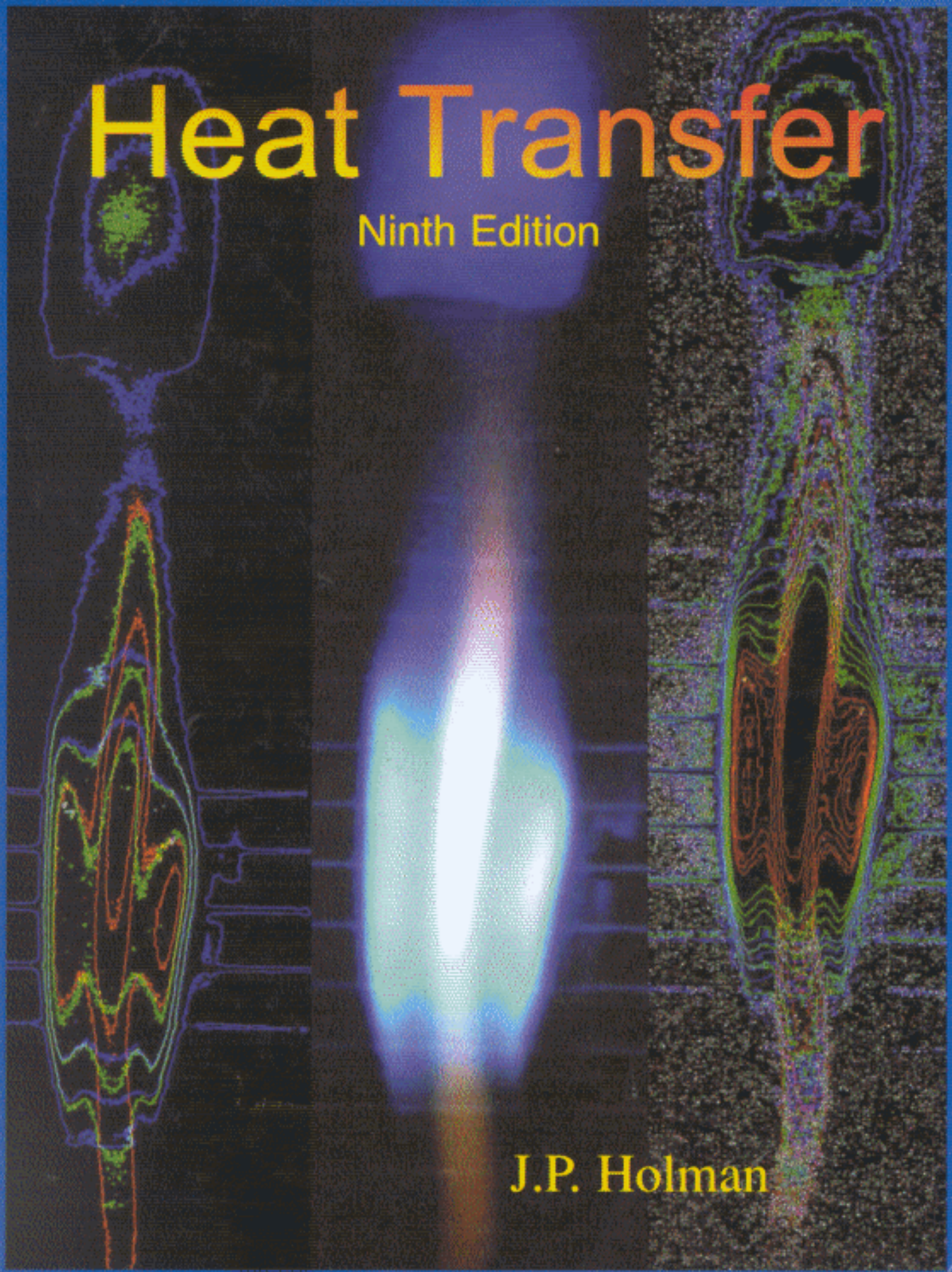
# Heat Transfer

Ninth Edition



J.P. Holman

# CONTENTS


Guide to Worked Examples ix

*Preface* xiii

About the Author xvi

List of Symbols xvii

CHAPTER **1**

**Introduction** 1

**1-1** Conduction Heat Transfer 1
**1-2** Thermal Conductivity 5
**1-3** Convection Heat Transfer 9
**1-4** *Radiation Heat Transfer* 12
**1-5** Dimensions and Units 13
**1-6** Summary 18
Review Questions 19
List of Worked Examples 20
Problems 20
References 23

