Introduction to Heat Transfer

Introduction to Heat Transfer

Bengt Sundén
Lund University, Sweden

WIT*PRESS* **Southampton, Boston**

Bengt Sundén
Lund University, Sweden

Published by

WIT Press
Ashurst Lodge, Ashurst, Southampton, SO40 7AA, UK
Tel: 44 (0) 238 029 3223; Fax: 44 (0) 238 029 2853
E-Mail: witpress@witpress.com
http://www.witpress.com

For USA, Canada and Mexico

WIT Press
25 Bridge Street, Billerica, MA 01821, USA
Tel: 978 667 5841; Fax: 978 667 7582
E-Mail: infousa@witpress.com
http://www.witpress.com

British Library Cataloguing-in-Publication Data

A Catalogue record for this book is available
from the British Library

ISBN (hardback): 978-1-84564-656-1
ISBN (paperback): 978-1-84564-
eISBN: 978-1-84564-657-8

Library of Congress Catalog Card Number: 2011939411

The texts of the papers in this volume were set individually by the authors or under their supervision.

Printed in Great Britain by Lightning Source, UK.

Contents

Nomenclature

A area [m^2]
a thermal diffusivity [m^2/s], (eq. (4.5))
a_λ monochromatic absorption coefficient [–], (eq. (12.48))
Bi Biot number [–], (eq. (4.5))
Bo boiling number [–], (eq. (14.69))
b length, thickness [m]
C heat capacity flow rate [W/K], (eq. (15.4))
C_D drag coefficient [–], (eq. (11.1))
C_F shear stress coefficient [–], (eq. (7.30))
C_p pressure coefficient [–], Fig. 11.3
c specific heat [J/(kg K)]
c propagation velocity for electromagnetic wave motion [m/s]
c_p specific heat at constant pressure [J/(kg K)]
D diameter [m]
D_h hydraulic diameter [m], (eq. (8.8))
d_ij deviatric stress tensor [N/m^2], (eq. (6.12))
E energy [J]
$\dot{E}$ energy per time unit [W]
E emitted radiation energy, emissive power [W/m^2]
E voltage [V]
E_B emitted black body radiation [W/m^2], (eq. (12.10))
E_λ emitted monochromatic radiation emissve power [W/(m^2 m)]
e specific energy [J/kg]
e_ij rate of strain tensor [1/s], (eq. (6.15))
F force [N]
F correction factor [–]
F_ij angle factor, view or shape factor [–], (eq. (12.26))
Fo Fourier number [–], (eq. (4.5))
Fr Froude number [–], (eq. (14.56))
f Darcy friction factor [–], (eq. (8.6))
f_s vortex frequency [s^{-1}], (eq. (11.2))
G incident radiation [W/m^2], (eq. (12.5))
G average mass velocity [kg/(m^2 s)]
Gr Grashof number [–], (eq. (10.4))

Gr^*	modified Grashof number [–], (eq. (10.51))
g	gravity constant [m/s^2]
H	enthalpy [J]
$\dot{H}$	enthalpy per time unit [W]
h	specific enthalpy [J/kg]
h	Planck's constant [J s], (eq. (12.2))
h_{fg}	latent heat [J/kg]
I	radiation intensity [W/m^2 sr], (eq. (12.20))
I	current [A]
I	momentum [kg m/s]
i, j, k	unit vectors
J	radiosity [W/m^2], (eq. (12.5))
Ja	Jakob number, (eq. (13.26))
j	Colburn factor [–], $St \cdot Pr^{2/3}$
K_c	contraction coefficient [–], (eq. (15.37))
K_e	expansion coefficient [–], (eq. (15.37))
L	length, thickness [m]
L_i	entrance length [m], (eq. (8.4))
$LMTD$	logarithmic mean temperature difference [K], [°C], (eq. (15.9))
l_m	mixing length [m], (eq. (9.51))
M	molecular weight [kg/kmol]
m	mass [kg]
$\dot{m}$	mass flow rate [kg/s]
N	number of tube rows
NTU	number of transfer units [–], (eq. (15.17))
Nu	Nusselt number [–], (eq. (6.62))
n	number of molecules per unit volume
P	efficiency parameter [–], (eq. (15.12))
P_R	reduced pressure [–]
Pr	Prandtl number [–], (eq. (6.50))
Pr_t	turbulent Prandtl number, [–], (eq. (9.33))
p	pressure [Pa]
p'	fluctuating pressure [Pa]
$\bar{p}$	time averaged pressure [Pa]
Q	heat [J]
$\dot{Q}$	heat transfer rate [W]
q	heat flux [W/m^2]
R	radius [m]
R	gas constant [J/(kg K)]
R	heat capacity flow rate ratio [–], (eq. (15.13))
R_P	surface roughness [µm]
Re	Reynolds number [–], (eq. (6.60))
r	radius [m]
r_s	latent heat melting [J/kg]
S_L	lateral tube pitch [m]

