

BASIC PRINCIPLES AND CALCULATIONS IN CHEMICAL ENGINEERING

NINTH EDITION

**David M. Himmelblau
James B. Riggs**




Boston • Columbus • New York • San Francisco • Amsterdam • Cape Town
Dubai • London • Madrid • Milan • Munich • Paris • Montreal • Toronto • Delhi • Mexico City
São Paulo • Sidney • Hong Kong • Seoul • Singapore • Taipei • Tokyo

CONTENTS

PREFACE	xv
HOW TO USE THIS BOOK	xvii
ACKNOWLEDGMENTS	xxi
ABOUT THE AUTHORS	xxiii
<i>PART I</i>	
<i>INTRODUCTION</i>	1
CHAPTER 1	INTRODUCTION TO CHEMICAL ENGINEERING
	3
1.1	A Brief History of Chemical Engineering
	3
1.2	Types of Jobs Chemical Engineers Perform
	6
1.3	Industries in Which Chemical Engineers Work
	8
1.4	Sustainability
	10
1.5	Ethics
	24
CHAPTER 2	INTRODUCTORY CONCEPTS
	29
2.1	Units of Measure
	29
2.2	Unit Conversions
	35
2.3	Equations and Units
	41
2.4	Measurement Errors and Significant Figures
	47
2.5	Validation of Results
	53
2.6	Mass, Moles, and Density
	55
2.7	Process Variables
	75
	ix









PART II	MATERIAL BALANCES	125
CHAPTER 3	MATERIAL BALANCES	127
	3.1 The Connection between a Process and Its Schematic	129
	3.2 Introduction to Material Balances	134
	3.3 A General Strategy for Solving Material Balance Problems	145
	3.4 Material Balances for Single Unit Systems	164
	3.5 Vectors and Matrices	188
	3.6 Solving Systems of Linear Equations with MATLAB	190
	3.7 Solving Systems of Linear Equations with Python	196
CHAPTER 4	MATERIAL BALANCES WITH CHEMICAL REACTION	225
	4.1 Stoichiometry	226
	4.2 Terminology for Reaction Systems	235
	4.3 Species Mole Balances	248
	4.4 Element Material Balances	268
	4.5 Material Balances for Combustion Systems	276
CHAPTER 5	MATERIAL BALANCES FOR MULTIUNIT PROCESSES	313
	5.1 Preliminary Concepts	314
	5.2 Sequential Multiunit Systems	317
	5.3 Recycle Systems	340
	5.4 Bypass and Purge	357
	5.5 The Industrial Application of Material Balances	367
PART III	GASES, VAPORS, AND LIQUIDS	401
CHAPTER 6	IDEAL AND REAL GASES	403
	6.1 Ideal Gases	405
	6.2 Real Gases: Equations of State	422

Contents		xi
6.3	Real Gases: Compressibility Charts	436
6.4	Real Gas Mixtures	444
CHAPTER 7	MULTIPHASE EQUILIBRIUM	473
7.1	Introduction	473
7.2	Phase Diagrams and the Phase Rule	475
7.3	Single-Component Two-Phase Systems (Vapor Pressure)	487
7.4	Two-Component Gas/Single-Component Liquid Systems	504
7.5	Two-Component Gas/Two-Component Liquid Systems	523
7.6	Multicomponent Vapor-Liquid Equilibrium	536
PART IV	ENERGY BALANCES	559
CHAPTER 8	ENERGY BALANCES WITHOUT REACTION	561
8.1	Terminology Associated with Energy Balances	564
8.2	Overview of Types of Energy and Energy Balances	569
8.3	Energy Balances for Closed, Unsteady-State Systems	574
8.4	Energy Balances for Open, Steady-State Systems	597
8.5	Mechanical Energy Balances	627
8.6	Energy Balances for Special Cases	640
CHAPTER 9	ENERGY BALANCES WITH REACTION	681
9.1	The Standard Heat (Enthalpy) of Formation	682
9.2	The Heat (Enthalpy) of Reaction	688
9.3	Integration of Heat of Formation and Sensible Heat	700
9.4	The Heat (Enthalpy) of Combustion	726

PART V	COMBINED MATERIAL AND ENERGY BALANCES	747
CHAPTER 10	HUMIDITY (PSYCHROMETRIC) CHARTS	749
	10.1 Terminology	751
	10.2 The Humidity (Psychrometric) Chart	755
	10.3 Applications of the Humidity Chart	765
CHAPTER 11	UNSTEADY-STATE MATERIAL AND ENERGY BALANCES	781
	11.1 Unsteady-State Balances	783
	11.2 Numerical Integration of ODEs	790
	11.3 Examples	799
CHAPTER 12	HEATS OF SOLUTION AND MIXING	825
CHAPTER 13	LIQUIDS AND GASES IN EQUILIBRIUM WITH SOLIDS	845
CHAPTER 14	SOLVING MATERIAL AND ENERGY BALANCES USING PROCESS SIMULATORS (FLOWSHEETING CODES)	857
PART VI	SUPPLEMENTARY MATERIAL	889
APPENDIXES		891
	A ATOMIC WEIGHTS AND NUMBERS	893
	B TABLES OF THE PITZER Z^0 AND Z^1 FACTORS	894
	C HEATS OF FORMATION AND COMBUSTION	899
	D ANSWERS TO SELECTED PROBLEMS	903
	E PHYSICAL PROPERTIES OF VARIOUS ORGANIC AND INORGANIC SUBSTANCES	908

Contents

xiii

 F	HEAT CAPACITY EQUATIONS	920
 G	VAPOR PRESSURES	924
 H	HEATS OF SOLUTION AND DILUTION	925
 I	ENTHALPY-CONCENTRATION DATA	926
 J	THERMODYNAMIC CHARTS	933
 K	PHYSICAL PROPERTIES OF PETROLEUM FRACTIONS	940
 L	SOLUTION OF SETS OF EQUATIONS	949
 M	FITTING FUNCTIONS TO DATA	971
	INDEX	975