

# CONTENTS

Preface xvii

## CHAPTER ONE

### INTRODUCTION AND BASIC CONCEPTS 1

- 1-1** Thermodynamics and Energy 2
  - Application Areas of Thermodynamics 3
- 1-2** Importance of Dimensions and Units 3
  - Some SI and English Units 6
  - Dimensional Homogeneity 8
  - Unity Conversion Ratios 9
- 1-3** Systems and Control Volumes 10
- 1-4** Properties of a System 12
  - Continuum 12
- 1-5** Density and Specific Gravity 13
- 1-6** State and Equilibrium 14
  - The State Postulate 15
- 1-7** Processes and Cycles 15
  - The Steady-Flow Process 16
- 1-8** Temperature and the Zeroth Law of Thermodynamics 17
  - Temperature Scales 18
  - The International Temperature Scale of 1990 (ITS-90) 20
- 1-9** Pressure 22
  - Variation of Pressure with Depth 24
- 1-10** Pressure Measurement Devices 27
  - The Barometer 27
  - The Manometer 30
  - Other Pressure Measurement Devices 33
- 1-11** Problem-Solving Technique 34
  - Step 1: Problem Statement 34
  - Step 2: Schematic 35
  - Step 3: Assumptions and Approximations 35
  - Step 4: Physical Laws 35
  - Step 5: Properties 35
  - Step 6: Calculations 35
  - Step 7: Reasoning, Verification, and Discussion 35
  - Engineering Software Packages 36

Engineering Equation Solver (EES) 37  
A Remark on Significant Digits 39  
Summary 40  
References and Suggested Readings 41  
Problems 41

## CHAPTER TWO

### ENERGY, ENERGY TRANSFER, AND GENERAL ENERGY ANALYSIS 51

- 2-1** Introduction 52
- 2-2** Forms of Energy 53
  - Some Physical Insight to Internal Energy 55
  - More on Nuclear Energy 56
  - Mechanical Energy 58
- 2-3** Energy Transfer by Heat 60
  - Historical Background on Heat 61
- 2-4** Energy Transfer by Work 62
  - Electrical Work 65
- 2-5** Mechanical Forms of Work 66
  - Shaft Work 66
  - Spring Work 67
  - Work Done on Elastic Solid Bars 67
  - Work Associated with the Stretching of a Liquid Film 68
  - Work Done to Raise or to Accelerate a Body 68
  - Nonmechanical Forms of Work 70
- 2-6** The First Law of Thermodynamics 70
  - Energy Balance 72
  - Energy Change of a System,  $\Delta E_{\text{system}}$  72
  - Mechanisms of Energy Transfer,  $E_{\text{in}}$  and  $E_{\text{out}}$  73
- 2-7** Energy Conversion Efficiencies 78
  - Efficiencies of Mechanical and Electrical Devices 82
- 2-8** Energy and Environment 85
  - Ozone and Smog 86
  - Acid Rain 87
  - The Greenhouse Effect:
    - Global Warming and Climate Change 88
  - Topic of Special Interest: Mechanisms of Heat Transfer* 91
  - Summary 96
  - References and Suggested Readings 97
  - Problems 97

## CHAPTER THREE

### PROPERTIES OF PURE SUBSTANCES 111

- 3-1** Pure Substance 112
- 3-2** Phases of a Pure Substance 112
- 3-3** Phase-Change Processes of Pure Substances 113
  - Compressed Liquid and Saturated Liquid 114
  - Saturated Vapor and Superheated Vapor 114
  - Saturation Temperature and Saturation Pressure 115
  - Some Consequences of  $T_{\text{sat}}$  and  $P_{\text{sat}}$  Dependence 116
- 3-4** Property Diagrams for Phase-Change Processes 118
  - 1 The  $T$ - $v$  Diagram 118
  - 2 The  $P$ - $v$  Diagram 120
  - Extending the Diagrams to Include the Solid Phase 120
  - 3 The  $P$ - $T$  Diagram 122
  - The  $P$ - $v$ - $T$  Surface 123
- 3-5** Property Tables 124
  - Enthalpy—A Combination Property 124
  - 1a Saturated Liquid and Saturated Vapor States 125
  - 1b Saturated Liquid–Vapor Mixture 127
  - 2 Superheated Vapor 130
  - 3 Compressed Liquid 131
  - Reference State and Reference Values 132
- 3-6** The Ideal-Gas Equation of State 134
  - Is Water Vapor an Ideal Gas? 137
- 3-7** Compressibility Factor—A Measure of Deviation from Ideal-Gas Behavior 138
- 3-8** Other Equations of State 141
  - van der Waals Equation of State 142
  - Beattie-Bridgeman Equation of State 142
  - Benedict-Webb-Rubin Equation of State 143
  - Virial Equation of State 144

