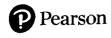
BASIC PRINCIPLES AND CALCULATIONS IN CHEMICAL ENGINEERING NINTH EDITION

David M. Himmelblau James B. Riggs



CONTENTS

PREFACE HOW TO USE THIS BOOK ACKNOWLEDGMENTS ABOUT THE AUTHORS			XV XVII XXI XXIII
PART I	INT	RODUCTION	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	INT	RODUCTORY CONCEPTS	29
	2.1	Units of Measure	2 9
	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
			iv

x			Contents
PART II	MA	TERIAL BALANCES	125
CHAPTER 3	MA	TERIAL 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	MAT	TERIAL 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	MAT	TERIAL 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	GAS	SES, VAPORS, AND LIQUIDS	401
CHAPTER 6	IDEA	AL 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	4 73
	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
	ENERGY RALAMORO WITHOUT REACTION	504
CHAPTER 8	ENERGY BALANCES WITHOUT REACTION	561
CHAPTER 8	8.1 Terminology Associated with Energy Balances	561 564
CHAPTER 8		
CHAPTER 8	8.1 Terminology Associated with Energy Balances	564
CHAPTER 8	8.1 Terminology Associated with Energy Balances8.2 Overview of Types of Energy and Energy Balances	564 569
CHAPTER 8	 8.1 Terminology Associated with Energy Balances 8.2 Overview of Types of Energy and Energy Balances 8.3 Energy Balances for Closed, Unsteady-State Systems 	564 569 574 597
CHAPTER 8	 8.1 Terminology Associated with Energy Balances 8.2 Overview of Types of Energy and Energy Balances 8.3 Energy Balances for Closed, Unsteady-State Systems 8.4 Energy Balances for Open, Steady-State Systems 	564 569 574 597 627
CHAPTER 8	 8.1 Terminology Associated with Energy Balances 8.2 Overview of Types of Energy and Energy Balances 8.3 Energy Balances for Closed, Unsteady-State Systems 8.4 Energy Balances for Open, Steady-State Systems 8.5 Mechanical Energy Balances 	564 569 574 597 627 640
	 8.1 Terminology Associated with Energy Balances 8.2 Overview of Types of Energy and Energy Balances 8.3 Energy Balances for Closed, Unsteady-State Systems 8.4 Energy Balances for Open, Steady-State Systems 8.5 Mechanical Energy Balances 8.6 Energy Balances for Special Cases 	564 569 574
	 8.1 Terminology Associated with Energy Balances 8.2 Overview of Types of Energy and Energy Balances 8.3 Energy Balances for Closed, Unsteady-State Systems 8.4 Energy Balances for Open, Steady-State Systems 8.5 Mechanical Energy Balances 8.6 Energy Balances for Special Cases ENERGY BALANCES WITH REACTION 	564 569 574 597 627 640 681 682
	 8.1 Terminology Associated with Energy Balances 8.2 Overview of Types of Energy and Energy Balances 8.3 Energy Balances for Closed, Unsteady-State Systems 8.4 Energy Balances for Open, Steady-State Systems 8.5 Mechanical Energy Balances 8.6 Energy Balances for Special Cases ENERGY BALANCES WITH REACTION 9.1 The Standard Heat (Enthalpy) of Formation 	564 569 574 597 627 640 681

xii		Contents
PART V	COMBINED MATERIAL AND ENERGY BALANCES	747
CHAPTER 10	HUMIDITY (PSYCHROMETRIC) CHARTS	749
	10.1 Terminology	<i>7</i> 51
	10.2 The Humidity (Psychrometric) Chart	<i>7</i> 55
	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 ANO 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
В	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 E	PHYSICAL PROPERTIES OF VARIOUS ORGANIC AND INORGANIC SUBSTANCES	908

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