

Contents

Nomenclature List xix

Preface xxi

About the Authors xxv

Part I Concepts and Basic Laws 1

Chapter 1 Basic Concepts and Systems of Units 3

1.1 Introduction 5

- 1.1.1 What is thermodynamics? 5
- 1.1.2 How do we use thermodynamics? 5
- 1.1.3 How do engineers use thermodynamics? 6
- 1.1.4 What is the history of thermodynamics? 6
- 1.1.5 What is the future of thermodynamics? 6
- 1.1.6 What are the fundamental concepts and assumptions? 7
- 1.1.7 What are the phases of matter? 8

1.2 Dimensions and Units 9

- 1.2.1 The SI system 9
- 1.2.2 The English system 11

1.3 Properties, Processes, and Equilibrium 12

- 1.3.1 Properties and state of a system 12
- 1.3.2 Density and specific volume 13
- 1.3.3 Processes and equilibrium 15

1.4 Pressure 17

- 1.4.1 What is pressure? 17
- 1.4.2 Absolute and gage pressure 17
- 1.4.3 Units of pressure 18
- 1.4.4 Pressure-measuring devices 19

Contents

1.5	Temperature	22
1.5.1	What is temperature?	22
1.5.2	Absolute and relative temperature scales	22
1.5.3	Temperature measurement	24
1.6	Energy	27
1.7	Summary	29

Chapter 2 Properties of Pure Substances **37**

2.1	Phases of a Substance	39
2.1.1	Phase-change process	40
2.1.2	Quality and compressed liquid calculations	44
2.1.3	Superheated vapor	47
2.1.4	Properties using the IRC Property Calculator	49
2.1.5	Phase diagrams	51
2.2	Internal Energy and Enthalpy	56
2.2.1	Internal energy	56
2.2.2	Enthalpy	57
2.2.3	Internal energy and enthalpy for liquids and solids	58
2.2.4	Latent heat	60
2.3	Refrigerants	61
2.4	Ideal-Gas Law	64
2.5	Real Gas Equations of State	66
2.6	Internal Energy and Enthalpy of Ideal Gases	69
2.7	Specific Heats of Liquids and Solids	73
2.8	Summary	75

Chapter 3 The First Law for Systems **85**

3.1	Work	88
3.1.1	Definition and units	88
3.1.2	Work due to pressure	88
3.1.3	Other forms of work	91
3.2	Heat Transfer	95
3.3	Problem-Solving Method	98

3.4	The First Law Applied to Systems	99
3.5	The First Law Applied to Various Processes	101
3.5.1	The constant-volume process	101
3.5.2	The constant-pressure process	102
3.5.3	The constant-temperature process	105
3.5.4	The adiabatic process	106
3.5.5	The polytropic process	110
3.6	Cycles	112
3.7	Summary	112

Chapter 4 The First Law Applied to Control Volumes **127**

4.1	The Conservation of Mass for Control Volumes	130
4.1.1	Basic information	130
4.1.2	The continuity equation	131
4.2	The First Law for Control Volumes	137
4.2.1	Turbines, compressors, and pumps	139
4.2.2	Throttling devices	143
4.2.3	Mixing chambers	145
4.2.4	Heat exchangers	148
4.2.5	Nozzles and diffusers	151
4.3	Unsteady Flow	155
4.4	Devices Combined into Cycles	158
4.4.1	The Rankine power cycle	158
4.4.2	The refrigeration cycle	160
4.4.3	The Brayton cycle	163
4.5	Summary	165

Chapter 5 The Second Law of Thermodynamics **179**

5.1	Second-Law Concepts	180
5.2	Statements of the Second Law of Thermodynamics	182
5.2.1	Kelvin-Planck statement—heat engines	182
5.2.2	Clausius statement—refrigerators	183

Contents

5.3 Cycle Performance Parameters 185

 5.3.1 The heat engine 185

 5.3.2 The refrigeration cycle 186

5.4 The Carnot Cycle 189

5.5 Summary 194

Chapter 6 Entropy

203

6.1 Inequality of Clausius 205

6.2 Entropy 207

6.3 Entropy Change in Substances for Systems 209

 6.3.1 Basic relationships 209

 6.3.2 Entropy change of an ideal gas with constant C_p and C_v 210

 6.3.3 Entropy change of a solid, a liquid, and a reservoir 213

 6.3.4 Entropy change of a phase-change substance 216

 6.3.5 Entropy change of an ideal gas with variable specific heats 218

6.4 Entropy Changes for a Control Volume 221

6.5 Isentropic Efficiency 225

 6.5.1 Isentropic turbine efficiency 225

 6.5.2 Isentropic compressor efficiency 226

 6.5.3 Pump efficiency 228

 6.5.4 Isentropic efficiency of a nozzle 229

6.6 Exergy (Availability) and Irreversibility 230

6.7 Summary 237

Chapter 7 Thermodynamic Relations

251

7.1 The Maxwell Relations 252

7.2 The Clapeyron Equation 255

7.3 Relationships for Internal Energy, Enthalpy, Entropy, and Specific Heats 258

7.4 The Joule–Thomson Coefficient 263

7.5 Real-Gas Effects 265

7.6 Summary 269

Part II Applications 275

Chapter 8 The Rankine Power Cycle 277

8.1	Energy Sustainability	279
8.2	The Rankine Cycle	279
8.2.1	Basic configuration and components	279
8.2.2	Improving Rankine cycle efficiency	286
8.3	Modified Rankine Cycles	290
8.3.1	The ideal reheat Rankine cycle	290
8.3.2	The ideal regenerative Rankine cycle	293
8.3.3	A combined reheat-regenerative ideal Rankine cycle	296
8.4	Cogeneration Cycles	299
8.5	Losses in Power Plants	302
8.6	Summary	303

