Heat Transfer - Zak Olech - 9/26/2019

General Information

Conversion Factors

Process

1 - Assumptions
2 - Properties
3 - Analysis

Assumptions

Metric Prefix

SI Prefixes

Multiplication Factor	Prefix†	Symbol
1 000 000 000 000 = 10^{12}	tera	T
1 000 000 000 = 10^{9}	giga	G
1 000 000 = 10^{6}	mega	M
1 000 = 10^{3}	kilo	k
100 = 10^{2}	hecto‡	h
10 = 10^{1}	deka‡	da
0.1 = 10^{-1}	deci‡	d
0.01 = 10^{-2}	centi‡	c
0.001 = 10^{-3}	milli	m
0.000 001 = 10^{-6}	micro	μ
0.000 000 001 = 10^{-9}	nano	n
0.000 000 000 001 = 10^{-12}	pico	p
0.000 000 000 000 001 = 10^{-15}	femto	f
0.000 000 000 000 000 001 = 10^{-18}	atto	a

Variables (Alphbetical By Variable)

A	area, m^2
A_b	area of prime (unfinned) surface, m^2
A_c	cross-sectional area, m^2
A_p	fin profile area, m^2
A_r	nozzle area ratio
a	acceleration, m/s^2; speed of sound, m/s
Bi	Biot number
Bo	Bond number
C	molar concentration, $kmol/m^3$; heat capacity rate, W/K
C_D	drag coefficient
C_f	friction coefficient
C_t	thermal capacitance, J/K
Co	Confinement number
c	specific heat, J/kg $\cdot$ K; speed of light, m/s
c_p	specific heat at constant pressure, J/kg $\cdot$ K
c_v	specific heat at constant volume, J/kg $\cdot$ K
D	diameter, m
D_{AB}	binary mass diffusivity, m^2/s
D_b	bubble diameter, m
D_h	hydraulic diameter, m
d	diameter of gas molecule, nm
E	thermal plus mechanical energy, J; electric potential, V; emissive power, W/m^2
E^{tot}	total energy, J
Ec	Eckert number
$\dot{E}_g$	rate of energy generation, W
$\dot{E}_{in}$	rate of energy transfer into a control volume, W
$\dot{E}_{out}$	rate of energy transfer out of control volume, W
$\dot{E}_{st}$	rate of increase of energy stored within a control volume, W
e	thermal internal energy per unit mass, J/kg; surface roughness, m
F	force, N; fraction of blackbody radiation in a wavelength band; view factor
Fo	Fourier number
Fr	Froude number
f	friction factor; similarity variable
G	irradiation, W/m^2; mass velocity, kg/s $\cdot$ m^2
Gr	Grashof number
Gz	Graetz number
g	gravitational acceleration, m/s^2
H	nozzle height, m; Henry's constant, bars
h	convection heat transfer coefficient, $W/m^2 \cdot K$; Planck's constant, J $\cdot$ s
h_{fg}	latent heat of vaporization, J/kg
h'_{fg}	modified heat of vaporization, J/kg
h_{sf}	latent heat of fusion, J/kg
h_m	convection mass transfer coefficient, m/s
h_{rad}	radiation heat transfer coefficient, $W/m^2 \cdot K$
I	electric current, A; radiation intensity, $W/m^2 \cdot sr$
i	electric current density, A/m^2; enthalpy per unit mass, J/kg
J	radiosity, W/m^2
Ja	Jakob number
J_i^*	diffusive molar flux of species i relative to the mixture molar average velocity, kmol/s $\cdot$ m^2
j_i	diffusive mass flux of species i relative to the mixture mass average velocity, kg/s $\cdot$ m^2
j_H	Colburn j factor for heat transfer
j_m	Colburn j factor for mass transfer
k	thermal conductivity, W/m $\cdot$ K
k_B	Boltzmann's constant, J/K
k_0	zero-order, homogeneous reaction rate constant, kmol/s $\cdot$ m^3
k_1	first-order, homogeneous reaction rate constant, s^{-1}
k''_1	first-order, surface reaction rate constant, m/s
L	length, m
Le	Lewis number

