Engineering Heat Transfer

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An Introduction to Engineering Fluid Mechanics

J. A. Fox

Principles of Engineering Thermodynamics

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Engineering Heat Transfer

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ISBN 978-0-333-18757-9   ISBN 978-1-349-15605-4 (eBook)

DOI 10.1007/978-1-349-15605-4

© J. R. Simonson 1975

Softcover reprint of the hardcover 1st edition 1975 978-0-333-18213-0

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First published 1975 by

THE MACMILLAN PRESS LTD

London and Basingstoke

Associated companies in New York Dublin

Melbourne Johannesburg and Madras

SBN 333 18213 8 (hard cover)

333 18757 1 (paper cover)

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Contents

<i>Preface</i>	ix
<i>Nomenclature</i>	xi
1 Introduction	1
2 The Equations of Heat Conduction	8
2.1 The Nature of Heat Conduction	8
2.2 The Differential Equation of Conduction in a Cartesian Coordinate System	10
2.3 The Differential Equation of Conduction in a Cylindrical Coordinate System	13
3 One-dimensional Steady State Conduction	16
3.1 Conduction in Plane Slabs	16
3.2 Effect of a Variable Conductivity in a Plane Slab	22
3.3 Radial Conduction in Cylindrical Layers	23
3.4 Critical Thickness of Insulation	26
3.5 Radial Conduction in Spherical Layers	27
3.6 Conduction with Heat Sources	27
4 Two-dimensional Steady State Conduction	35
4.1 A Numerical Solution to Two-dimensional Conduction	36
4.2 Elementary Computing Procedures for Two-dimensional Steady State Conduction	40
4.3 The Electrical Analogy of Two-dimensional Conduction	46
5 Transient Conduction	52
5.1 The Uniform Temperature, or Lumped Capacity, System	52
5.2 The Solution of Transient Conduction Problems in One Dimension	55
5.3 Two-dimensional Transient Conduction	61
5.4 Periodic Temperature Changes at a Surface	62
6 Forced Convection: Boundary Layer Principles	72
6.1 Introduction	72
6.2 Equations of the Laminar Boundary Layer on a Flat Plate	74
6.3 Laminar Forced Convection on a Flat Plate	81
6.4 Laminar Forced Convection in a Tube	86

7	Forced Convection: Reynolds Analogy and Dimensional Analysis	95
7.1	Reynolds Analogy	95
7.2	Dimensional Analysis of Forced Convection	105
7.3	Empirical Relationships for Forced Convection	109
8	Natural Convection	115
8.1	The Body Force	116
8.2	Dimensional Analysis of Natural Convection	116
8.3	Formulae for the Prediction of Natural Convection	117
9	Separated Flow Convection	125
9.1	Relationship between Heat Transfer and Pressure Loss in a Complex Flow System	126
9.2	Convection from a Single Cylinder in Cross Flow	128
9.3	Convection in Flow across Tube Bundles	128
10	Convection with Phase Change	133
10.1	Description of Condensing Flow	133
10.2	A Theoretical Model of Condensing Flow	134
10.3	Boiling Heat Transfer	138
11	Mass Transfer by Convection	145
11.1	Mass and Mole Concentrations	146
11.2	Molecular Diffusion	146
11.3	Eddy Diffusion	147
11.4	Molecular Diffusion from an Evaporating Fluid Surface	150
11.5	Mass Transfer in Laminar and Turbulant Convection	
11.6	Reynolds Analogy	153
11.7	Combined Heat and Mass Transfer	155
12	Extended Surfaces	160
12.1	The Straight Fin and Spine	160
12.2	Limit of Usefulness of the Straight Fin	167
12.3	Fin and Finned Surface Effectiveness	167
12.4	Overall Coefficients of Finned Surfaces	169
12.5	Numerical Relationships for Fins	172
13	Heat Exchangers	178
13.1	Types of Heat Exchanger, and Definitions	178
13.2	Determination of Heat Exchanger Performance	183

CONTENTS		vii
13.3	Heat Exchanger Transfer Units	187
13.4	Plate Heat Exchangers	193
14	The Laws of Black- and Grey-body Radiation	200
14.1	Absorption and Reflection of Radiant Energy	201
14.2	Emission, Radiosity and Irradiation	202
14.4	Black and Non-black Bodies	202
14.4	Kirchoff's Law	205
14.5	Intensity of Radiation	207
14.6	Radiation Exchange Between Black Surfaces	209
14.7	Grey-body Radiation Exchanges	214
14.8	Non-luminous Gas Radiation	218
14.9	Solar Radiation	221
<i>Appendix 1</i>	<i>Heat Transfer Literature</i>	226
<i>Appendix 2</i>	<i>Units and Conversion Factors</i>	227
<i>Appendix 3</i>	<i>Tables of Property Values</i>	230
<i>Appendix 4</i>	<i>Gas Emissivities</i>	247
<i>Index</i>		251

Preface

The aim of this book, which is a revised edition of a book previously published by McGraw-Hill, is to introduce the reader to the subject of heat transfer. It will take him sufficiently along the road to enable him to start reading profitably the many more extensive texts on the subject, and the latest research papers to be found in scientific periodicals. This book is therefore intended for students of engineering in universities and technical colleges, and it will also be of assistance to the practising engineer who needs a concise reference to the fundamental principles of the subject. The engineering student will find most, if not all, aspects of the subject taught in undergraduate courses and, thus equipped, he will be in a position to undertake further studies at postgraduate level.

The aim throughout has been to introduce the principles of heat transfer in simple and logical steps. The need for an easily assimilated introduction to a subject becomes more urgent when the subject itself continues to grow at an ever-increasing rate. It is hoped that the material selected and presented will be of value at all levels of readership. Indebtedness is acknowledged to all those, past and present, who have contributed to the science of heat transfer with their original work, and as far as possible detailed references are given at the end of each chapter. Also grateful thanks are extended to various persons and organizations for permission to use certain diagrams, tables, and photographs; credit for these is given at appropriate points throughout the text.

