Appendix A

Nomenclature:

A	empirical constant [-]
A	cross-sectional area of tube [m^2]
A_a	actual heat transfer area per unit length [m^2/m]
A_{cfl}	circumferential flow area [m^2]
A_{fa}	actual free flow cross-sectional area [m^2/m]
A_{eff}	effective surface area of finned tube per unit length [m^2/m]
A_{fin}	surface area of fins per unit length [m^2/m]
A_{fo}	external heat transfer area of low finned tube per unit length [m^2/m]
A_G	cross sectional area occupied by vapor [m^2]
A_{Gd}	dimensionless cross sectional area occupied by vapor [-]
A_{hex}	hexagonal area [m^2]
A_L	cross-sectional area occupied by liquid-phase [m^2]
A_{Ld}	dimensionless cross sectional area occupied
A_o	external heat transfer area of tube bundle [m^2]
A_p	cross-sectional area of fin [m^2]
Ar_L	Archimedes number [-]
A_{root}	root area between fins on tube per unit length [m^2/m]
A_{total}	total surface area of finned tube per unit length [m^2/m]
a	empirical constant [-]
a	one-half of long side of rectangular channel [m]
a_0-a_4	empirical constants [-]
a_1-a_4	empirical constants [-]
a_L	thermal diffusivity of the liquid [m^2/s]
B	empirical constant [-]
B	empirical factor [-]
B_B	Chisholm parameter for bubbly flow transition [-]
B_c	baffle cut [%]
B_F	Chisholm parameter for spray flow transition [-]
B_f	empirical constant of Rose [-]
Bo	boiling number [-]
BR	boiling range (or temperature glide) [K]
Br	Brinkman number [-]
B_S	Chisholm parameter for stratified flow transition [-]
B_s	empirical constant of Rose [-]
B_t	empirical constant of Rose [-]
B_1	empirical constant of Rose [-]
b	empirical constant [-]
b	empirical exponent [-]
b	interfin spacing at the fin tips [m]
b	one-half of short side of rectangular channel [m]
b_0-b_4	empirical constants [-]
b_1-b_4	empirical constants [-]
C	constant in DNB equation [-]
C	constant in Katto and Ohno correlation
C	empirical constant [-]

C_o	Shah factor [-]
C_o	distribution parameter [-]
C_1	constant in Rohsenow correlation [-]
C_1	constant in tube number expression [-]
C_{bh}	constant in bundle bypass expression [-]
C_{bp}	constant in bundle bypass expression [-]
C_{drag}	drag coefficient [-]
C_{ft}	empirical friction factor constant for finned tube [-]
C_{fth}	empirical heat transfer constant for finned tube [-]
C_{sf}	empirical surface factor in Rohsenow correlation [-]
Ca	capillary number [m]
Cap	capillary number [-]
c	empirical exponent [-]
c_b	fraction of tube perimeter retaining condensate [-]
c_L	similarity factor [$m^{-3/4}$]
c_o	constant [-]
c_p	specific heat [J/kg K]; specific heat at constant pressure [J/kg K]
c_{pG}	vapor specific heat [J/kg K]
$(c_p)_G$	vapor specific heat [J/kg K]
c_{pL}	liquid specific heat [J/kg K]
$(c_p)_L$	liquid specific heat [J/kg K]
c_1, c_2	empirical parameters [-]
c_1-c_5	empirical constants [-]
D	droplet diameter [m]
D	exponent [-]
D	external tube diameter [m]
D	tube diameter [m]
D	fin tip diameter [m]
D	tube or cylinder diameter [m]
D_b	diameter of baffle [m]
D_{ctl}	centerline tube limit diameter of tube bundle [m]
D_δ	diameter of liquid ring on tube [m]
D_{fo}	diameter over fins [m]
D_{fr}	root diameter of low finned tube [m]
D_{otl}	outer tube limit diameter of tube bundle [m]
D_{req}	equivalent projected tube diameter of low finned tube [m]
D_{root}	root diameter of finned tube [m]
D_s	internal diameter of heat exchanger shell [m]
D_t	outside tube diameter [m]
d	empirical constant [-]
d_{bub}	bubble departure diameter [m]
d_f	internal tube diameter at base of microfins [m]
d_h	hydraulic diameter [m]
d_i	internal tube diameter [m]
d_{im}	melt down internal tube diameter [m]
$d_{i,o}$	reference internal tube diameter (= 0.01 m) [m]
d_{mean}	internal tube diameter at mean height of microfins [m]
d_p	droplet detachment diameter [m]
dT_{bub}	rise in bubble point temperature [K]
E	convection enhancement factor [-]
E	dimensionless factor [-]

