

# Heat Transfer

Ninth Edition

MOGRAW-HILL NOT FOR RESALE  
DONATION 09ASAD09

J.P. Holman

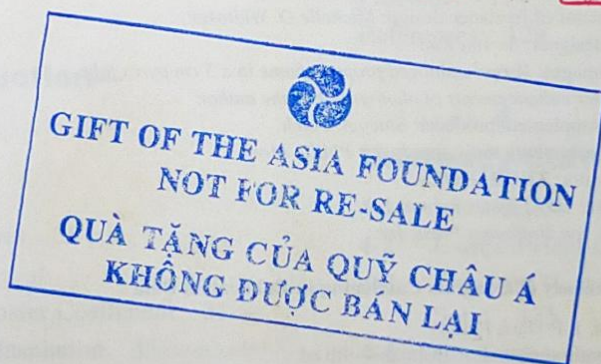


# Heat Transfer

**Ninth Edition**

**J. P. Holman**

*Professor of Mechanical Engineering  
Southern Methodist University*



Boston Burr Ridge, IL Dubuque, IA Madison, WI New York San Francisco St. Louis  
Bangkok Bogotá Caracas Kuala Lumpur Lisbon London Madrid Mexico City  
Milan Montreal New Delhi Santiago Seoul Singapore Sydney Taipei Toronto



# McGraw-Hill Higher Education

A Division of The McGraw-Hill Companies

## HEAT TRANSFER, NINTH EDITION

Published by McGraw-Hill, a business unit of The McGraw-Hill Companies, Inc., 1221 Avenue of the Americas, New York, NY 10020. Copyright © 2002, 1997, 1990, 1986, 1981, 1976, 1972, 1968, 1963 by The McGraw-Hill Companies, Inc. All rights reserved. No part of this publication may be reproduced or distributed in any form or by any means, or stored in a database or retrieval system, without the prior written consent of The McGraw-Hill Companies, Inc., including, but not limited to, in any network or other electronic storage or transmission, or broadcast for distance learning.

Some ancillaries, including electronic and print components, may not be available to customers outside the United States.

This book is printed on acid-free paper.

International 24 25 26 27 28 29 30 VNH/VNH 0 9 8 7

Domestic 7 8 9 10 11 12 VNH/VNH 0 9 8 7

ISBN-13: 978-0-07-240655-9

ISBN-10: 0-07-240655-0

ISBN-13: 978-0-07-112230-6 (ISE)

ISBN-10: 0-07-112230-3 (ISE)

General manager: *Thomas E. Casson*

Publisher: *Elizabeth A. Jones*

Sponsoring editor: *Jonathan Plant*

Associate editor: *Debra D. Matteson*

Marketing manager: *Ann Caven*

Project manager: *Richard H. Hecker*

Senior production supervisor: *Sandy Ludovissy*

Coordinator of freelance design: *Michelle D. Whitaker*

Cover designer: *So Yon Kim*

Cover images: *Vortex stabilized propane flame in a 5 cm pyrex tube.*

*Computer enhancements of photograph by the author.*

Senior supplement producer: *Stacy A. Patch*

Media technology senior producer: *Phillip Meek*

Compositor: **TECHBOOKS**

Typeface: *10/12 Times Roman*

Printer: *Von Hoffmann Press, Inc.*

### Library of Congress Cataloging-in-Publication Data

Holman, J. P. (Jack Philip)

Heat transfer / J. P. Holman.—9th ed.

p. cm.—(McGraw-Hill series in mechanical engineering)

Includes bibliographical references and index.

ISBN 0-07-240655-0 (acid-free paper)

1. Heat—Transmission. I. Title. II. Series.

QC320 .H64 2002

621.402'2—dc21

2001034522

CIP

INTERNATIONAL EDITION ISBN 0-07-112230-3

Copyright © 2002. Exclusive rights by The McGraw-Hill Companies, Inc., for manufacture and export. This book cannot be re-exported from the country to which it is sold by McGraw-Hill. The International Edition is not available in North America.

www.mhhe.com



# 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