It is also hoped that in this edition the changes made will further enhance the value of the book. Greater attention has been given to numerical methods in conduction, and some basic procedures in digital computing are included. The chapter on radiation has been extended to include an introduction to non-luminous gas radiation and a short section on solar radiation. Numerous small changes have

been made throughout in the light of reviews and criticisms received. New worked examples are included to extend the range of applicability, and some of the original problems set have been replaced by more recent ones. SI units are now used exclusively, and conversion factors for British units are included in appendix 2.

Many of the problems included are university examination questions; the source is stated in each case. Where necessary the units in the numerical examples have been converted to SI. Indebtedness is acknowledged to the owners of the copyright of these questions for permission to use them, and for permission to convert the units. The universities concerned are in no way committed to the approval of numerical answers quoted.

Much of the material in this book has been taught for a number of years at undergraduate level to students at The City University. Grateful thanks are due to Professor J. C. Levy, Head of the Department of Mechanical Engineering, and to Mr B. M. Hayward, Head of the Thermodynamics Section. Discussions with colleagues at City and elsewhere have also contributed in numerous ways, and for this help sincere thanks are expressed.

Finally, thanks are due to Malcom Stewart, of The Macmillan Press, who has been responsible for the production of both editions, and also to my wife, who has typed the manuscript revisions.

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Nomenclature

a	distance increment
A	area
b, l, t, w	linear dimension
c	concentration
C	capacity ratio of heat exchanger
C, K	constants of integration
Cd	average friction factor
Cf	skin friction coefficient
c_p	specific heat at constant pressure
C_p	volumetric specific heat at constant pressure
d	diameter
D	diffusion coefficient
E	effectiveness of heat exchanger
f	friction factor
F	geometric configuration factor
$\mathcal{F}$	geometric emissivity factor
f_D	drag factor
g	gravitational acceleration
g	mass transfer per unit area and time
G	irradiation, mass velocity
h	convection coefficient
h_{fg}	latent enthalpy of evaporation
h_m	mass transfer coefficient
h_R	radiation coefficient
i	current density
I	current
I	intensity of radiation
J	radiosity
k	thermal conductivity
L, D, T, W	linear dimension
L, M, T, θ	dimensions of length, mass, time, temperature
m	mass flow, or mass in transient conduction
n	coordinate direction
n	frequency of temperature variation
NTU	number of transfer units
$p, P, \Delta p$	pressure, difference of pressure
P	perimeter
PN	plate number
q	heat transfer per unit area and time
q'	heat generation per unit volume and time

Q	heat transfer per unit time, or a physical variable in dimensionless analysis
r	radius, radial direction
r	residual value
R	resistance
R_m	universal gas constant
S	scaling factors in electrical analogy
S_i	electrical shape factor
S_q	thermal shape factor
t	temperature
T	absolute temperature
$t, \Delta t, T$	time, time increment time constant
U, U_A, U_L	overall heat transfer coefficients
U	velocity of temperature wave
v	velocity
v	specific volume
V	electrical potential, volume
x, y, z	coordinate direction, linear dimension
X	length of temperature wave
α	thermal diffusivity
α	absorptivity
β	coefficient of cubical expansion
δ	boundary layer thickness
δ_b	thickness of laminar sub-boundary layer
δ_t	thermal boundary layer thickness
δ'_t	equivalent conducting film thickness
ε	emissivity
ε	eddy diffusivity
ε_q	eddy thermal diffusivity
ε_m	eddy mass diffusivity
η_f	fin effectiveness
η_{fe}	equivalent effectiveness of finned surface
θ, θ_m	temperature difference, logarithmic temperature difference
θ	angle in cylindrical coordinate system
λ	wave-length
μ	dynamic viscosity
ν	kinematic viscosity
ρ	density
ρ	electrical resistivity
ρ	reflectivity
σ	Stefan-Boltzmann constant, surface tension
τ	shear stress
τ	transmissivity
τ_t	turbulent shear stress
ϕ	angle in spherical coordinate system

Dimensionless groups

F	Fourier number, $\Delta t \alpha / a^2$

NOMENCLATURE

xiii

Gr	Grashof number, $\beta g \theta \rho^2 l^3 / \mu^2$
J	Colburn J -factor, $St. Pr^{2/3}$
Le	Lewis number, D/α
Nu_l	Nusselt number, hl/k
Pr	Prandtl number, $c_p \mu / k$
Ra	Rayleigh number, $Gr.Pr$
Re_i	Reynolds number, $\rho v l / \mu$
Sc	Schmidt number, ν / D
$(Sc)_t$	turbulent Schmidt number, $\varepsilon / \varepsilon_m$
Sh	Sherwood number, $h_m l (p_i)_{im} / DP$
St	Stanton number, $h / \rho v c_p$
$(St)_M$	mass transfer Stanton number, $Sh / (Re.Sc)$
<i>Suffices</i>	
a	at axis of tube
a, w	air, water, (in hygrometry)
b	black body
b	limit of laminar sub-boundary layer
c	cold fluid
d, l, x	length terms used in dimensionless groups
e	equivalent
f	fluid
h	hot fluid, heated length
i, j	components of mixture (in mass transfer)
i, o	inlet, outlet, (in heat exchangers)
m	mean value
n	direction of component
0	datum length
r	radial direction, or radial position
s	surroundings, of free stream
sat.	saturated temperature
t	temperature, turbulent
w	wall
x, y, z	direction of component
θ	angular component
λ	monochromatic
<i>Superscript</i>	
—	average value