E_2 stratified flow correction factor [-]
Ec Eckert number [-]
E_{mf} microfin factor [-]
E_{new} new convection enhancement factor [-]
E_{RB} microfin convection factor [-]
e empirical constant [-]
e fin or rib or obstruction height [m]
e surface roughess [m]
e corrugation depth [m]
e fraction of liquid entrained as droplets [-]
e_{eff} effective fin height of Rose method [m]
e_f fin height [m]
F two-phase multiplier [-]
F dimensionless factor [-]
F apparent wet fraction of tube [-]
F_{aspect} aspect ratio correction factor [-]
F_i interfacial correction factor [-]
F(M) residual correction factor [-]
$F_1(q)$ dimensionless exponent as function of q [-]
$F_2(q)$ dimensionless exponent as function of q [-]
F_C area fraction occupied by tubes between baffle tips [-]
F_ε bundle boiling void fraction correction factor [-]
F_c mixture correction factor [-]
F_{drag} drag force [N]
F_{flat} correction factor for flattened tubes [-]
F_m non-equilibrium mixture factor [-]
F_{nb} nucleate boiling correction factor [-]
F_P pressure correction factor [-]
F_{PF} pressure correction factor of Gorenflo [-]
Fr_G Froude number of vapor phase [-]
Fr_H Froude number for homogeneous flow [-]
Fr_L liquid Froude number [-]
Fr_{so} Soliman liquid Froude number [-]
F_{pf} pressure correction factor [-]
F_{round} correction factor to Grönnerud correlation [-]
F_S Shah factor [-]
F_s fraction of fin flank area covered by condensate wedge [-]
F_{sbp} ratio of bypass area to cross flow area [-]
F_t fraction of interfin root area covered by condensate wedge [-]
F_w area fraction occupied by baffle window [-]
F_{wL} radiative view factor from wall to liquid droplets [-]
F_{wG} radiative view factor from wall to vapor [-]
F_{tp} two-phase convective multiplier [-]
f empirical constant [-]
fpm fins per meter [m^{-1}]
f Fanning friction factor [-]
f friction factor [-]
f_{app} apparent friction factor [-]
$f_{Blasius}$ Blasius friction factor [-]
f_{cd} cumulative deposition factor [-]

f_{ft} finned tube friction factor [-]
f_G vapor-phase friction factor [-]
f_i interfacial friction factor [-]
f_I tube bank friction factor [-]
$f_{I,plain}$ plain tube bank friction factor [-]
f_k friction factor of phase k (where k is either G or L) [-]
f_L Fanning friction factor of liquid [-]
f_{lam} friction factor for laminar flow [-]
f_{oil} mixture factor on pressure drop [-]
f_S swirl friction factor [-]
f_{trans} friction factor for transition flow [-]
f_{turb} friction factor for turbulent flow [-]
G total mass velocity [kg/m^{2}s]
G_f Rose low finned tube parameter for fin flanks [-]
G_s Rose low finned tube parameter for interfin root area [-]
G_t Rose low finned tube parameter for fin tips [-]
Ga_L Galileo number of liquid [-]
Gr_G Grashof number of vapor [-]
Gz Graetz number [-]
g acceleration due to gravity [9.81 m/s^2]
g empirical exponent [-]
H dimensionless factor [-]
H height of channel [m]
H height of nozzle above top tube row [m]
h liquid height inside channel [m]
h height of flattened tube [m]
h enthalpy [J/kg]
$h_{G,a}$ actual vapor enthalpy [J/kg]
$h_{G,e}$ equilibrium vapor enthalpy [J/kg]
$h_{G,sat}$ enthalpy of saturated vapor [J/kg]
$h_{L,sat}$ enthalpy of saturated liquid [J/kg]
h_L enthalpy of saturated liquid [J/kg]
h_{Ld} dimensionless liquid height inside channel [m]
h_{LG} latent heat of vaporization [J/kg]
h'_{LG} latent heat of vaporization corrected from subcooling [J/kg]
h_{latent} latent heat absorbed by fluid [J/kg]
h_{LV} latent heat of vaporization [J/kg]
$h_{sensible}$ sensible heat absorbed by fluid [J/kg]
h_{total} total heat absorbed by fluid [J/kg]
dh change in enthalpy [J/kg]
$\Delta h_{L,inlet}$ inlet subcooling enthalpy change [J/kg]
Ja_L Jakob number of liquid [-]
J_B bundle bypass correction factor [-]
J_C baffle cut correction factor [-]
J_f laminar flow correction factor for low finned tubes [-]
J_g superficial velocity (m/s)
j Colburn j-factor [-]
j_I ideal heat transfer factor [-]
J_L baffle leakage correction factor [-]