*Topic of Special Interest: Vapor Pressure and Phase Equilibrium* 146

Summary 150

References and Suggested Readings 151

Problems 151

## CHAPTER FOUR

### ENERGY ANALYSIS OF CLOSED SYSTEMS 163

- 4-1** Moving Boundary Work 164
  - Polytropic Process 168

- 4-2** Energy Balance for Closed Systems 169
- 4-3** Specific Heats 174
- 4-4** Internal Energy, Enthalpy, and Specific Heats of Ideal Gases 176
  - Specific Heat Relations of Ideal Gases 178
- 4-5** Internal Energy, Enthalpy, and Specific Heats of Solids and Liquids 183
  - Internal Energy Changes 184
  - Enthalpy Changes 184

*Topic of Special Interest: Thermodynamic Aspects of Biological Systems* 187

Summary 195

References and Suggested Readings 195

Problems 196

## CHAPTER FIVE

### MASS AND ENERGY ANALYSIS OF CONTROL VOLUMES 213

- 5-1** Conservation of Mass 214
  - Mass and Volume Flow Rates 214
  - Conservation of Mass Principle 216
  - Mass Balance for Steady-Flow Processes 218
  - Special Case: Incompressible Flow 219
- 5-2** Flow Work and the Energy of a Flowing Fluid 221
  - Total Energy of a Flowing Fluid 222
  - Energy Transport by Mass 223
- 5-3** Energy Analysis of Steady-Flow Systems 225
- 5-4** Some Steady-Flow Engineering Devices 228
  - 1 Nozzles and Diffusers 229
  - 2 Turbines and Compressors 232
  - 3 Throttling Valves 234
  - 4a Mixing Chambers 236
  - 4b Heat Exchangers 238
  - 5 Pipe and Duct Flow 240
- 5-5** Energy Analysis of Unsteady-Flow Processes 242
  - Topic of Special Interest: General Energy Equation* 247
  - Summary 251
  - References and Suggested Readings 252
  - Problems 252

## CHAPTER SIX

## THE SECOND LAW OF THERMODYNAMICS 275

- 6-1** Introduction to the Second Law 276
- 6-2** Thermal Energy Reservoirs 277
- 6-3** Heat Engines 278  
Thermal Efficiency 279  
Can We Save  $Q_{\text{out}}$ ? 281  
The Second Law of Thermodynamics:  
Kelvin–Planck Statement 283
- 6-4** Refrigerators and Heat Pumps 283  
Coefficient of Performance 284  
Heat Pumps 285  
Performance of Refrigerators, Air-Conditioners,  
and Heat Pumps 286  
The Second Law of Thermodynamics:  
Clausius Statement 288  
Equivalence of the Two Statements 289
- 6-5** Perpetual-Motion Machines 290
- 6-6** Reversible and Irreversible Processes 292  
Irreversibilities 293  
Internally and Externally Reversible Processes 294
- 6-7** The Carnot Cycle 295  
The Reversed Carnot Cycle 297
- 6-8** The Carnot Principles 297
- 6-9** The Thermodynamic Temperature Scale 299
- 6-10** The Carnot Heat Engine 301  
The Quality of Energy 302  
Quantity versus Quality in Daily Life 303
- 6-11** The Carnot Refrigerator and Heat Pump 304  
*Topic of Special Interest: Household Refrigerators* 307  
Summary 311  
References and Suggested Readings 312  
Problems 312

## CHAPTER SEVEN

## ENTROPY 329

- 7-1** Entropy 330  
A Special Case: Internally Reversible  
Isothermal Heat Transfer Processes 333
- 7-2** The Increase of Entropy Principle 334  
Some Remarks about Entropy 336
- 7-3** Entropy Change of Pure Substances 337

