

CONTENTS

Preface xvii

CHAPTER ONE

INTRODUCTION AND OVERVIEW 1

- 1-1 Introduction to Thermal-Fluid Sciences 2
- 1-2 Thermodynamics 4
- 1-3 Heat Transfer 5
- 1-4 Fluid Mechanics 6
- 1-5 Importance of Dimensions and Units 7
- 1-6 Problem-Solving Technique 14

Summary 18
References and Suggested Readings 19
Problems 19

PART 1 THERMODYNAMICS 23

CHAPTER TWO

BASIC CONCEPTS OF THERMODYNAMICS 25

- 2-1 Systems and Control Volumes 26
- 2-2 Properties of a System 27
- 2-3 Density and Specific Gravity 28
- 2-4 State and Equilibrium 29
- 2-5 Processes and Cycles 30
- 2-6 Temperature and the Zeroth Law of Thermodynamics 32
- 2-7 Pressure 37
- 2-8 The Manometer 41
- 2-9 The Barometer and Atmospheric Pressure 44

Summary 48
References and Suggested Readings 49
Problems 49

CHAPTER THREE

ENERGY, ENERGY TRANSFER, AND GENERAL ENERGY ANALYSIS 59

- 3-1 Introduction 60
- 3-2 Forms of Energy 61
- 3-3 Energy Transfer by Heat 68
- 3-4 Energy Transfer by Work 70
- 3-5 Mechanical Forms of Work 74
- 3-6 The First Law of Thermodynamics 78
- 3-7 Energy Conversion Efficiencies 86

Summary 94
References and Suggested Readings 95
Problems 95

CHAPTER FOUR

PROPERTIES OF PURE SUBSTANCES 103

- 4-1 Pure Substance 104
- 4-2 Phases of a Pure Substance 104
- 4-3 Phase-Change Processes of Pure Substances 105
- 4-4 Property Diagrams for Phase-Change Processes 110
- 4-5 Property Tables 116
- 4-6 The Ideal-Gas Equation of State 126
- 4-7 Compressibility Factor—A Measure of Deviation from Ideal-Gas Behavior 129

Summary 133
References and Suggested Readings 134
Problems 135

CHAPTER FIVE

ENERGY ANALYSIS OF CLOSED SYSTEMS 145

- 5-1 Moving Boundary Work 146
- 5-2 Energy Balance for Closed Systems 151
- 5-3 Specific Heats 156
- 5-4 Internal Energy, Enthalpy, and Specific Heats of Ideal Gases 158
- 5-5 Internal Energy, Enthalpy, and Specific Heats of Solids and Liquids 165
 - Summary 169
 - References and Suggested Readings 170
 - Problems 171

CHAPTER SIX

MASS AND ENERGY ANALYSIS OF CONTROL VOLUMES 185

- 6-1 Conservation of Mass 186
- 6-2 Flow Work and the Energy of a Flowing Fluid 193
- 6-3 Energy Analysis of Steady-Flow Systems 196
- 6-4 Some Steady-Flow Engineering Devices 199
- 6-5 Energy Analysis of Unsteady-Flow Processes 212
 - Summary 217
 - References and Suggested Readings 218
 - Problems 219

CHAPTER SEVEN

THE SECOND LAW OF THERMODYNAMICS 237

- 7-1 Introduction to the Second Law 238
- 7-2 Thermal Energy Reservoirs 239
- 7-3 Heat Engines 240
- 7-4 Refrigerators and Heat Pumps 245

- 7-5 Reversible and Irreversible Processes 252
- 7-6 The Carnot Cycle 255
- 7-7 The Carnot Principles 257
- 7-8 The Thermodynamic Temperature Scale 259
- 7-9 The Carnot Heat Engine 261
- 7-10 The Carnot Refrigerator and Heat Pump 263
 - Summary 266
 - References and Suggested Readings 267
 - Problems 267

CHAPTER EIGHT

ENTROPY 279

- 8-1 Entropy 280
- 8-2 The Increase of Entropy Principle 283
- 8-3 Entropy Change of Pure Substances 287
- 8-4 Isentropic Processes 290
- 8-5 Property Diagrams Involving Entropy 292
- 8-6 What is Entropy? 293
- 8-7 The $T ds$ Relations 297
- 8-8 Entropy Change of Liquids and Solids 298
- 8-9 The Entropy Change of Ideal Gases 302
- 8-10 Reversible Steady-Flow Work 309
- 8-11 Isentropic Efficiencies of Steady-Flow Devices 313
- 8-12 Entropy Balance 320
 - Summary 330
 - References and Suggested Readings 331
 - Problems 331

