

CONTENTS

75	Differential Momentum Balance; Equations of Motion	
81	Preface	xxiii
86	Mechanical Energy Equation	
<hr/>		
95	SECTION I Introduction	
97	References	243
98	1 Definitions and Principles	3
98	Unit Operations	4
98	Unit Systems	4
101	Physical Quantities / SI Units / CGS Units / FPS Engineering Units /	
108	Gas Constant / Conversion of Units / Units and Equations	171
121	Dimensional Analysis	16
128	Basic Concepts	20
129	Equations of State of Gases	
132	Symbols	24
133	Problems	25
133	References	28
<hr/>		
138	SECTION II Fluid Mechanics	
142	Adiabatic Friction Flow	
150	2 Fluid Statics and Its Applications	31
152	Hydrostatic Equilibrium	32
153	Applications of Fluid Statics	35
154	Symbols	41
155	Problems	42
155	References	44
163	3 Fluid Flow Phenomena	45
167	Laminar Flow, Shear Rate, and Shear Stress	46
177	Rheological Properties of Fluids	47
188	Turbulence	53
189	Boundary Layers	60
192	Symbols	65
194	Problems	66
194	References	67
202	Pumps	

4	Basic Equations of Fluid Flow	68
	Mass Balance in a Flowing Fluid; Continuity	68
	Differential Momentum Balance; Equations of Motion	75
	Macroscopic Momentum Balances	81
	Mechanical Energy Equation	86
	Symbols	94
	Problems	96
	References	97
5	Incompressible Flow in Pipes and Channels	98
	Shear Stress and Skin Friction in Pipes	98
	Laminar Flow in Pipes and Channels	101
	Turbulent Flow in Pipes and Channels	108
	Friction from Changes in Velocity or Direction	121
	Symbols	128
	Problems	129
	References	132
6	Flow of Compressible Fluids	133
	Definitions and Basic Equations	133
	Processes of Compressible Flow	138
	Isentropic Flow through Nozzles	139
	Adiabatic Friction Flow	145
	Isothermal Friction Flow	150
	Symbols	152
	Problems	153
	References	154
7	Flow Past Immersed Objects	155
	Drag and Drag Coefficients	155
	Flow through Beds of Solids	163
	Motion of Particles through Fluids	167
	Fluidization	177
	Symbols	188
	Problems	189
	References	192
8	Transportation and Metering of Fluids	194
	Pipe, Fittings, and Valves	194
	Pumps	202

	<i>Positive-Displacement Pumps / Centrifugal Pumps</i>	212
	Fans, Blowers, and Compressors	214
	<i>Fans / Blowers and Compressors / Comparison of Devices for Moving Fluids</i>	217
	Measurement of Flowing Fluids	224
	<i>Full-Bore Meters / Insertion Meters</i>	
	Symbols	240
	Problems	241
	References	243
9	Agitation and Mixing of Liquids	244
	Agitated Vessels	245
	Blending and Mixing	265
	Suspension of Solid Particles	271
	Dispersion Operations	276
	Agitator Selection and Scaleup	284
	Symbols	287
	Problems	289
	References	292

SECTION III Heat Transfer and Its Applications

10	Heat Transfer by Conduction	299
	Basic Law of Conduction	299
	Steady-State Conduction	301
	Unsteady-State Conduction	308
	Symbols	321
	Problems	321
	References	324
11	Principles of Heat Flow in Fluids	325
	Typical Heat-Exchange Equipment	325
	Energy Balances	329
	Heat Flux and Heat-Transfer Coefficients	331
	<i>Overall Heat-Transfer Coefficient / Individual Heat-Transfer Coefficients</i>	
	Symbols	343
	Problems	344
	References	346

12 Heat Transfer to Fluids Without Phase Change	347
Boundary Layers	347
Heat Transfer by Forced Convection in Laminar Flow	350
Heat Transfer by Forced Convection in Turbulent Flow	357
<i>Transfer by Turbulent Eddies and Analogy Between Transfer of Momentum and Heat</i>	
Heat Transfer in Transition Region Between Laminar and Turbulent Flow	369
Heat Transfer to Liquid Metals	371
Heating and Cooling of Fluids in Forced Convection Outside Tubes	373
Natural Convection	376
Symbols	382
Problems	384
References	387
13 Heat Transfer to Fluids With Phase Change	388
Heat Transfer from Condensing Vapors	388
Heat Transfer to Boiling Liquids	400
Symbols	412
Problems	413
References	415
14 Radiation Heat Transfer	417
Emission of Radiation	418
Absorption of Radiation by Opaque Solids	422
Radiation Between Surfaces	424
Radiation to Semitransparent Materials	433
Combined Heat Transfer by Conduction-Convection and Radiation	434
Symbols	436
Problems	437
References	439
15 Heat-Exchange Equipment	440
Shell-and-Tube Heat Exchangers	441
Plate-Type Exchangers	455
Extended-Surface Equipment	459
Heat Pipes	465