Chapter 9 Gas Power Cycles 315

9.1	Air-Standard Analysis	317
9.2	Reciprocating Engine Terminology	320
9.3	The Otto Cycle	322
9.3.1	The four-stroke Otto cycle	322
9.3.2	Otto cycle analysis	323
9.3.3	Two-stroke Otto cycle engine	327
9.3.4	The Wankel engine	328
9.4	The Diesel Cycle	330
9.5	Other Gas Power Cycles	334
9.5.1	The dual cycle	335
9.5.2	The Stirling and Ericsson cycles	337
9.6	The Brayton Cycle	341
9.6.1	The Brayton cycle with regenerative heating	346
9.6.2	The Brayton cycle with regeneration, intercooling, and reheat	348
9.6.3	The turbojet engine	350
9.7	The Combined Brayton–Rankine Cycle	351
9.8	Summary	354

Contents

Chapter 10 Refrigeration Cycles	365
10.1 The Vapor Compression-Refrigeration Cycle	367
10.1.1 Refrigeration cycle terminology	367
10.1.2 The ideal refrigeration cycle	368
10.1.3 An actual refrigeration cycle	370
10.1.4 Heat pumps	371
10.1.5 Refrigerants	373
10.2 Cascade Refrigeration Systems	374
10.3 Absorption Refrigeration	377
10.4 Gas Refrigeration Systems	377
10.5 Summary	380
Chapter 11 Mixtures and Psychrometrics	387
11.1 Gas Mixtures	389
11.1.1 Definitions and terminology	389
11.1.2 The Amagat and Dalton laws	391
11.2 Air-Vapor Mixtures and Psychrometry	396
11.2.1 Terminology and definitions	396
11.2.2 Adiabatic saturation temperature	399
11.2.3 Psychrometrics	401
11.3 Air-Conditioning Processes	405
11.4 Summary	412
Chapter 12 Combustion	423
12.1 Introduction	425
12.2 Combustion Reactions	426
12.3 The Enthalpy of Formation and the Enthalpy of Combustion	434
12.4 Flame Temperature	442
12.5 Equilibrium Reactions	447
12.6 Summary	450

Part III Contemporary Topics

459

Chapter 13 Alternative Energy Conversion

461

13.1 Biofuels 462

13.1.1 Ethanol 463

13.1.2 Biodiesel 464

13.1.3 Algae fuel 467

13.2 Solar Energy 467

13.2.1 Photovoltaic cells 467

13.2.2 Active solar heating 468

13.2.3 Passive solar heating 470

13.3 Fuel Cells 470

13.4 Thermoelectric Generators 472

13.5 Geothermal Energy 473

13.6 Wind Energy 473

13.7 Ocean and Hydroelectric Energy 474

13.7.1 Wave energy 474

13.7.2 Ocean thermal energy conversion 475

13.7.3 Hydroelectric power 477

13.8 Osmotic Power Generation 478

13.9 Summary 479

Chapter 14 Thermodynamics of Living Organisms

483

14.1 Energy Conversion in Plants 485

14.2 Energy Conversion in Animals 487

14.3 The Generation of Biological Work 490

14.4 Temperature Regulation in Biological Systems 491

14.4.1 Endothermic organisms 492

14.4.2 Ectothermic organisms 492

14.4.3 Temperature regulation in plants 493

14.5 Summary 494

The Appendices

A	Conversions of Units	499
B	Material Properties	501
B-1	Properties of the U.S. Standard Atmosphere	501
B-2	Properties of Various Ideal Gases (at 25°C)	502
B-3	Critical-Point Constants	503
B-4	Specific Heats and Densities of Liquids and Solids	504
B-5	Ideal-Gas Specific Heat of Several Common Gases as a Cubic Function of Temperature	504
B-6	Ideal-Gas Specific Heats of Several Common Gases at Different Temperatures	505
B-7	Enthalpy of Formation and Enthalpy of Vaporization	506
B-8	Enthalpy of Combustion and Enthalpy of Vaporization	507
B-9	Natural Logarithms of the Equilibrium Constant K_p	508
B-10	Constants for the van der Waals Equation of State	508
C	Steam Tables	509
C-1	Properties of Saturated H ₂ O—Temperature Table	509
C-2	Properties of Saturated H ₂ O—Pressure Table	511
C-3	Superheated Steam	512
C-4	Compressed Liquid	518
C-5	Saturated Solid-Vapor	519
D	Properties of R134a	521
D-1	Saturated R134a—Temperature Table	521
D-2	Saturated R134a—Pressure Table	523
D-3	Superheated R134a	524
E	Properties of Ammonia	529
E-1	Saturated Ammonia	529
E-2	Superheated Ammonia	531
F	Ideal-Gas Tables	533
F-1	Properties of Air	533
F-2	Molar Properties of Nitrogen, N ₂	534
F-3	Molar Properties of Oxygen, O ₂	535
F-4	Molar Properties of Carbon Dioxide, CO ₂	536
F-5	Molar Properties of Carbon Monoxide, CO	537

Contents

F-6	Molar properties of hydrogen, H ₂	538	
F-7	Molar Properties of Water, H ₂ O	539	
G	Psychrometric Charts	541	
	Figure G-1	Psychrometric chart, $P = 1$ atm, SI units	541
H	Compressibility Charts	543	
	Figure H-1	Compressibility chart, low pressures	543
	Figure H-2	Compressibility chart, high pressures	544
I	Enthalpy Departure Charts	545	
	Figure I-1	Enthalpy departure chart, SI units	545
J	Entropy Departure Charts	547	
	Figure J-1	Entropy departure chart, SI units	547
Answers to Selected Problems			
	Index	557	