J_R	laminar flow correction factor [-]
$(J_R)_{20}$	laminar flow correction factor at Re = 20 [-]
J_S	unequal baffle spacing correction factor [-]
J_μ	wall viscosity correction factor [-]
K	Taitel and Dukler parameter [-]
K	factor in hydrodynamic developing flow [-]
K_{ff}	falling film heat transfer multiplier relative to pool boiling [-]
K_{fluid}	thermal conductivity of fluid [W/m K]
K_i	inlet subcooling factor at conditions i = 1 to 3 [-]
K_p	boiling factor of Danilova [-]
Ka	Kapitza number [-]
KE_G	kinetic energy of vapor phase [J]
KE_k	kinetic energy of phase k [J]
KE_L	kinetic energy of liquid phase [J]
k	thermal conductivity [W/m K]
k_G	thermal conductivity of vapor [W/m K]
k_L	liquid thermal conductivity [W/m K]
k_{wall}	thermal conductivity of wall material [W/m K]
L	length [m]
L	length of tube [m]
L_{bb}	diametral clearance between D_s and D_{otl} [m]
L_{bi}	inlet baffle spacing [m]
L_{bc}	central baffle spacing [m]
L_{bch}	height of baffle cut [m]
L_{bo}	outlet baffle spacing [m]
L_{dev}	developing length [m]
L_{fin}	equivalent vertical height of fin [m]
L_{fh}	fin height [m]
L_{fs}	average fin thickness assuming rectangular profile [m]
L_G	chordal length through vapor phase [m]
L_L	chordal length through liquid phase [m]
L_p	width of pass partition lane [m]
L_{pl}	width of bypass lane between tubes [m]
L_{pn}	tube pitch normal to direction of flow [m]
L_{pp}	tube pitch parallel to direction of flow [m]
L_S	swirl flow streamline length [m]
L_{sb}	diametral clearance between D_s and D_b [m]
L_{ta}	effective tube length [m]
L_{tb}	tube-to-baffle hole diametral clearance [m]
L_{tp}	tube pitch from tube center to tube center [m]
$L_{tp,eff}$	effective tube pitch from tube center to tube center [m]
L_x	length of outside of a rectangular channel [m]
L_y	length of outside of a rectangular channel [m]
M	mass flow rate [kg/s]
M	molecular weight [kg/kmol]
M_N	additional term from integration [$(kg/ms)^{4/3}$]
m	Blasius exponent [-]
m	exponent [-]
m	exponent on velocity profile [-]
m	fin efficiency parameter [m^{-1}]
m	mass of droplet [kg]