- 7-4** Isentropic Processes 340
- 7-5** Property Diagrams Involving Entropy 342
- 7-6** What Is Entropy? 343  
Entropy and Entropy Generation in Daily Life 346
- 7-7** The  $T ds$  Relations 347
- 7-8** Entropy Change of Liquids and Solids 349
- 7-9** The Entropy Change of Ideal Gases 352  
Constant Specific Heats (Approximate Analysis) 353  
Variable Specific Heats (Exact Analysis) 353  
Isentropic Processes of Ideal Gases 355  
Constant Specific Heats (Approximate Analysis) 355  
Variable Specific Heats (Exact Analysis) 356  
Relative Pressure and Relative Specific Volume 356
- 7-10** Reversible Steady-Flow Work 359  
Proof that Steady-Flow Devices Deliver  
the Most and Consume the Least Work  
When the Process is Reversible 362
- 7-11** Minimizing the Compressor Work 363  
Multistage Compression with Intercooling 364
- 7-12** Isentropic Efficiencies of Steady-Flow  
Devices 367  
Isentropic Efficiency of Turbines 367  
Isentropic Efficiencies of Compressors and Pumps 369  
Isentropic Efficiency of Nozzles 371
- 7-13** Entropy Balance 373  
Entropy Change of a System,  $\Delta S_{\text{system}}$  374  
Mechanisms of Entropy Transfer,  $S_{\text{in}}$  and  $S_{\text{out}}$  374  
1 Heat Transfer 374  
2 Mass Flow 375  
Entropy Generation,  $S_{\text{gen}}$  376  
Closed Systems 377  
Control Volumes 378  
Entropy Generation Associated  
with a Heat Transfer Process 385  
*Topic of Special Interest: Reducing the Cost of  
Compressed Air* 386  
Summary 395  
References and Suggested Readings 396  
Problems 397

## CHAPTER EIGHT

## EXERGY 421

- 8-1** Exergy: Work Potential of Energy 422  
Exergy (Work Potential) Associated  
with Kinetic and Potential Energy 423
- 8-2** Reversible Work and Irreversibility 425

- 8-3** Second-Law Efficiency 430
- 8-4** Exergy Change of a System 433
  - Exergy of a Fixed Mass: Nonflow (or Closed System) Exergy 433
  - Exergy of a Flow Stream: Flow (or Stream) Exergy 436
- 8-5** Exergy Transfer by Heat, Work, And Mass 438
  - Exergy by Heat Transfer,  $Q$  439
  - Exergy Transfer by Work,  $W$  440
  - Exergy Transfer by Mass,  $m$  440
- 8-6** The Decrease of Exergy Principle and Exergy Destruction 441
  - Exergy Destruction 442
- 8-7** Exergy Balance: Closed Systems 443
- 8-8** Exergy Balance: Control Volumes 454
  - Exergy Balance for Steady-Flow Systems 455
  - Reversible Work 456
  - Second-Law Efficiency of Steady-Flow Devices 456

*Topic of Special Interest: Second-Law Aspects of Daily Life* 463

Summary 467

References and Suggested Readings 468

Problems 468

## CHAPTER NINE

### GAS POWER CYCLES 485

- 9-1** Basic Considerations in the Analysis of Power Cycles 486
- 9-2** The Carnot Cycle and its Value in Engineering 488
- 9-3** Air-Standard Assumptions 490
- 9-4** An Overview of Reciprocating Engines 490
- 9-5** Otto Cycle: The Ideal Cycle for Spark-Ignition Engines 492
- 9-6** Diesel Cycle: The Ideal Cycle for Compression-Ignition Engines 499
- 9-7** Stirling and Ericsson Cycles 502
- 9-8** Brayton Cycle: The Ideal Cycle for Gas-Turbine Engines 506
  - Development of Gas Turbines 509
  - Deviation of Actual Gas-Turbine Cycles from Idealized Ones 512

- 9-9** The Brayton Cycle with Regeneration 513
- 9-10** The Brayton Cycle with Intercooling, Reheating, and Regeneration 516
- 9-11** Ideal Jet-Propulsion Cycles 520
  - Modifications to Turbojet Engines 524
- 9-12** Second-Law Analysis of Gas Power Cycles 526
  - Topic of Special Interest: Saving Fuel and Money by Driving Sensibly* 530
  - Summary 536
  - References and Suggested Readings 538
  - Problems 538