CHAPTER NINE

POWER AND REFRIGERATION CYCLES 351

- 9-1 Basic Considerations in the Analysis of Power Cycles 352
- 9-2 The Carnot Cycle and its Value in Engineering 354
- 9-3 Air-Standard Assumptions 356

- 9-4 An Overview of Reciprocating Engines 357
- 9-5 Otto Cycle: The Ideal Cycle for Spark-Ignition Engines 358
- 9-6 Diesel Cycle: The Ideal Cycle for Compression-Ignition Engines 364
- 9-7 Brayton Cycle: The Ideal Cycle for Gas-Turbine Engines 368
- 9-8 The Brayton Cycle with Regeneration 375
- 9-9 The Carnot Vapor Cycle 378
- 9-10 Rankine Cycle: The Ideal Cycle for Vapor Power Cycles 379
- 9-11 Deviation of Actual Vapor Power Cycles from Idealized Ones 382
- 9-12 How Can We Increase the Efficiency of the Rankine Cycle? 385
- 9-13 The Ideal Reheat Rankine Cycle 389
- 9-14 Refrigerators and Heat Pumps 393
- 9-15 The Reversed Carnot Cycle 394
- 9-16 The Ideal Vapor-Compression Refrigeration Cycle 395
- 9-17 Actual Vapor-Compression Refrigeration Cycle 398
 - Summary 400
 - References and Suggested Readings 402
 - Problems 402

PART 2 FLUID MECHANICS 421

CHAPTER TEN

INTRODUCTION AND PROPERTIES OF FLUIDS 423

- 10-1 The No-Slip Condition 424
- 10-2 Classification of Fluid Flows 425
- 10-3 Vapor Pressure and Cavitation 429
- 10-4 Viscosity 431
- 10-5 Surface Tension and Capillary Effect 436
 - Summary 441
 - References and Suggested Readings 442
 - Problems 442

CHAPTER ELEVEN

FLUID STATICS 447

- 11-1 Introduction to Fluid Statics 448
- 11-2 Hydrostatic Forces on Submerged Plane Surfaces 448
- 11-3 Hydrostatic Forces on Submerged Curved Surfaces 454
- 11-4 Buoyancy and Stability 457
 - Summary 463
 - References and Suggested Readings 463
 - Problems 464

CHAPTER TWELVE

BERNOULLI AND ENERGY EQUATIONS 471

- 12-1 The Bernoulli Equation 472
- 12-2 General Energy Equation 487
- 12-3 Energy Analysis of Steady Flows 488
 - Summary 495
 - References and Suggested Readings 495
 - Problems 496

CHAPTER THIRTEEN

MOMENTUM ANALYSIS OF FLOW SYSTEMS 505

- 13-1 Newton's Laws 506
- 13-2 Choosing a Control Volume 507
- 13-3 Forces Acting on a Control Volume 508
- 13-4 The Reynolds Transport Theorem 510
- 13-5 The Linear Momentum Equation 515
 - Summary 527
 - References and Suggested Readings 528
 - Problems 528

CHAPTER FOURTEEN

INTERNAL FLOW 537

- 14-1 Introduction 538
- 14-2 Laminar and Turbulent Flows 539

- 14-3 The Entrance Region 541
- 14-4 Laminar Flow in Pipes 543
- 14-5 Turbulent Flow in Pipes 551
- 14-6 Minor Losses 560
- 14-7 Piping Networks and Pump Selection 567
 - Summary 574
 - References and Suggested Readings 576
 - Problems 576

CHAPTER FIFTEEN

EXTERNAL FLOW: DRAG AND LIFT 587

- 15-1 Introduction 588
- 15-2 Drag and Lift 590
- 15-3 Friction and Pressure Drag 594
- 15-4 Drag Coefficients of Common Geometries 597
- 15-5 Parallel Flow over Flat Plates 605
- 15-6 Flow over Cylinders and Spheres 610
- 15-7 Lift 614
 - Summary 621
 - References and Suggested Readings 622
 - Problems 623

PART 3 HEAT TRANSFER 633

CHAPTER SIXTEEN

MECHANISMS OF HEAT TRANSFER 635

- 16-1 Introduction 636
- 16-2 Conduction 636
- 16-3 Convection 644
- 16-4 Radiation 646
- 16-5 Simultaneous Heat Transfer Mechanisms 649
 - Summary 654
 - References and Suggested Readings 655
 - Problems 655