M	mass, kg
$\dot{M}_i$	rate of transfer of mass for species, i, kg/s
$\dot{M}_{i,g}$	rate of increase of mass of species i due to chemical reactions, kg/s
$\dot{M}_{\text{in}}$	rate at which mass enters a control volume, kg/s
$\dot{M}_{\text{out}}$	rate at which mass leaves a control volume, kg/s
$\dot{M}_{\text{st}}$	rate of increase of mass stored within a control volume, kg/s
$\mathcal{M}_i$	molecular weight of species i, kg/kmol
Ma	Mach number
m	mass, kg
$\dot{m}$	mass flow rate, kg/s
m_i	mass fraction of species i, ρ_i/ρ
N	integer number
N_L, N_T	number of tubes in longitudinal and transverse directions
Nu	Nusselt number
NTU	number of transfer units
N_i	molar transfer rate of species i relative to fixed coordinates, kmol/s
N_i''	molar flux of species i relative to fixed coordinates, $\text{kmol/s} \cdot \text{m}^2$
$\dot{N}_i$	molar rate of increase of species i per unit volume due to chemical reactions, $\text{kmol/s} \cdot \text{m}^3$
$\dot{N}_i''$	surface reaction rate of species i, $\text{kmol/s} \cdot \text{m}^2$
$\mathcal{N}$	Avogadro's number
n_i''	mass flux of species i relative to fixed coordinates, $\text{kg/s} \cdot \text{m}^2$
$\dot{n}_i$	mass rate of increase of species i per unit volume due to chemical reactions, $\text{kg/s} \cdot \text{m}^3$
P	power, W; perimeter, m
P_L, P_T	dimensionless longitudinal and transverse pitch of a tube bank
Pe	Peclet number
Pr	Prandtl number
p	pressure, N/m^2
Q	energy transfer, J
q	heat transfer rate, W
$\dot{q}$	rate of energy generation per unit volume, W/m^3
q'	heat transfer rate per unit length, W/m
q''	heat flux, W/m^2
q^*	dimensionless conduction heat rate
R	cylinder radius, m; gas constant, $\text{J/kg} \cdot \text{K}$
$\mathcal{R}$	universal gas constant, $\text{J/kmol} \cdot \text{K}$
Ra	Rayleigh number
Re	Reynolds number
R_e	electric resistance, Ω
R_f	fouling factor, $\text{m}^2 \cdot \text{K/W}$
R_m	mass transfer resistance, s/m^3
$R_{m,n}$	residual for the m, n nodal point
R_t	thermal resistance, K/W
$R_{t,c}$	thermal contact resistance, K/W
$R_{t,f}$	fin thermal resistance, K/W
$R_{t,o}$	thermal resistance of fin array, K/W
r_o	cylinder or sphere radius, m
r, ϕ, z	cylindrical coordinates
r, θ, ϕ	spherical coordinates
S	solubility, $\text{kmol/m}^3 \cdot \text{atm}$; shape factor for two-dimensional conduction, m; nozzle pitch, m; plate spacing, m; Seebeck coefficient, V/K
S_c	solar constant, W/m^2
S_D, S_L, S_T	diagonal, longitudinal, and transverse pitch of a tube bank, m
Sc	Schmidt number
Sh	Sherwood number
St	Stanton number
T	temperature, K
t	time, s
U	overall heat transfer coefficient, $\text{W/m}^2 \cdot \text{K}$; internal energy, J
u, v, w	mass average fluid velocity components, m/s
u^*, v^*, w^*	molar average velocity components, m/s
V	volume, m^3; fluid velocity, m/s
v	specific volume, $\text{m}^3\text{/kg}$
W	width of a slot nozzle, m
$\dot{W}$	rate at which work is performed, W
We	Weber number
X	vapor quality
X_{tt}	Martinelli parameter
X, Y, Z	components of the body force per unit volume, N/m^3
x, y, z	rectangular coordinates, m
x_c	critical location for transition to turbulence, m
$x_{\text{fd},c}$	concentration entry length, m
$x_{\text{fd},h}$	hydrodynamic entry length, m
$x_{\text{fd},t}$	thermal entry length, m
x_i	mole fraction of species i, C_i/C
Z	thermoelectric material property, K^{-1}