S_T	longitudinal tube pitch [m]
Sr	Strouhal number [–], (eq. (11.2))
St	Stanton number [–], (eq. (7.42))
T	absolute temperature [K]
T^+	dimensionless temperature [–], (eq. (9.82))
TR	thermal resistance [K/W], (eq. (15.1))
t	temperature [°C]
t'	fluctuating temperature [°C]
$\bar{t}$	time averaged temperature [°C]
U	internal energy [J]
$\dot{U}$	internal energy per time unit (effekt) [W]
U	(mean) velocity [m/s]
U_∞	freestream velocity [m/s]
U	overall heat transfer coefficient [W/(m^2 K)], (eq. (15.1))
u, v, w	local velocity [m/s]
u', v', w'	fluctuating velocity [m/s]
$\bar{u}, \bar{v}, \bar{w}$	time averaged velocity [m/s], (eq. (9.4))
u^+	dimensionless velocity [–]
u_{fS}	fictious liquid velocity [m/s], (eq. (14.43))
u_{gS}	fictious gas velocity [m/s], (eq. (14.44))
u_m	mean velocity [m/s]
u_τ, u^*	friction velocity [m/s]
V	volume [m^3]
X	coordinate [m]
X	Martinelli parameter [–], (eq. (14.52))
X_F	flowing mass fraction [–], (eq. (14.40))
X_S	static mass fraction [–], (eq. (14.41))
x, y, z	coordinates [m]
y^+	dimensionless coordinate perpendicular to a solid surface [–], (eq. (9.45))
W	work [J]
$\dot{W}$	work per time unit [W]
We	Weber number [–], (eq. (14.23))
Z	width, length [m]
α	heat transfer coefficient [W/(m^2 K)], (eq. (1.23))
α	absorptance [–], (eq. (12.3))
β	thermal expansion coefficient [1/K]
β	angle [rad]
γ	ratio of specific heats, c_p/c_v [–]
δ	angle [rad]
δ	boundary layer thickness [m]
δ_{ij}	Kronecker's delta [–], (eq. (6.12))
ε	emissivity [–], (eq. (12.11))
ε	void [–], (eq. (14.39))
ε	efficiency [–], (eq. (15.14))

ε_m turbulent kinematic viscosity [m^2/s], (eq. (9.31))
ε_q turbulent diffusivity [m^2/s], (eq. (9.32))
η dimensionless coordinate [–]
η fin effectiveness [–], (eq. (3.48))
θ dimensionless temperature [–]
θ angle [rad]
θ thermal length [–], (eq. (15.43))
ϑ temperature [°C]
κ von Karmans constant [–], (eq. (9.51))
λ parameter [–]
λ thermal conductivity [W/(m K)], (eq. (1.1))
λ wavelength [m]
λ_1 mean free path for molecular motion [m]
μ dynamic viscosity [kg/(m s)]
ν kinematic viscosity [m^2/s]
ρ density [kg/m^3]
ρ reflectance [–], (eq. (12.3))
ρ resistivity [Ω m]
σ Stefan-Boltzmann constant [$W/(m^2 K^4)$], (eq. (12.10))
σ shear stress [N/m^2]
σ surface tension [N/m]
σ electric conductivity [1/(Ω m)]
σ area ratio [–], (eq. (15.35))
τ time [s]
τ transmittance [–], (eq. (12.3))
ϕ angle [rad]
φ fin efficiency [–], (eq. (3.49))
Φ radiation energy [W/m^2], (eq. (12.21))
ψ stream function [s^{-1}], (eq. (10.21))
ω solid angle [sr], (eq. (12.16))

Index

B bulk, blackbody
C convective boiling
f at film temperature, fluid
g gas
i inner
KK nucleate boiling
m mean
o outer
TF two-phase
w wall
λ monochromatic
∞ freestream

Preface

This book aims as an introduction of heat transfer at undergraduate and graduate levels. Compared to other similar textbooks it differs significantly as it is much more comprehensive in describing the thermal conductivity of various substances, providing deeper analysis of fin heat transfer, and it includes buried pipes. For convective heat transfer the relation to fluid mechanics is much more highlighted. The turbulent convection, evaporation and heat exchanger chapters are all more comprehensive than other general heat transfer textbooks available. The textbook has been used for exchange students and PhD students for several years. The text has been developed and improved over the years.

At the end of the book a number of problems in heat transfer can be found. These can be solved by the methods presented in the various chapters.

Lund in September 2011

Bengt Sundén
Professor in Heat Transfer
Department of Energy Sciences
Lund University