22	Scraped-Surface Exchangers	466
	Condensers and Vaporizers	468
607	Heat Transfer in Agitated Vessels	471
610	Heat Transfer in Packed Beds	474
613	Symbols	479
613	Problems	481
613	References	484
616	16 Evaporation	486
616	Types of Evaporators	488
620	Performance of Tubular Evaporators	492
624	<i>Evaporator Capacity / Evaporator Economy</i>	
628	Vapor Recompression	514
632	Symbols	515
632	Problems	516
640	References	518
642		
	SECTION IV Mass Transfer and Its Applications	
643		
646	17 Principles of Diffusion and Mass Transfer Between Phases	527
650	Theory of Diffusion	528
651	Prediction of Diffusivities	535
653	Transient Diffusion	540
653	Mass-Transfer Theories	542
653	<i>Film Theory / Boundary Layer Theory / Penetration Theory / Two-Film Theory</i>	
656	Mass-Transfer Coefficients	549
656	<i>Experimental Measurements / Coefficients for Mass Transfer Through Known Areas</i>	
659	Symbols	559
701	Problems	561
712	References	564
722	18 Gas Absorption	565
724	Packings and Packed Tower Design	565
727	Principles of Absorption	576
730	Absorption from Rich Gases	593

466	Mass-Transfer Correlations	599
468	<i>Absorption in Plate Columns</i>	
471	Absorption With Chemical Reaction	607
474	<i>Absorption in Tanks</i>	
479	Symbols	610
481	Problems	612
484	References	615
486	19 Humidification Operations	616
488	Definitions	616
492	Humidity Chart	620
514	Wet-Bulb Temperature	624
515	Cooling Towers	628
516	<i>Theory of Counterflow Cooling Towers</i>	
518	Symbols	639
	Problems	640
	References	642
	20 Equilibrium-Stage Operations	643
	Equipment for Stage Contacts	643
	Principles of Stage Processes	646
	<i>Equilibrium-Stage Calculations for Multicomponent Systems</i>	
527	Symbols	660
528	Problems	661
532	References	662
540	21 Distillation	663
542	Flash Distillation	663
549	Continuous Distillation With Reflux	666
	<i>Material Balances in Plate Columns / Number of Ideal Plates;</i> <i>McCabe-Thiele Method</i>	
559	Enthalpy Balances	694
561	Design of Sieve-Plate Columns	701
564	Plate Efficiencies	712
	<i>Theory of Plate Efficiency</i>	
568	Distillation in Packed Columns	722
568	Batch Distillation	724
570	Symbols	727
593	Problems	730
	References	736

22	Introduction to Multicomponent Distillation	737
	Phase Equilibria in Multicomponent Distillation	737
	Flash Distillation of Multicomponent Mixtures	741
	Fractionation of Multicomponent Mixtures	742
	Azeotropic and Extractive Distillation	759
	Symbols	760
	Problems	761
	References	763
23	Leaching and Extraction	764
	Leaching	764
	<i>Leaching Equipment / Principles of Continuous Countercurrent Leaching</i>	
	Liquid Extraction	772
	<i>Extraction Equipment / Principles of Extraction</i>	
	Special Extraction Techniques	789
	<i>Supercritical Fluid Extraction</i>	
	Symbols	791
	Problems	792
	References	795
24	Drying of Solids	796
	Principles of Drying	798
	<i>Phase Equilibria</i>	
	Cross-Circulation Drying	804
	Through-Circulation Drying	812
	<i>Drying of Suspended Particles</i>	
	Freeze-Drying	815
	Drying Equipment	818
	<i>Dryers for Solids and Pastes / Dryers for Solutions and Slurries / Selection of Drying Equipment</i>	
	Symbols	831
	Problems	833
	References	835
25	Adsorption and Fixed-Bed Separations	836
	Adsorption	836
	Adsorption Equipment	837
	<i>Equilibria; Adsorption Isotherms / Principles of Adsorption / Basic Equations for Adsorption / Solutions to Mass-Transfer Equations / Adsorber Design / Continuous Operation</i>	