Greek Letters

α	thermal diffusivity, m^2/s; accommodation coefficient; absorptivity
β	volumetric thermal expansion coefficient, K^{-1}
Γ	mass flow rate per unit width in film condensation, $kg/s \cdot m$
γ	ratio of specific heats
δ	hydrodynamic boundary layer thickness, m
δ_c	concentration boundary layer thickness, m
δ_p	thermal penetration depth, m
δ_t	thermal boundary layer thickness, m
ε	emissivity; porosity; heat exchanger effectiveness
ε_f	fin effectiveness
η	thermodynamic efficiency; similarity variable
η_f	fin efficiency
η_o	overall efficiency of fin array
θ	zenith angle, rad; temperature difference, K
κ	absorption coefficient, m^{-1}
λ	wavelength, μm
λ_{mfp}	mean free path length, nm

μ	viscosity, $kg/s \cdot m$
ν	kinematic viscosity, m^2/s; frequency of radiation, s^{-1}
ρ	mass density, kg/m^3; reflectivity
ρ_e	electric resistivity, Ω/m
σ	Stefan–Boltzmann constant, $W/m^2 \cdot K^4$; electrical conductivity, $1/\Omega \cdot m$; normal viscous stress, N/m^2; surface tension, N/m
Φ	viscous dissipation function, s^{-2}
φ	volume fraction
ϕ	azimuthal angle, rad
ψ	stream function, m^2/s
τ	shear stress, N/m^2; transmissivity
ω	solid angle, sr; perfusion rate, s^{-1}

Subscripts

A, B	species in a binary mixture
abs	absorbed
am	arithmetic mean
atm	atmospheric
b	base of an extended surface; blackbody
C	carnot
c	cross-sectional; concentration; cold fluid; critical
cr	critical insulation thickness
cond	conduction
conv	convection
CF	counterflow
D	diameter; drag
dif	diffusion
e	excess; emission; electron
evap	evaporation
f	fluid properties; fin conditions; saturated liquid conditions
fc	forced convection
fd	fully developed conditions
g	saturated vapor conditions
H	heat transfer conditions
h	hydrodynamic; hot fluid; helical
i	general species designation; inner surface of an annulus; initial condition; tube inlet condition; incident radiation
L	based on characteristic length
l	saturated liquid conditions
lat	latent energy
lm	log mean condition
m	mean value over a tube cross section
max	maximum
o	center or midplane condition; tube outlet condition; outer
p	momentum
ph	phonon
R	reradiating surface
r, ref	reflected radiation
rad	radiation
S	solar conditions
s	surface conditions; solid properties; saturated solid conditions
sat	saturated conditions
sens	sensible energy
sky	sky conditions
ss	steady state
sur	surroundings
t	thermal
tr	transmitted
v	saturated vapor conditions
x	local conditions on a surface
λ	spectral
∞	free stream conditions

Superscripts

*	molar average; dimensionless quantity

Overbar

—	surface average conditions; time mean

Chapter 1 - Introduction

1 - What and how

2 - Physical Origins and Rate Equations

3 - Relationship to Thermodynamics

Chapter 2 - Introduction to Conduction

1 - The Conduction Rate Equation

2 - The Thermal Properties of Matter

3 - The Heat Diffusion Equation

4 - Boundary and Initial Conditions

Chapter 3 - One-Dimensional Steady-State Conduction

1 - The Plane Wall

2 - An Alternative Conduction Analysis

3 - Radial Systems

4 - Summary of One-Dimensional Conduction Results

5 - Conduction with Thermal Energy Generation

Ohmic heating

$$\dot{q} = \frac{\dot{E}_g}{\forall} = \frac{I^2 R_e}{\forall} \tag{1}$$

Absorption of Radiation

The Plane Wall

Heat Equation

$$\frac{d}{dx}\left(k\frac{dT}{dx}\right) + \dot{q} = 0 \rightarrow \frac{d^2T}{dx^2} + \frac{\dot{q}}{k} = 0 \tag{2}$$

General Solution
Symmetric Surface Conditions
- Temperature Distribution
- Overall Energy Balance

Radial Systems

Cylindrical (Tube) Wall
Solid Cylinder (Circular Rod)
- Heat Equation (Cylindrical)
Spherical Wall (Shell)
Solid Sphere
- Heat Equation (Spherical)

6 - Extended Surfaces

Appendix

Appendix C.