## CHAPTER TEN

### VAPOR AND COMBINED POWER CYCLES 553

- 10-1** The Carnot Vapor Cycle 554
- 10-2** Rankine Cycle: The Ideal Cycle for Vapor Power Cycles 555
  - Energy Analysis of the Ideal Rankine Cycle 555
- 10-3** Deviation of Actual Vapor Power Cycles from Idealized Ones 558
- 10-4** How Can We Increase the Efficiency of the Rankine Cycle? 561
  - Lowering the Condenser Pressure (*Lowers  $T_{low,avg}$* ) 561
  - Superheating the Steam to High Temperatures (*Increases  $T_{high,avg}$* ) 562
  - Increasing the Boiler Pressure (*Increases  $T_{high,avg}$* ) 562
- 10-5** The Ideal Reheat Rankine Cycle 565
- 10-6** The Ideal Regenerative Rankine Cycle 569
  - Open Feedwater Heaters 569
  - Closed Feedwater Heaters 571
- 10-7** Second-Law Analysis of Vapor Power Cycles 577
- 10-8** Cogeneration 579
- 10-9** Combined Gas–Vapor Power Cycles 584
  - Topic of Special Interest: Binary Vapor Cycles* 587
  - Summary 589
  - References and Suggested Readings 590
  - Problems 590

**CHAPTER ELEVEN****REFRIGERATION CYCLES 607**

- 11-1** Refrigerators and Heat Pumps 608
- 11-2** The Reversed Carnot Cycle 609
- 11-3** The Ideal Vapor-Compression Refrigeration Cycle 610
- 11-4** Actual Vapor-Compression Refrigeration Cycle 613
- 11-5** Second-Law Analysis of Vapor-Compression Refrigeration Cycle 615
- 11-6** Selecting the Right Refrigerant 620
- 11-7** Heat Pump Systems 622
- 11-8** Innovative Vapor-Compression Refrigeration Systems 623
- Cascade Refrigeration Systems 624
- Multistage Compression Refrigeration Systems 626
- Multipurpose Refrigeration Systems with a Single Compressor 628
- Liquefaction of Gases 629
- 11-9** Gas Refrigeration Cycles 630
- 11-10** Absorption Refrigeration Systems 633
- Topic of Special Interest:* Thermoelectric Power Generation and Refrigeration Systems 636
- Summary 638
- References and Suggested Readings 639
- Problems 639

**CHAPTER TWELVE****THERMODYNAMIC PROPERTY RELATIONS 655**

- 12-1** A Little Math—Partial Derivatives and Associated Relations 656
- Partial Differentials 657
- Partial Differential Relations 659
- 12-2** The Maxwell Relations 661
- 12-3** The Clapeyron Equation 662
- 12-4** General Relations For  $du$ ,  $dh$ ,  $ds$ ,  $c_v$ , and  $c_p$  665
- Internal Energy Changes 666
- Enthalpy Changes 666
- Entropy Changes 667
- Specific Heats  $c_v$  and  $c_p$  668

- 12-5** The Joule-Thomson Coefficient 672
- 12-6** The  $\Delta h$ ,  $\Delta u$ , and  $\Delta s$  of Real Gases 674
- Enthalpy Changes of Real Gases 674
- Internal Energy Changes of Real Gases 675
- Entropy Changes of Real Gases 676
- Summary 679
- References and Suggested Readings 680
- Problems 680

**CHAPTER THIRTEEN****GAS MIXTURES 687**

- 13-1** Composition of a Gas Mixture: Mass and Mole Fractions 688
- 13-2**  $P$ - $v$ - $T$  Behavior of Gas Mixtures: Ideal and Real Gases 690
- Ideal-Gas Mixtures 691
- Real-Gas Mixtures 692
- 13-3** Properties of Gas Mixtures: Ideal and Real Gases 695
- Ideal-Gas Mixtures 696
- Real-Gas Mixtures 700
- Topic of Special Interest:* Chemical Potential and the Separation Work of Mixtures 704
- Summary 714
- References and Suggested Readings 715
- Problems 716

**CHAPTER FOURTEEN****GAS-VAPOR MIXTURES AND AIR-CONDITIONING 725**

- 14-1** Dry and Atmospheric Air 726
- 14-2** Specific and Relative Humidity of Air 727
- 14-3** Dew-Point Temperature 729
- 14-4** Adiabatic Saturation and Wet-Bulb Temperatures 731
- 14-5** The Psychrometric Chart 734
- 14-6** Human Comfort and Air-Conditioning 735
- 14-7** Air-Conditioning Processes 737
- Simple Heating and Cooling ( $\omega = \text{constant}$ ) 738
- Heating with Humidification 739
- Cooling with Dehumidification 740
- Evaporative Cooling 742