	Ion Exchange	864
	<i>Equilibria / Mass-Transfer Rates / Operation of Ion Exchangers</i>	
	Chromatography	870
	Symbols	877
	Problems	878
	References	880
26	Membrane Separation Processes	882
	Separation of Gases	882
	Separation of Liquids	904
	<i>Dialysis / Membranes for Liquid-Liquid Extraction /</i>	
	<i>Pervaporation / Reverse Osmosis</i>	
	Symbols	923
	Problems	925
	References	927
27	Crystallization	929
	Crystal Geometry	930
	Equilibria and Yields	931
	Nucleation	938
	Crystal Growth	945
	Crystallization Equipment	949
	Crystallizer Design: Crystal Size Distribution	954
	<i>MSMPR Crystallizer</i>	
	Crystallization from Melts	958
	Symbols	959
	Problems	961
	References	963

SECTION V Operations Involving Particulate Solids

28	Properties and Handling of Particulate Solids	967
	Characterization of Solid Particles	967
	Properties of Masses of Particles	974
	<i>Storage and Conveying of Solids</i>	
	Mixing of Solids	977
	<i>Mixers for Noncohesive Solids / Mixers for Cohesive Solids</i>	
	Size Reduction	984

*Computer Simulation of Milling Operations / Equipment
for Size Reduction*

Ultrafine Grinders	993
Symbols	997
Problems	999
References	1000

29 Mechanical Separations 1001

Screening	1001
-----------------	------

Screening Equipment

Filtration; General Considerations	1006
--	------

Cake Filters	1007
--------------------	------

Centrifugal Filters / Filter Media / Filter Aids /

Principles of Cake Filtration / Washing Filter Cakes

Clarifying Filters	1033
--------------------------	------

Liquid Clarification / Gas Cleaning / Principles of Clarification

Crossflow Filtration; Membrane Filters	1037
--	------

Types of Membranes / Permeate Flux for Ultrafiltration /

Concentration Polarization / Applications of Ultrafiltration /

Diafiltration / Microfiltration

Gravity Sedimentation Processes	1055
---------------------------------------	------

Centrifugal Sedimentation Processes	1065
---	------

Symbols	1077
---------------	------

Problems	1079
----------------	------

References	1083
------------------	------

Appendix 1 Conversion Factors and Constants of Nature	1085
---	------

Appendix 2 Dimensionless Groups	1088
---------------------------------------	------

Appendix 3 Dimensions, Capacities, and Weights of Standard Steel Pipe	1090
--	------

Appendix 4 Condenser and Heat-Exchanger Tube Data	1091
---	------

Appendix 5 Tyler Standard Screen Scale	1092
--	------

Appendix 6 Properties of Liquid Water	1093
---	------

Appendix 7 Properties of Saturated Steam and Water	1094
--	------

Appendix 8 Viscosities of Gases	1096
---------------------------------------	------

Appendix 9 Viscosities of Liquids	1098
---	------

Appendix 10 Thermal Conductivities of Metals	1101
--	------

Appendix 11 Thermal Conductivities of Various Solids and Insulating Materials	1102
--	------

Appendix 12 Thermal Conductivities of Gases and Vapors	1104
--	------

Appendix 13 Thermal Conductivities of Liquids Other Than Water	1105
Appendix 14 Specific Heats of Gases	1106
Appendix 15 Specific Heats of Liquids	1107
Appendix 16 Prandtl Numbers for Gases at 1 atm and 100°C	1108
Appendix 17 Prandtl Numbers for Liquids	1109
Appendix 18 Diffusivities and Schmidt Numbers for Gases in Air at 0°C and 1 atm	1110
Appendix 19 Collision Integral and Lennard-Jones Force Constants	1111
Index	1113
Cake Filters	1113
Centrifugal Filters / Filter Media / Filter Aids / Filterability	1113
Principles of Cake Filtration / Washing Filter Cakes	1113
Clarifying Filters	1113
Liquid Clarification / Gas Cleaning / Principles of Clarification	1113
Crossflow Filtration; Membrane Filters	1113
Types of Membranes / Permeate Flux for Ultrafiltration / Concentration Polarization / Applications of Ultrafiltration / Diffusion / Microfiltration	1113
Gravity Sedimentation Processes	1113
Centrifugal Sedimentation Processes	1113
Symbols	1113
Problems	1113
References	1113
Appendix 1 Conversion Factors and Constants of Nature	1113
Appendix 2 Dimensionless Groups	1113
Appendix 3 Dimensions, Capacities, and Weights of Standard Steel Pipe	1113
Appendix 4 Condenser and Heat-Exchanger Tube Data	1113
Appendix 5 Tyler Standard Screen Scale	1113
Appendix 6 Properties of Liquid Water	1113
Appendix 7 Properties of Saturated Steam and Water	1113
Appendix 8 Viscosities of Gases	1113
Appendix 9 Viscosities of Liquids	1113
Appendix 10 Thermal Conductivities of Metals	1113
Appendix 11 Thermal Conductivities of Various Solids and Insulating Materials	1113
Appendix 12 Thermal Conductivities of Gases and Vapors	1113