CHAPTER **2**

**Steady-State Conduction—One Dimension** 25

**2-1** Introduction 25
**2-2** The Plane Wall 25
**2-3** Insulation and $R$ Values 26
**2-4** Radial Systems 27
**2-5** The Overall Heat-Transfer Coefficient 31
**2-6** Critical Thickness of Insulation 35
**2-7** Heat-Source Systems 37
**2-8** Cylinder with Heat Sources 38
**2-9** Conduction-Convection Systems 41
**2-10** Fins 43
**2-11** Thermal Contact Resistance 53
Review Questions 56
List of Worked Examples 56
Problems 56
References 70

CHAPTER **3**

**Steady-State Conduction—Multiple Dimensions** 71

**3-1** Introduction 71
**3-2** Mathematical Analysis of Two-Dimensional Heat Conduction 71
**3-3** Graphical Analysis 75
**3-4** The Conduction Shape Factor 77
**3-5** Numerical Method of Analysis 82
**3-6** Numerical Formulation in Terms of Resistance Elements 91
**3-7** Gauss-Seidel Iteration 93
**3-8** Accuracy Considerations 96
**3-9** Electrical Analogy for Two-Dimensional Conduction 112
**3-10** Summary 113
Review Questions 113
List of Worked Examples 114
Problems 114
References 129

CHAPTER **4**

**Unsteady-State Conduction** 131

**4-1** Introduction 131
**4-2** Lumped-Heat-Capacity System 133
**4-3** Transient Heat Flow in a Semi-Infinite Solid 135
**4-4** Convection Boundary Conditions 139
**4-5** Multidimensional Systems 153
**4-6** Transient Numerical Method 158
**4-7** Thermal Resistance and Capacity Formulation 166
**4-8** Summary 184
Review Questions 184
List of Worked Examples 184
Problems 185
References 204

CHAPTER 5
**Principles of Convection** 205

5-1 Introduction 205
5-2 Viscous Flow 205
5-3 Inviscid Flow 208
5-4 Laminar Boundary Layer on a Flat Plate 212
5-5 Energy Equation of the Boundary Layer 218
5-6 The Thermal Boundary Layer 221
5-7 The Relation Between Fluid Friction and Heat Transfer 230
5-8 Turbulent-Boundary-Layer Heat Transfer 232
5-9 Turbulent-Boundary-Layer Thickness 239
5-10 Heat Transfer in Laminar Tube Flow 242
5-11 Turbulent Flow in a Tube 246
5-12 Heat Transfer in High-Speed Flow 248
5-13 Summary 253
Review Questions 253
List of Worked Examples 255
Problems 255
References 263

CHAPTER 6
**Empirical and Practical Relations for Forced-Convection Heat Transfer** 265

6-1 Introduction 265
6-2 Empirical Relations for Pipe and Tube Flow 267
6-3 Flow Across Cylinders and Spheres 281
6-4 Flow Across Tube Banks 291
6-5 Liquid-Metal Heat Transfer 296
6-6 Summary 299
Review Questions 301
List of Worked Examples 302
Problems 302
References 311

CHAPTER 7
**Natural Convection Systems** 315

7-1 Introduction 315
7-2 Free-Convection Heat Transfer on a Vertical Flat Plate 315
7-3 Empirical Relations for Free Convection 321
7-4 Free Convection from Vertical Planes and Cylinders 321
7-5 Free Convection from Horizontal Cylinders 328
7-6 Free Convection from Horizontal Plates 330
7-7 Free Convection from Inclined Surfaces 332
7-8 Nonnewtonian Fluids 333
7-9 Simplified Equations for Air 333
7-10 Free Convection from Spheres 334
7-11 Free Convection in Enclosed Spaces 335
7-12 Combined Free and Forced Convection 346
7-13 Summary 349
7-14 Summary Procedure for All Convection Problems 350
Review Questions 351
List of Worked Examples 353
Problems 353
References 363