Adiabatic Mixing of Airstreams 743  
Wet Cooling Towers 745

Summary 747  
References and Suggested Readings 748  
Problems 749

## CHAPTER FIFTEEN

### CHEMICAL REACTIONS 759

- 15-1** Fuels and Combustion 760
- 15-2** Theoretical and Actual Combustion Processes 764
- 15-3** Enthalpy of Formation and Enthalpy of Combustion 771
- 15-4** First-Law Analysis of Reacting Systems 774
  - Steady-Flow Systems 775
  - Closed Systems 776
- 15-5** Adiabatic Flame Temperature 780
- 15-6** Entropy Change of Reacting Systems 782
- 15-7** Second-Law Analysis of Reacting Systems 784
  - Topic of Special Interest: Fuel Cells* 790
  - Summary 792
  - References and Suggested Readings 793
  - Problems 793

## CHAPTER SIXTEEN

### CHEMICAL AND PHASE EQUILIBRIUM 805

- 16-1** Criterion for Chemical Equilibrium 806
- 16-2** The Equilibrium Constant for Ideal-Gas Mixtures 808
- 16-3** Some Remarks about the  $K_p$  of Ideal-Gas Mixtures 812
- 16-4** Chemical Equilibrium for Simultaneous Reactions 816
- 16-5** Variation of  $K_p$  with Temperature 818
- 16-6** Phase Equilibrium 820
  - Phase Equilibrium for a Single-Component System 820
  - The Phase Rule 822
  - Phase Equilibrium for a Multicomponent System 822

Summary 828  
References and Suggested Readings 829  
Problems 829

## CHAPTER SEVENTEEN

### COMPRESSIBLE FLOW 839

- 17-1** Stagnation Properties 840
- 17-2** Speed of Sound and Mach Number 843
- 17-3** One-Dimensional Isentropic Flow 845
  - Variation of Fluid Velocity with Flow Area 847
  - Property Relations for Isentropic Flow of Ideal Gases 849
- 17-4** Isentropic Flow Through Nozzles 851
  - Converging Nozzles 852
  - Converging–Diverging Nozzles 856
- 17-5** Shock Waves and Expansion Waves 860
  - Normal Shocks 860
  - Oblique Shocks 866
  - Prandtl–Meyer Expansion Waves 870
- 17-6** Duct Flow with Heat Transfer and Negligible Friction (Rayleigh Flow) 875
  - Property Relations for Rayleigh Flow 881
  - Choked Rayleigh Flow 882
- 17-7** Steam Nozzles 884
  - Summary 887
  - References and Suggested Readings 888
  - Problems 889

## CHAPTER EIGHTEEN (WEB CHAPTER)

### RENEWABLE ENERGY

- 18-1** Introduction
- 18-2** Solar Energy
  - Solar Radiation
  - Flat-Plate Solar Collector
  - Concentrating Solar Collector
  - Linear Concentrating Solar Power Collector
  - Solar-Power Tower Plant
  - Solar Pond
  - Photovoltaic Cell
  - Passive Solar Applications
  - Solar Heat Gain through Windows

**18-3 Wind Energy**  
 Wind Turbine Types and Power  
 Performance Curve  
 Wind Power Potential  
 Wind Power Density  
 Wind Turbine Efficiency  
 Betz Limit for Wind Turbine Efficiency

**18-4 Hydropower**  
 Analysis of Hydroelectric Power Plant  
 Turbine Types

**18-5 Geothermal Energy**  
 Geothermal Power Production

**18-6 Biomass Energy**  
 Biomass Resources  
 Conversion of Biomass to Biofuel  
 Biomass Products  
 Electricity and Heat Production by Biomass  
 Solid Municipality Waste