$\dot{m}$ mass velocity of fluid [kg/m^2 s]
$\dot{m}$ mass velocity of fluid at maximum cross-section of bundle [kg/m^2 s]
$\dot{m}$ total mass velocity of liquid and vapor [kg/m^2 s]
$\dot{m}_{bubbly}$ bubbly flow transition mass velocity [kg/m^{2}s]
$\dot{m}_e$ equivalent mass velocity [kg/m^2 s]
$\dot{m}_{dryout}$ mass velocity at onset of dryout [kg/m^2 s]
$\dot{m}_G$ mass velocity of vapor [kg/m^{2}s]
$\dot{m}_{high}$ mass velocity at transition from annular to stratified-wavy flow [kg/m^2 s]
$\dot{m}_L$ mass velocity of liquid [kg/m^{2}s]
$\dot{m}_{low}$ mass velocity at transition from stratified-wavy to stratified flow [kg/m^2 s]
$\dot{m}_{min}$ minimum value of mist flow transition mass velocity [kg/m^{2}s]
$\dot{m}_{mist}$ mass velocity at transition from mist flow [kg/m^2 s]
$\dot{m}_{ref}$ reference mass velocity [= 500 kg/m^2 s]
$\dot{m}_{strat}$ mass velocity at transition from stratified-wavy to stratified flow [kg/m^2 s]
$\dot{m}_{total}$ total mass velocity of liquid plus vapor [kg/m^{2}s]
$\dot{m}_w$ window mass velocity of fluid [kg/m^2 s]
$\dot{m}_{wavy}$ mass velocity at transition from annular to stratified-wavy flow [kg/m^2 s]
$\dot{m}_{wavy(new)}$ new wavy flow transition mass velocity [kg/m^{2}s]
N number of tubes passed in crossflow [-]
N Shah parameter [-]
N tube row number from top [-]
N_b number of baffles [-]
N_c total number of tube rows crossed by flow in entire heat exchanger [-]
N_f number of fins per unit length of tube [fins/m]
N_{ss} number of sealing strip pairs [-]
N_{tcc} number of tube rows crossed between baffle tips in one baffle compartment [-]
N_{tcw} number of tube rows crossed in one baffle window [-]
N_{tt} number of tubes [-]
N_{tw} number of tubes in the window [-]
Nu Nusselt number [-]
Nu_c Nusselt number for forced convection condensation [-]
Nu_D Nusselt number based on droplet diameter [-]
Nu_D mean Nusselt number based on tube diameter [-]
Nu_{D-B} Dittus-Boelter Nusselt number [-]
Nu_{ft} internally finned tube Nusselt number [-]
Nu_G Nusselt number of vapor [-]
Nu_{grav} Nusselt number for gravity controlled condensation [-]
Nu_H mean or fully developed Nusselt number at uniform heat flux condition [-]
$Nu_{H,visc}$ fully developed Nusselt number at uniform heat flux condition [-]
Nu_{HA} Nusselt number for 2nd type of uniform heat flux condition [-]
$Nu_{H,z}$ local Nusselt number at uniform heat flux condition [-]
Nu_L liquid Nusselt number [-]
Nu_{mf} microfin Nusselt number [-]
Nu_{nb} nucleate boiling Nusselt number [-]
Nu_Γ liquid film Nusselt number [-]
$Nu_{\Gamma,lam}$ laminar liquid film Nusselt number [-]
$Nu_{\Gamma,sub}$ subcooled liquid film Nusselt number [-]

