

# Contents

---

**Preface to the First Edition ix**

**Preface to the Third Edition xi**

**To the Instructor xiii**

**Interactive Chemical Process Principles xv**

**Nomenclature xvii**

**Glossary xx**

## **PART 1 ENGINEERING PROBLEM ANALYSIS 1**

**Chapter 1 What Some Chemical Engineers Do for a Living 3**

**Chapter 2 Introduction to Engineering Calculations 7**

- 2.0 Instructional Objectives 7
- 2.1 Units and Dimensions 8
- 2.2 Conversion of Units 9
- 2.3 Systems of Units 10
- 2.4 Force and Weight 12
- 2.5 Numerical Calculation and Estimation 13
- 2.6 Dimensional Homogeneity and Dimensionless Quantities 20
- 2.7 Process Data Representation and Analysis 22
- 2.8 Summary 30
- Problems 31

**Chapter 3 Processes and Process Variables 42**

- 3.0 Instructional Objectives 43
- 3.1 Mass and Volume 43
- 3.2 Flow Rate 45
- 3.3 Chemical Composition 47
- 3.4 Pressure 54
- 3.5 Temperature 60
- 3.6 Summary 63
- Problems 65

## **PART 2 MATERIAL BALANCES 81**

### **Chapter 4 Fundamentals of Material Balances 83**

- 4.0 Instructional Objectives 83
- 4.1 Process Classification 84
- 4.2 Balances 85
- 4.3 Material Balance Calculations 89
- 4.4 Balances on Multiple-Unit Processes 104
- 4.5 Recycle and Bypass 110
- 4.6 Chemical Reaction Stoichiometry 116
- 4.7 Balances on Reactive Processes 125
- 4.8 Combustion Reactions 142
- 4.9 Some Additional Considerations about Chemical Processes 151
- 4.10 Summary 153
- Problems 155

### **Chapter 5 Single-Phase Systems 187**

- 5.0 Instructional Objectives 188
- 5.1 Liquid and Solid Densities 189
- 5.2 Ideal Gases 191
- 5.3 Equations of State for Nonideal Gases 199
- 5.4 The Compressibility Factor Equation of State 206
- 5.5 Summary 213
- Problems 214

### **Chapter 6 Multiphase Systems 237**

- 6.0 Instructional Objectives 239
- 6.1 Single-Component Phase Equilibrium 240
- 6.2 The Gibbs Phase Rule 247
- 6.3 Gas-Liquid Systems: One Condensable Component 249
- 6.4 Multicomponent Gas-Liquid Systems 255
- 6.5 Solutions of Solids in Liquids 264
- 6.6 Equilibrium Between Two Liquid Phases 271
- 6.7 Adsorption on Solid Surfaces 275
- 6.8 Summary 278
- Problems 280

## **PART 3 ENERGY BALANCES 311**

### **Chapter 7 Energy and Energy Balances 313**

- 7.0 Instructional Objectives 314
- 7.1 Forms of Energy: The First Law of Thermodynamics 315
- 7.2 Kinetic and Potential Energy 317
- 7.3 Energy Balances on Closed Systems 318

7.4	Energy Balances on Open Systems at Steady State	320
7.5	Tables of Thermodynamic Data	325
7.6	Energy Balance Procedures	329
7.7	Mechanical Energy Balances	333
7.8	Summary	337
	Problems	340

## **Chapter 8**

### **Balances on Nonreactive Processes 357**

8.0	Instructional Objectives	357
8.1	Elements of Energy Balance Calculations	358
8.2	Changes in Pressure at Constant Temperature	365
8.3	Changes in Temperature	366
8.4	Phase Change Operations	377
8.5	Mixing and Solution	395
8.6	Summary	406
	Problems	409

## **Chapter 9**

### **Balances on Reactive Processes 440**

9.0	Instructional Objectives	441
9.1	Heats of Reaction	442
9.2	Measurement and Calculation of Heats of Reaction: Hess's Law	445
9.3	Formation Reactions and Heats of Formation	447
9.4	Heats of Combustion	448
9.5	Energy Balances on Reactive Processes	450
9.6	Fuels and Combustion	464
9.7	Summary	473
	Problems	475

## **Chapter 10**

### **Computer-Aided Balance Calculations 504**

10.0	Instructional Objectives	504
10.1	Degree-of-Freedom Analysis Revisited	504
10.2	Sequential Modular Simulation	511
10.3	Equation-Based Simulation	522
10.4	Commercial Process Simulation Packages	533
10.5	Final Considerations	533
	Problems	534

## **Chapter 11**

### **Balances on Transient Processes 543**

11.0	Instructional Objectives	543
11.1	The General Balance Equation ... Again	544
11.2	Material Balances	548
11.3	Energy Balances on Single-Phase Nonreactive Processes	554
11.4	Simultaneous Transient Balances	560
11.5	Summary	563
	Problems	564

**PART 4 CASE STUDIES 577**

**Chapter 12 Production of Chlorinated Polyvinyl Chloride 579**

PVC Chlorination Reaction Chemistry 580

Process Description 581

Problems 584

**Chapter 13 Steam Reforming of Natural Gas  
and Subsequent Synthesis of Methanol 591**

Process Description 592

Problems 595

**Chapter 14 Scrubbing of Sulfur Dioxide from Power Plant Stack Gases 607**

Process Description 603

Problems 605

**Appendix A Computational Techniques 607**

A.1 The Method of Least Squares 607

A.2 Iterative Solution of Nonlinear Algebraic Equations 610

A.3 Numerical Integration 622

**Appendix B Physical Property Tables 627**

B.1 Selected Physical Property Data 628

B.2 Heat Capacities 635

B.3 Vapor Pressure of Water 638

B.4 Antoine Equation Constants 640

B.5 Properties of Saturated Steam: Temperature Table 642

B.6 Properties of Saturated Steam: Pressure Table 644

B.7 Properties of Superheated Steam 650

B.8 Specific Enthalpies of Selected Gases: SI Units 652

B.9 Specific Enthalpies of Selected Gases: American Engineering Units 652

B.10 Atomic Heat Capacities for Kopp's Rule 653

B.11 Integral Heats of Solution and Mixing at 25°C 653

**Answers to Test Yourself 655**

**Answers to Selected Problems 665**

**Index 669**