Summary  
 References and Suggested Readings  
 Problems

## APPENDIX ONE

### PROPERTY TABLES AND CHARTS (SI UNITS) 897

<b>Table A-1</b>	Molar mass, gas constant, and critical-point properties 898	<b>Figure A-14</b>	<i>P-h</i> diagram for refrigerant-134a 921
<b>Table A-2</b>	Ideal-gas specific heats of various common gases 899	<b>Figure A-15</b>	Nelson–Obert generalized compressibility chart 922
<b>Table A-3</b>	Properties of common liquids, solids, and foods 902	<b>Table A-16</b>	Properties of the atmosphere at high altitude 923
<b>Table A-4</b>	Saturated water—Temperature table 904	<b>Table A-17</b>	Ideal-gas properties of air 924
<b>Table A-5</b>	Saturated water—Pressure table 906	<b>Table A-18</b>	Ideal-gas properties of nitrogen, N <sub>2</sub> 926
<b>Table A-6</b>	Superheated water 908	<b>Table A-19</b>	Ideal-gas properties of oxygen, O <sub>2</sub> 928
<b>Table A-7</b>	Compressed liquid water 912	<b>Table A-20</b>	Ideal-gas properties of carbon dioxide, CO <sub>2</sub> 930
<b>Table A-8</b>	Saturated ice–water vapor 913	<b>Table A-21</b>	Ideal-gas properties of carbon monoxide, CO 932
<b>Figure A-9</b>	<i>T-s</i> diagram for water 914	<b>Table A-22</b>	Ideal-gas properties of hydrogen, H <sub>2</sub> 934
<b>Figure A-10</b>	Mollier diagram for water 915	<b>Table A-23</b>	Ideal-gas properties of water vapor, H <sub>2</sub> O 935
<b>Table A-11</b>	Saturated refrigerant-134a—Temperature table 916	<b>Table A-24</b>	Ideal-gas properties of monatomic oxygen, O 937
<b>Table A-12</b>	Saturated refrigerant-134a—Pressure table 918	<b>Table A-25</b>	Ideal-gas properties of hydroxyl, OH 937
<b>Table A-13</b>	Superheated refrigerant-134a 919	<b>Table A-26</b>	Enthalpy of formation, Gibbs function of formation, and absolute entropy at 25°C, 1 atm 938
		<b>Table A-27</b>	Properties of some common fuels and hydrocarbons 939
		<b>Table A-28</b>	Natural logarithms of the equilibrium constant <i>K<sub>p</sub></i> 940
		<b>Figure A-29</b>	Generalized enthalpy departure chart 941
		<b>Figure A-30</b>	Generalized entropy departure chart 942
		<b>Figure A-31</b>	Psychrometric chart at 1 atm total pressure 943
		<b>Table A-32</b>	One-dimensional isentropic compressible-flow functions for an ideal gas with <i>k</i> = 1.4 944
		<b>Table A-33</b>	One-dimensional normal-shock functions for an ideal gas with <i>k</i> = 1.4 945
		<b>Table A-34</b>	Rayleigh flow functions for an ideal gas with <i>k</i> = 1.4 946

## APPENDIX TWO

### PROPERTY TABLES AND CHARTS (ENGLISH UNITS) 947

**Table A-1E** Molar mass, gas constant, and critical-point properties 948

**Table A-2E** Ideal-gas specific heats of various common gases 949

**Table A-3E** Properties of common liquids, solids, and foods 952

**Table A-4E** Saturated water—Temperature table 954

**Table A-5E** Saturated water—Pressure table 956

**Table A-6E** Superheated water 958

**Table A-7E** Compressed liquid water 962

**Table A-8E** Saturated ice–water vapor 963

**Figure A-9E**  $T$ - $s$  diagram for water 964

**Figure A-10E** Mollier diagram for water 965

**Table A-11E** Saturated refrigerant-134a—Temperature table 966

**Table A-12E** Saturated refrigerant-134a—Pressure table 967

**Table A-13E** Superheated refrigerant-134a 968

**Figure A-14E**  $P$ - $h$  diagram for refrigerant-134a 970

**Table A-16E** Properties of the atmosphere at high altitude 971

**Table A-17E** Ideal-gas properties of air 972

**Table A-18E** Ideal-gas properties of nitrogen,  $N_2$  974

**Table A-19E** Ideal-gas properties of oxygen,  $O_2$  976

**Table A-20E** Ideal-gas properties of carbon dioxide,  $CO_2$  978

**Table A-21E** Ideal-gas properties of carbon monoxide,  $CO$  980

**Table A-22E** Ideal-gas properties of hydrogen,  $H_2$  982

**Table A-23E** Ideal-gas properties of water vapor,  $H_2O$  983

**Table A-26E** Enthalpy of formation, Gibbs function of formation, and absolute entropy at  $77^\circ C$ , 1 atm 985

**Table A-27E** Properties of some common fuels and hydrocarbons 986

**Figure A-31E** Psychrometric chart at 1 atm total pressure 987

### INDEX 989