$Nu_{\Gamma,turb}$ turbulent liquid film Nusselt number [-]
Nu_{strat} local Nusselt number for stratified flow [-]
Nu_T mean or fully developed Nusselt number at uniform wall temperature condition [-]
$Nu_{T,tt}$ Nusselt number for twisted tape insert at uniform wall temperature condition [-]
$Nu_{T,z}$ local Nusselt number at uniform wall temperature condition [-]
Nu_{tt} twisted tape Nusselt number [-]
$Nu_{y=\infty}$ twisted tape Nusselt number without twist [-]
Nu(x) local Nusselt number [-]
Nu(z) local film Nusselt number [-]
n empirical exponent [-]
n exponent [-]
n exponent on void fraction profile [-]
n factor equal to 3 [-]
n power law exponent [-]
n_1 exponent [-]
n_2 exponent [-]
n_3 exponent [-]
n_B void fraction factor [-]
$n_{corners}$ number of sharp corners facing flow of rib or fin [-]
nf exponent on heat flux [-]
nf nucleate boiling exponent [-]
n_s number of starts or fins [-]
P perimeter of channel [m]
P_G dry perimeter in contact with vapor [m]
P_{Gd} dimensionless dry perimeter in contact with vapor [m]
P_i perimeter of liquid-vapor interface [m]
P_{id} dimensionless perimeter of liquid-vapor interface [m]
P_k phase [-]
P_L wetted perimeter [m]
P_{Ld} dimensionless wetted perimeter [m]
Po Poiseuille number [-]
Pr Prandtl number [-]
Pr_G Prandtl number of vapor [-]
Pr_L liquid Prandtl number [-]
p axial pitch [m]
p exponent
p pressure [N/m^2]
p pitch of corrugation [m]
p_{crit} critical pressure [N/m^2]
p_f axial fin pitch [m]
p_G vapor pressure [N/m^2]
p_r reduced pressure ($p_r = p_{sat}/p_{crit}$) [-]
p_{ro} reference reduced pressure of Gorenflo [-]
p_{sat} saturation pressure [N/m^2]
p_{wall} saturation pressure at wall temperature [N/m^2]
Δp pressure drop [Pa]
Δp_{bI} ideal bundle pressure drop for one baffle compartment [N/m^2]
Δp_c central baffle compartment pressure drop [N/m^2]
Δp_e end zone pressure drop [N/m^2]
Δp_{total} bundle pressure drop [N/m^2]

Δp_w window zone pressure drop [N/m^2]
$(dp/dz)_G$ frictional pressure gradient of the vapor [Pa/m]
$(dp/dz)_L$ frictional pressure gradient of the liquid [Pa/m]
$(dp/dz)_{frict}$ frictional pressure gradient [Pa/m]
Q heat transfer rate [W]
Q volumetric flow rate [m^3/s]
$\dot{Q}_G$ vapor volumetric flow rate [m^3/s]
$\dot{Q}_k$ volumetric flow rate of phase k [m^3/s]
$\dot{Q}_L$ liquid volumetric flow rate [m^3/s]
q heat flux [W/m^2]
q_o reference heat flux [W/m^2]
q_{crit} critical heat flux [W/m^2]
$q_{crit,i}$ reference critical heat flux at conditions i = 1 to 5 [W/m^2]
q_{DNB} heat flux at departure from nucleate boiling (critical heat flux) [W/m^2]
$q_{DNB,tube}$ heat flux at DNB of tube [W/m^2]
q_{dry} heat flux on dry fraction of tube [W/m^2]
q_G heat flux resulting from wall-to-droplet evaporation [W/m^2]
q_L heat flux resulting from droplet evaporation [W/m^2]
q_{ONB} heat flux at onset of nucleate boiling [W/m^2]
q_r radiation heat flux [W/m^2]
q_{wet} heat flux on wet fraction of tube [W/m^2]
R density ratio in Katto and Ohno correlation [-]
R fouling factor on fin [m K/W]
R Chisholm parameter [-]
R radius of tube [m]
R^+ turbulent dimensionless radius of tube [-]
R_c mixture resistance [m^{2}K/W]
R_b bypass pressure drop correction factor [-]
R_L leakage pressure drop correction factor [-]
R_p root mean surface roughness [μm]
R_{po} reference root mean surface roughness of Gorenflo [μm]
$R_{p,o}$ standard surface roughness (= 1.0 μm) [μm]
R_S baffle end zones pressure drop correction factor [-]
R_μ viscosity pressure drop correction factor [-]
Ra Rayleigh number [-]
Ra_L Rayleigh number [-]
Re Reynolds number [-]
Re_{crit} critical film Reynolds number [-]
Re_D droplet Reynolds number [-]
Re_δ Reynolds number of liquid film on tube bundle [-]
Re_e equivalent liquid Reynolds number [-]
Re_{eq} equivalent liquid Reynolds number [-]
Re_G local vapor Reynolds number [-]
Re_{GH} homogeneous Reynolds number [-]
Re_{Go} local vapor only Reynolds number [-]
Re_{Gs} superficial vapor Reynolds number, also Re_{SG} [-]
Re_{Gt} Reynolds number with total flow as vapor [-]
Re_L liquid Reynolds number for all flow as liquid [-]
Re_L liquid film Reynolds number for liquid fraction of flow [-]

