

Contents

Preface

xv

Part One Introduction

1. History of Chemical Engineering and Mass Transfer Operations	3
References	5
2. Transport Phenomena vs Unit Operations Approach	7
References	10
3. Basic Calculations	11
Introduction	11
Units and Dimensions	11
Conversion of Units	15
The Gravitational Constant g_c	17
Significant Figures and Scientific Notation	17
References	18
4. Process Variables	19
Introduction	19
Temperature	20
Pressure	22
Moles and Molecular Weight	23
Mass, Volume, and Density	25
Viscosity	25
Reynolds Number	28
pH	29
Vapor Pressure	31
Ideal Gas Law	31
References	35

5. Equilibrium vs Rate Considerations 37

Introduction	37
Equilibrium	37
Rate	38
Chemical Reactions	39
References	40

6. Phase Equilibrium Principles 41

Introduction	41
Gibb's Phase Rule	44
Raoult's Law	45
Henry's Law	53
Raoult's Law vs Henry's Law	59
Vapor-Liquid Equilibrium in Nonideal Solutions	61
Vapor-Solid Equilibrium	64
Liquid-Solid Equilibrium	68
References	69

7. Rate Principles 71

Introduction	71
The Operating Line	72
Fick's Law	73
Diffusion in Gases	75
Diffusion in Liquids	79
Mass Transfer Coefficients	80
Individual Mass Transfer Coefficients	81
Equimolar Counterdiffusion	83
Diffusion of Component A Through Non-diffusing Component B	84
Overall Mass Transfer Coefficients	87
Equimolar Counterdiffusion and/or Diffusion in Dilute Solutions	88
Gas Phase Resistance Controlling	89
Liquid Phase Resistance Controlling	89
Experimental Mass Transfer Coefficients	90
References	93

Part Two Applications: Component and Phase Separation Processes**8. Introduction to Mass Transfer Operations** 97

Introduction	97
--------------	----

Classification of Mass Transfer Operations	97
Contact of Immiscible Phases	98
Miscible Phases Separated by a Membrane	101
Direct Contact of Miscible Phases	102
Mass Transfer Equipment	102
Distillation	103
Absorption	104
Adsorption	104
Extraction	104
Humidification and Drying	105
Other Mass Transfer Unit Operations	105
The Selection Decision	106
Characteristics of Mass Transfer Operations	107
Unsteady-State vs Steady-State Operation	108
Flow Pattern	109
Stagewise vs Continuous Operation	116
References	117

9. Distillation **119**

Introduction	119
Flash Distillation	120
Batch Distillation	127
Continuous Distillation with Reflux	133
Equipment and Operation	133
Equilibrium Considerations	140
Binary Distillation Design: McCabe–Thiele Graphical Method	142
Multicomponent Distillation: Fenske–Underwood–Gilliland (FUG) Method	161
Packed Column Distillation	184
References	185

10. Absorption and Stripping **187**

Introduction	187
Description of Equipment	189
Packed Columns	189
Plate Columns	196
Design and Performance Equations—Packed Columns	200
Liquid Rate	200
Column Diameter	207
Column Height	210
Pressure Drop	224

Design and Performance Equations—Plate Columns	227
Stripping	235
Packed vs Plate Tower Comparison	241
Summary of Key Equations	242
References	243

11. Adsorption **245**

Introduction	245
Adsorption Classification	247
Activated Carbon	248
Activated Alumina	248
Silica Gel	249
Molecular Sieves	249
Adsorption Equilibria	250
Freundlich Equation	253
Langmuir Isotherms	253
Description of Equipment	257
Design and Performance Equations	264
Regeneration	283
References	291

12. Liquid–Liquid and Solid–Liquid Extraction **293**

Introduction	293
Liquid–Liquid Extraction	294
The Extraction Process	294
Equipment	295
Solvent Selection	298
Equilibrium	300
Graphical Procedures	301
Analytical Procedures	304
Solid–Liquid Extraction (Leaching)	312
Process Variables	313
Equipment and Operation	315
Design and Predictive Equations	317
References	325

13. Humidification and Drying **327**

Introduction	327
Psychrometry and the Psychrometric Chart	327
Humidification	339

Equipment	341
Describing Equations	343
Drying	347
Rotary Dryers	352
Spray Dryers	361
References	369

14. Crystallization **371**

Introduction	371
Phase Diagrams	373
The Crystallization Process	379
Crystal Physical Characteristics	382
Equipment	391
Describing Equations	393
Design Considerations	397
References	404

15. Membrane Separation Processes **407**

Introduction	407
Reverse Osmosis	408
Describing Equations	414
Ultrafiltration	420
Describing Equations	421
Microfiltration	427
Describing Equations	428
Gas Permeation	432
Describing Equations	433
References	437

16. Phase Separation Equipment **439**

Introduction	439
Fluid–Particle Dynamics	442
Gas–Solid (G–S) Equipment	446
Gravity Settlers	447
Cyclones	449
Electrostatic Precipitators	454
Venturi Scrubbers	457
Baghouses	461

Gas–Liquid (G–L) Equipment	465
Liquid–Solid (L–S) Equipment	467
Sedimentation	467
Centrifugation	471
Flotation	472
Liquid–Liquid (L–L) Equipment	475
Solid–Solid (S–S) Equipment	477
High-Gradient Magnetic Separation	477
Solidification	477
References	479

Part Three Other Topics

17. Other and Novel Separation Processes **483**

Freeze Crystallization	484
Ion Exchange	484
Liquid Ion Exchange	484
Resin Adsorption	485
Evaporation	485
Foam Fractionation	486
Dissociation Extraction	486
Electrophoresis	486
Vibrating Screens	487
References	488

18. Economics and Finance **489**

Introduction	489
The Need for Economic Analyses	489
Definitions	491
Simple Interest	491
Compound Interest	491
Present Worth	492
Evaluation of Sums of Money	492
Depreciation	493
Fabricated Equipment Cost Index	493
Capital Recovery Factor	493
Present Net Worth	494
Perpetual Life	494
Break-Even Point	495
Approximate Rate of Return	495

Exact Rate of Return	495
Bonds	496
Incremental Cost	496

Principles of Accounting	496
Applications	499
References	511

19. Numerical Methods **513**

Introduction	513
Applications	514
References	531

20. Open-Ended Problems **533**

Introduction	533
Developing Students' Power of Critical Thinking	534
Creativity	534
Brainstorming	536
Inquiring Minds	536
Failure, Uncertainty, Success: Are They Related?	537
Angels on a Pin	538
Applications	539
References	547

21. Ethics **549**

Introduction	549
Teaching Ethics	550
Case Study Approach	551
Integrity	553
Moral Issues	554
Guardianship	556
Engineering and Environmental Ethics	557
Future Trends	559
Applications	561
References	563

22. Environmental Management and Safety Issues **565**

Introduction	565
Environmental Issues of Concern	566
Health Risk Assessment	568
Risk Evaluation Process for Health	570

Hazard Risk Assessment 571
 Risk Evaluation Process for Accidents 572
Applications 574
References 591

Appendix

Appendix A. Units 595

A.1 The Metric System 595
A.2 The SI System 597
A.3 Seven Base Units 597
A.4 Two Supplementary Units 598
A.5 SI Multiples and Prefixes 599
A.6 Conversion Constants (SI) 599
A.7 Selected Common Abbreviations 603

Appendix B. Miscellaneous Tables 605

Appendix C. Steam Tables 615

Index 623
