# Symbols

| | |
|---|---|
| $A$ | 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*, $\rho_i/\rho$ |
| $N$ | 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, kmol/s · m$^2$ |
| $\dot{N}_i$ | molar rate of increase of species *i* per unit volume due to chemical reactions, kmol/s · m$^3$ |
| $N''_i$ | surface reaction rate of species *i*, kmol/s · m$^2$ |
| $\mathcal{N}$ | Avogadro's number |
| $n''_i$ | mass flux of species *i* relative to fixed coordinates, kg/s · m$^2$ |
| $\dot{n}_i$ | mass rate of increase of species *i* per unit volume due to chemical reactions, kg/s · 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, J/kg · K |
| $\mathcal{R}$ | universal gas constant, J/kmol · K |
| $Ra$ | Rayleigh number |
| $Re$ | Reynolds number |
| $R_e$ | electric resistance, Ω |
| $R_f$ | fouling factor, m$^2$ · 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 |
| $r, \phi, z$ | cylindrical coordinates |
| $r, \theta, \phi$ | spherical coordinates |
| $S$ | solubility, kmol/m$^3$ · 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, W/m$^2$ · 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

| | |
|---|---|
| $\alpha$ | thermal diffusivity, m$^2$/s; accommodation coefficient; absorptivity |
| $\beta$ | volumetric thermal expansion coefficient, K$^{-1}$ |
| $\Gamma$ | mass flow rate per unit width in film condensation, kg/s · m |
| $\gamma$ | ratio of specific heats |
| $\delta$ | hydrodynamic boundary layer thickness, m |
| $\delta_c$ | concentration boundary layer thickness, m |
| $\delta_p$ | thermal penetration depth, m |
| $\delta_t$ | thermal boundary layer thickness, m |
| $\varepsilon$ | emissivity; porosity; heat exchanger effectiveness |
| $\varepsilon_f$ | fin effectiveness |
| $\eta$ | thermodynamic efficiency; similarity variable |
| $\eta_f$ | fin efficiency |
| $\eta_o$ | overall efficiency of fin array |
| $\theta$ | zenith angle, rad; temperature difference, K |
| $\kappa$ | absorption coefficient, m$^{-1}$ |
| $\lambda$ | wavelength, $\mu$m |
| $\lambda_{\text{mfp}}$ | mean free path length, nm |

| | |
|---|---|
| $\mu$ | viscosity, kg/s · m |
| $\nu$ | kinematic viscosity, $m^2/s$; frequency of radiation, $s^{-1}$ |
| $\rho$ | mass density, $kg/m^3$; reflectivity |
| $\rho_e$ | electric resistivity, Ω/m |
| $\sigma$ | Stefan–Boltzmann constant, $W/m^2 \cdot K^4$; electrical conductivity, 1/Ω · m; normal viscous stress, $N/m^2$; surface tension, N/m |
| $\Phi$ | viscous dissipation function, $s^{-2}$ |
| $\varphi$ | volume fraction |
| $\phi$ | azimuthal angle, rad |
| $\psi$ | stream function, $m^2/s$ |
| $\tau$ | shear stress, $N/m^2$; transmissivity |
| $\omega$ | 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 |
| $\lambda$ | spectral |
| $\infty$ | free stream conditions |

Superscripts

| | |
|---|---|
| * | molar average; dimensionless quantity |

Overbar

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|---|---|
| $\bar{\ }$ | surface average conditions; time mean |