General Information

Conversion Factors

Process

0 - Known
1 - Find
2 - Schematic
3 - Assumptions
3 - Analysis

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

Geometric Relationships

Circle

$$\pi r^2 \tag{1}$$

$$\pi r^2/4 \tag{2}$$

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 · K; speed of light, m/s
c_p	specific heat at constant pressure, J/kg · K
c_v	specific heat at constant volume, J/kg · 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 · 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 · K; Planck's constant, J · 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 · K
I	electric current, A; radiation intensity, W/m^2 · 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 · m^2
j_i	diffusive mass flux of species i relative to the mixture mass average velocity, kg/s · m^2
j_H	Colburn j factor for heat transfer
j_m	Colburn j factor for mass transfer
k	thermal conductivity, W/m · K
k_B	Boltzmann's constant, J/K
k_0	zero-order, homogeneous reaction rate constant, kmol/s · 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, m^3/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

$\overline{}$	surface average conditions; time mean

Chapter 1 - Introduction

1 - What and how

2 - Physical Origins and Rate Equations

3 - Relationship to Thermodynamics

Thermal and Mechanical Energy Equation at an Instat (t)

$$\delta E_{\text{st}} = E_{\text{in}} - E_{\text{out}} + E_{\text{gen}} \tag{3}$$

$$\dot{E_{\text{st}}} = \frac{dE_{\text{st}}}{dt} = \dot{E}_{\text{in}} - \dot{E}_{\text{out}} + \dot{E}_{\text{gen}} \tag{4}$$

Simplified Steady-Flow Thermal Energy Equation

$$q = \dot{(m)} c_p (T_{\text{out}} - T_{\text{in}}) \tag{5}$$

General Heat Transfer Relationships

Multiple equations 1.1, 1.3a, and 1.7 by A if you need to calculate per unit area.

TABLE 1.5 Summary of heat transfer processes

Mode	Mechanism(s)	Rate Equation	Equation Number	Transport Property or Coefficient
Conduction	Diffusion of energy due to random molecular motion	$q''_x(\text{W/m}^2) = -k\dfrac{dT}{dx}$	(1.1)	k (W/m · K)
Convection	Diffusion of energy due to random molecular motion plus energy transfer due to bulk motion (advection)	$q''(\text{W/m}^2) = h(T_s - T_\infty)$	(1.3a)	h (W/m^2 · K)
Radiation	Energy transfer by electromagnetic waves	$q''(\text{W/m}^2) = \varepsilon\sigma(T_s^4 - T_{\text{sur}}^4)$ or $q(\text{W}) = h_r A(T_s - T_{\text{sur}})$	(1.7) (1.8)	ε h_r (W/m^2 · K)

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

$$\dot{q} = \frac{\dot{E}_g}{\forall} = \frac{I^2 R_e}{\forall} \tag{6}$$

Absorption of Radiation

The Plane Wall

Heat Equation

$$\frac{d}{dx}(k\frac{dT}{dx}) + \dot{q} = 0 \rightarrow \frac{d^2T}{dx^2} + \frac{\dot{q}}{k} = 0 \tag{7}$$

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)

TABLE 3.3 One-dimensional, steady-state solutions to the heat equation with no generation

	Plane Wall	Cylindrical Wall[a]	Spherical Wall[a]
Heat equation	$\dfrac{d^2T}{dx^2} = 0$	$\dfrac{1}{r}\dfrac{d}{dr}\left(r\dfrac{dT}{dr}\right) = 0$	$\dfrac{1}{r^2}\dfrac{d}{dr}\left(r^2\dfrac{dT}{dr}\right) = 0$
Temperature distribution	$T_{s,1} - \Delta T\dfrac{x}{L}$	$T_{s,2} + \Delta T\dfrac{\ln(r/r_2)}{\ln(r_1/r_2)}$	$T_{s,1} - \Delta T\left[\dfrac{1-(r_1/r)}{1-(r_1/r_2)}\right]$
Heat flux (q'')	$k\dfrac{\Delta T}{L}$	$\dfrac{k\,\Delta T}{r\ln(r_2/r_1)}$	$\dfrac{k\,\Delta T}{r^2[(1/r_1)-(1/r_2)]}$
Heat rate (q)	$kA\dfrac{\Delta T}{L}$	$\dfrac{2\pi Lk\,\Delta T}{\ln(r_2/r_1)}$	$\dfrac{4\pi k\,\Delta T}{(1/r_1)-(1/r_2)}$
Thermal resistance ($R_{t,\text{cond}}$)	$\dfrac{L}{kA}$	$\dfrac{\ln(r_2/r_1)}{2\pi Lk}$	$\dfrac{(1/r_1)-(1/r_2)}{4\pi k}$

[a]The critical radius of insulation is $r_{cr} = k/h$ for the cylinder and $r_{cr} = 2k/h$ for the sphere.

TABLE 3.4 Temperature distribution and heat loss for fins of uniform cross section

Case	Tip Condition ($x = L$)	Temperature Distribution θ/θ_b	Fin Heat Transfer Rate q_f
A	Convection heat transfer: $h\theta(L) = -kd\theta/dx\rvert_{x=L}$	$\dfrac{\cosh m(L-x) + (h/mk)\sinh m(L-x)}{\cosh mL + (h/mk)\sinh mL}$ (3.75)	$M\dfrac{\sinh mL + (h/mk)\cosh mL}{\cosh mL + (h/mk)\sinh mL}$ (3.77)
B	Adiabatic: $d\theta/dx\rvert_{x=L} = 0$	$\dfrac{\cosh m(L-x)}{\cosh mL}$ (3.80)	$M\tanh mL$ (3.81)
C	Prescribed temperature: $\theta(L) = \theta_L$	$\dfrac{(\theta_L/\theta_b)\sinh mx + \sinh m(L-x)}{\sinh mL}$ (3.82)	$M\dfrac{(\cosh mL - \theta_L/\theta_b)}{\sinh mL}$ (3.83)
D	Infinite fin ($L \rightarrow \infty$): $\theta(L) = 0$	e^{-mx} (3.84)	M (3.85)

$\theta \equiv T - T_\infty$ $\quad m^2 \equiv hP/kA_c$
$\theta_b = \theta(0) = T_b - T_\infty$ $\quad M \equiv \sqrt{hPkA_c}\,\theta_b$

Chapter 4

Appendix

Appendix C.