CHAPTER 8
**Radiation Heat Transfer** 367

8-1 Introduction 367
8-2 Physical Mechanism 367
8-3 Radiation Properties 369
8-4 Radiation Shape Factor 376
8-5 Relations between Shape Factors 385
8-6 Heat Exchange between Nonblackbodies 392
8-7 Infinite Parallel Surfaces 400
8-8 Radiation Shields 405
8-9 Gas Radiation 409
8-10 Radiation Network for an Absorbing and Transmitting Medium 410
8-11 Radiation Exchange with Specular Surfaces 415
8-12 Radiation Exchange with Transmitting, Reflecting, and Absorbing Media 420
8-13 Formulation for Numerical Solution 426
8-14 Solar Radiation 441
8-15 Radiation Properties of the Environment 446
8-16 Effect of Radiation on Temperature Measurement 449
8-17 The Radiation Heat-Transfer Coefficient 450
8-18 Summary 451

Review Questions 452
List of Worked Examples 452
Problems 453
References 474

CHAPTER 9
**Condensation and Boiling Heat Transfer** 477

**9-1** Introduction 477
**9-2** Condensation Heat-Transfer Phenomena 477
**9-3** The Condensation Number 482
**9-4** Film Condensation Inside Horizontal Tubes 483
**9-5** Boiling Heat Transfer 486
**9-6** Simplified Relations for Boiling Heat Transfer with Water 497
**9-7** The Heat Pipe 499
**9-8** Summary and Design Information 501
Review Questions 502
List of Worked Examples 503
Problems 503
References 508

CHAPTER 10
**Heat Exchangers** 511

**10-1** Introduction 511
**10-2** The Overall Heat-Transfer Coefficient 511
**10-3** Fouling Factors 517
**10-4** Types of Heat Exchangers 518
**10-5** The Log Mean Temperature Difference 521
**10-6** Effectiveness-NTU Method 530
**10-7** Compact Heat Exchangers 546
**10-8** Analysis for Variable Properties 549
**10-9** Heat-Exchanger Design Considerations 556
Review Questions 557
List of Worked Examples 557
Problems 557
References 573

CHAPTER 11
**Mass Transfer** 575

**11-1** Introduction 575
**11-2** Fick's Law of Diffusion 575
**11-3** Diffusion in Gases 577
**11-4** Diffusion in Liquids and Solids 581
**11-5** The Mass-Transfer Coefficient 582
**11-6** Evaporation Processes in the Atmosphere 586
Review Questions 588
List of Worked Examples 589
Problems 589
References 591

APPENDIX A
**Tables** 593

**A-1** The Error Function 593
**A-2** Property Values for Metals 594
**A-3** Properties of Nonmetals 597
**A-4** Properties of Saturated Liquids 600
**A-5** Properties of Air at Atmospheric Pressure 602
**A-6** Properties of Gases at Atmospheric Pressure 603
**A-7** Physical Properties of Some Common Low-Melting-Point Metals 605
**A-8** Diffusion Coefficients of Gases and Vapors in Air at 25°C and 1 atm 605
**A-9** Properties of Water (Saturated Liquid) 606
**A-10** Normal Total Emissivity of Various Surfaces 607
**A-11** Steel-Pipe Dimensions 609
**A-12** Conversion Factors 610

APPENDIX B
**Exact Solutions of Laminar-Boundary-Layer Equations** 611

APPENDIX C
**Analytical Relations for the Heisler Charts** 616

APPENDIX D
**Use of Microsoft Excel for Solution of Heat-Transfer Problems** 621

**D-1** Introduction 621
**D-2** Excel Template for Solution of Steady-State Heat-Transfer Problems 621

**D-3** Solution of Equations for Nonuniform Grid and/or Nonuniform Properties 625

**D-4** Heat Sources and Radiation Boundary Conditions 625

**D-5** Excel Procedure for Transient Heat Transfer 626

**D-6** Formulation for Heating of Lumped Capacity with Convection and Radiation 640

*List of Worked Examples* 655

References 655

**Index** 657