CHAPTER SEVENTEEN

STEADY HEAT CONDUCTION 663

- 17-1 Steady Heat Conduction in Plane Walls 664
- 17-2 Thermal Contact Resistance 674
- 17-3 Generalized Thermal Resistance Networks 679
- 17-4 Heat Conduction in Cylinders and Spheres 682
- 17-5 Critical Radius of Insulation 688
- 17-6 Heat Transfer from Finned Surfaces 691
 - Summary 707
 - References and Suggested Readings 708
 - Problems 709

CHAPTER EIGHTEEN

TRANSIENT HEAT CONDUCTION 727

- 18-1 Lumped System Analysis 728
- 18-2 Transient Heat Conduction in Large Plane Walls, Long Cylinders, and Spheres with Spatial Effects 734
- 18-3 Transient Heat Conduction in Semi-Infinite Solids 749
- 18-4 Transient Heat Conduction in Multidimensional Systems 756
 - Summary 761
 - References and Suggested Readings 763
 - Problems 763

CHAPTER NINETEEN

FORCED CONVECTION 775

- 19-1 Physical Mechanism of Convection 776
- 19-2 Thermal Boundary Layer 779
- 19-3 Parallel Flow over Flat Plates 780
- 19-4 Flow across Cylinders and Spheres 786
- 19-5 General Considerations for Pipe Flow 791
- 19-6 General Thermal Analysis 795
- 19-7 Laminar Flow in Tubes 800
- 19-8 Turbulent Flow in Tubes 805
 - Summary 812
 - References and Suggested Readings 813
 - Problems 814

CHAPTER TWENTY

NATURAL CONVECTION 831

- 20-1** Physical Mechanism of Natural Convection 832
- 20-2** Equation of Motion and the Grashof Number 835
- 20-3** Natural Convection over Surfaces 838
- 20-4** Natural Convection Inside Enclosures 846
 - Summary 855
 - References and Suggested Readings 856
 - Problems 857

CHAPTER TWENTY-ONE

RADIATION HEAT TRANSFER 869

- 21-1** Introduction 870
- 21-2** Thermal Radiation 871
- 21-3** Blackbody Radiation 873
- 21-4** Radiative Properties 880
- 21-5** The View Factor 887
- 21-6** Radiation Heat Transfer: Black Surfaces 900
- 21-7** Radiation Heat Transfer: Diffuse, Gray Surfaces 902
 - Summary 911
 - References and Suggested Readings 913
 - Problems 913

CHAPTER TWENTY-TWO

HEAT EXCHANGERS 927

- 22-1** Types of Heat Exchangers 928
- 22-2** The Overall Heat Transfer Coefficient 931
- 22-3** Analysis of Heat Exchangers 937
- 22-4** The Log Mean Temperature Difference Method 939
- 22-5** The Effectiveness–NTU Method 949
 - Summary 959
 - References and Suggested Readings 960
 - Problems 961

APPENDIX

PROPERTY TABLES AND CHARTS 973

- Table A-1** Molar mass, gas constant, and critical-point properties 974
- Table A-2** Ideal-gas specific heats of various common gases 975
- Table A-3** Properties of common liquids, solids, and foods 978
- Table A-4** Saturated water—Temperature table 980
- Table A-5** Saturated water—Pressure table 982
- Table A-6** Superheated water 984
- Table A-7** Compressed liquid water 988
- Table A-8** Saturated ice–water vapor 989
- Figure A-9** *T-s* diagram for water 990
- Figure A-10** Mollier diagram for water 991
- Table A-11** Saturated refrigerant-134a—Temperature table 992
- Table A-12** Saturated refrigerant-134a—Pressure table 994
- Table A-13** Superheated refrigerant-134a 995
- Figure A-14** *P-h* diagram for refrigerant-134a 997
- Table A-15** Properties of saturated water 998
- Table A-16** Properties of saturated refrigerant-134a 999
- Table A-17** Properties of saturated ammonia 1000
- Table A-18** Properties of saturated propane 1001
- Table A-19** Properties of liquids 1002
- Table A-20** Properties of liquid metals 1003
- Table A-21** Ideal-gas properties of air 1004
- Table A-22** Properties of air at 1 atm pressure 1006
- Table A-23** Properties of gases at 1 atm pressure 1007
- Table A-24** Properties of solid metals 1009
- Table A-25** Properties of solid nonmetals 1012
- Table A-26** Emissivities of surfaces 1013
- Figure A-27** The Moody chart 1015
- Figure A-28** Nelson–Obert generalized compressibility chart 1016

Index 1017

Nomenclature 1043