17.6° Precipitation 756
17.7* Melt Crystallization 758
17.8° Zone Melting 762
17.9° Desublimation 764
17.10* Evaporation 766
17.11[B] Bioproduct Crystallization 773
Summary, References, Exercises

18. Drying of Solids 790
18.1° Equipment 791
18.2* Psychrometry 807
18.3* Moisture Content 814
18.4* Drying Periods 817
18.5° Dryer Models 830
18.6[B] Drying of Bioproducts 838
Summary, References, Exercises

PART 5
MECHANICAL SEPARATION OF PHASES

19. Mechanical Phase Separations 848
19.1° Separation Devices 850
19.2° Industrial Particle Separators 851
19.3* Design of Particle Separators 859
19.4* Design Features for Cake Filtration 866
19.5* Centrifuge Devices 872
19.6* Wash Cycles 874
19.7[B] Mechanical Separations in Biotechnology 876
Summary, References, Exercises

Answers to Selected Exercises 887
Index 891
Study Questions (Online)

* Suitable for an UG course
° Optional
• Advanced
[B] Bioseparations