

Contents

Preface *xiii*

Acknowledgments *xvii*

- 1 What Is Chemical Engineering?** *1*
 - What Do Chemical Engineers Do? *4*
 - Topics to Be Covered *6*
 - Discussion Questions *13*
 - Review Questions (Answers in Appendix with Explanations) *13*
 - Additional Resources *14*

- 2 Safety and Health: The Role and Responsibilities in Chemical Engineering Practice** *15*
 - Basic Health and Safety Information: The Material Safety Data Sheet (MSDS) *15*
 - Procedures *19*
 - Fire and Flammability *20*
 - Chemical Reactivity *23*
 - Toxicology *23*
 - Emergency Response *24*
 - Transportation Emergencies *24*
 - HAZOP *25*
 - Layer of Protection Analysis (LOPA) *28*
 - Summary *29*
 - Discussion Questions *31*
 - Review Questions (Answers in Appendix with Explanations) *32*
 - Additional Resources *34*

- 3 The Concept of Balances** *35*
 - Mass Balance Concepts *35*
 - Energy Balances *40*
 - Momentum Balances *41*

- Summary 42
- Discussion Questions 43
- Review Questions (Answers in Appendix with Explanations) 43
- Additional Resources 44

- 4 Stoichiometry, Thermodynamics, Kinetics, Equilibrium, and Reaction Engineering 45**
 - Stoichiometry and Thermodynamics 45
 - Kinetics, Equilibrium, and Reaction Engineering 50
 - Physical Properties Affecting Energy Aspects of a Reaction System 53
 - Kinetics and Rates of Reaction 55
 - Catalysts 59
 - Summary 61
 - Discussion Questions 63
 - Review Questions (Answers in Appendix with Explanations) 65
 - Additional Resources 67

- 5 Flow Sheets, Diagrams, and Materials of Construction 69**
 - Materials of Construction 73
 - Summary 74
 - Discussion Questions 75
 - Review Questions (Answers in Appendix with Explanations) 76
 - Additional Resources 77

- 6 Economics and Chemical Engineering 79**
 - Summary 85
 - Discussion Questions 86
 - Review Questions (Answers in Appendix with Explanations) 86
 - Additional Resources 87

- 7 Fluid Flow, Pumps, and Liquid Handling and Gas Handling 89**
 - Fluid Properties 89
 - Characterizing Fluid Flow 93
 - Pump Types 96
 - Net Positive Suction Head (NPSH) for Centrifugal Pumps 100
 - Positive Displacement Pumps 101
 - Variable Speed Drive Pumps 103
 - Water “Hammer” 103
 - Piping and Valves 103
 - Flow Measurement 104
 - Gas Laws 105
 - Gas Flows 107
 - Gas Compression 107

Discussion Questions	109
Review Questions (Answers in Appendix with Explanations)	110
Additional Resources	113
8 Heat Transfer and Heat Exchangers	115
Types of Heat Exchangers	117
Heat Transfer Coefficient	121
Utility Fluids	123
Air Coolers	124
Scraped Wall Exchangers	124
Plate and Frame Heat Exchangers	125
Leaks	125
Mechanical Design Concerns	125
Cleaning Heat Exchangers	126
Radiation Heat Transfer	127
High Temperature Transfer Fluids	127
Summary	129
Discussion Questions	130
Review Questions (Answers in Appendix with Explanations)	131
Additional Resources	133
9 Reactive Chemicals Concepts	135
Summary	137
Discussion Questions	138
Review Questions (Answers in Appendix with Explanations)	139
Additional Resources	140
10 Distillation	141
Raoult's Law	146
Batch Distillation	148
Flash Distillation	148
Continuous Multistage Distillation	149
Reflux Ratio and Operating Line	150
Pinch Point	154
Feed Plate Location	154
Column Internals and Efficiency	155
Unique Forms of Distillation	156
Multiple Desired Products	161
Column Internals and Efficiencies	163
Tray Contacting Systems	163
Packed Towers in Distillation	165
Summary	168
Discussion Questions	168

- Review Questions (Answers in Appendix with Explanations) 169
Additional Resources 171
- 11 Other Separation Processes: Absorption, Stripping, Adsorption, Chromatography, Membranes 173**
Absorption 173
Stripping/Desorption 178
Adsorption 180
Ion Exchange 185
Reverse Osmosis 187
Gas Separation Membranes 189
Leaching 191
Liquid–Liquid Extraction 192
Summary 197
Discussion Questions 197
Review Questions (Answers in Appendix with Explanations) 198
Additional Resources 201
- 12 Evaporation and Crystallization 203**
Evaporation 203
Operational Issues with Evaporators 205
Vacuum and Multi-effect Evaporators 207
Crystallization 209
Crystal Phase Diagrams 214
Supersaturation 215
Crystal Purity and Particle Size Control 216
Summary 216
Discussion Questions 217
Review Questions (Answers in Appendix with Explanations) 217
Additional Resources 219
- 13 Liquid–Solids Separation 221**
Filtration and Filters 221
Filtration Rates 222
Filtration Equipment 223
Centrifuges 227
Particle Size and Particle Size Distribution 228
Liquid Properties 228
Summary 228
Discussion Questions 231
Review Questions (Answers in Appendix with Explanations) 231
Additional Resources 233

- 14 Drying** 235
 - Rotary Dryers 236
 - Spray Dryers 237
 - Fluid Bed Dryers 238
 - Belt Dryer 239
 - Freeze Dryers 240
 - Summary 240
 - Discussion Questions 242
 - Review Questions (Answers in Appendix with Explanations) 242
 - Additional Resources 243

- 15 Solids Handling** 245
 - Safety and General Operational Concerns 245
 - Solids Transport 248
 - Pneumatic Conveyors 251
 - Solids Size Reduction Equipment 256
 - Cyclones 259
 - Screening 260
 - Hoppers and Bins 261
 - Solids Mixing 263
 - Discussion Questions 264
 - Review Questions (Answers in Appendix with Explanations) 265
 - Additional Resources 265
 - Videos of Solids Handling Equipment 266

- 16 Tanks, Vessels, and Special Reaction Systems** 267
 - Categories 267
 - Corrosion 268
 - Heating and Cooling 275
 - Power Requirements 275
 - Tanks and Vessels as Reactors 278
 - Static Mixers 280
 - Summary 280
 - Discussion Questions 281
 - Review Questions (Answers in Appendix with Explanations) 281
 - Additional Resources 282

- 17 Chemical Engineering in Polymer Manufacture and Processing** 285
 - What are Polymers? 285
 - Polymer Types 287
 - Polymer Properties and Characteristics 288
 - Polymer Processes 290

Polymer Additives	293
End-Use Polymer Processing	293
Plastics Recycling	294
Summary	295
Discussion Questions	295
Review Questions (Answers in Appendix with Explanations)	296
Additional Resources	297

18 Process Control 299

Elements of a Process Control System	300
Control Loops	302
On-off Control	303
Proportional Control	304
Proportional-Integral Control	305
Derivative Control	306
Ratio Control	307
Cascade Control	307
Measurement Systems	308
Control Valves	308
Valve Capacity	312
Utility Failure	312
Process Control as a Buffer	313
Instruments that “Lie”	314
Summary	314
Discussion Questions	316
Review Questions (Answers in Appendix with Explanations)	316
Additional Resources	318

19 Beer Brewing Revisited 321

Appendix I: Future Challenges for Chemical Engineers and Chemical Engineering	325
Appendix II: Additional Downloadable Resources	331
Appendix III: Answers to Chapter Review Questions	337
Index	377