Re_{Ls} superficial liquid Reynolds number, also Re_{SL} [-]
Re_{Lt} Reynolds number with total flow as liquid [-]
$(Re_L)_{film}$ Reynolds number with total flow as liquid [-]
Re_{RB} Reynolds number [-]
Re_{root} film Reynolds number of the condensate flowing in the root area [-]
Re_{Γ} film Reynolds number [-]
Re_{Γ} liquid Reynolds number of film [-]
$Re_{*\Gamma}$ modified liquid Reynolds number of film [-]
$Re_{\Gamma,trans}$ transition liquid film Reynolds number [-]
Re_{nb} nucleate boiling Reynolds number [-]
Re_{onset} falling film Reynolds number at top of tube at onset of dryout [-]
Re_{peak} falling film Reynolds number at top of tube at peak performance [-]
Re_S swirl Reynolds number [-]
Re_{SG} vapor superficial Reynolds number [-]
Re_{SL} liquid superficial Reynolds number [-]
Re_{top} falling film Reynolds number at top of tube [-]
Re_{tp} two-phase Reynolds number [-]
Ri Richardson number [-]
R_{wall} wall thermal resistance [K/W]
r constant [-]
r external radius of tube [m]
r radius from centreline [m]
r_i internal tube radius [m]
r_{lm} leakage area parameter [-]
r_o critical nucleation radius [m]
r_s leakage area parameter [-]
r_{ss} sealing strip parameter [-]
S nucleation suppression factor
S velocity ratio [-]
S vertical pitch between centerline of tubes [m]
S_2 stratified flow correction factor [-]
S_b bypass area [m]
S_m cross-sectional flow area at centerline [m]
S_{sb} shell-to-baffle leakage area [m]
S_{tb} tube-to-baffle leakage area [m]
S_w net flow area in window [m]
S_{wg} gross flow area in window without tubes [m]
S_{wt} area in window occupied by tubes [m]
St_{lam} Stanton number for laminar flow [-]
St_{turb} Stanton number for turbulent flow [-]
Sw swirl number [-]
s fin pitch [m]
s specific gravity [-]
T temperature [K or °C]
T time [s]
T^+ turbulent dimensionless temperature [-]
T_{bub} bubble point temperature [K]
T_{bub} bubble point temperature of mixture [K]
T_{bulk} mean bulk temperature of fluid [K]
T_{crit} critical temperature of mixture [K]

T_{dew}	dew point temperature of condensable mixture [K]
T_D	droplet temperature [K]
T_{DNB}	wall temperature at point DNB [K]
T_f	Rose low finned tube parameter for fin flanks [-]
T_G	vapor temperature [K]
$T_{G,a}$	actual bulk vapor temperature [K]
$T_{G\infty}$	bulk temperature of gas-vapor mixture [K]
T_{Gi}	interfacial temperature of gas-vapor mixture [K]
T_{IB}	wall temperature at point IB [K]
T_L	local subcooled temperature of liquid [K]
T_{MFB}	wall temperature at point MFB [K]
T_{man}	manufacturers reference temperature [°C]
T_s	Rose low finned tube parameter for interfin root area [-]
T_{sat}	saturation temperature [K]
T_{sat}	saturation temperature of pure refrigerant [K]
T_t	Rose low finned tube parameter for fin tips [-]
T_w	wall temperature [K]
T_{wall}	wall temperature [°C]
T_{wall}	wall temperature [K]
ΔT	wall-to-fluid temperature difference [K]
ΔT	wall superheat [K]
ΔT_{bp}	boiling range or temperature glide of mixture [K]
ΔT_{bulk}	bulk temperature difference from inlet to outlet [K]
ΔT_f	temperature difference across film (= T_{sat}-T_w) [K]
ΔT_{glide}	temperature glide of a zeotropic mixture [K]
ΔT_I	ideal wall superheat for boiling of a mixture [K]
ΔT_q	bulk temperature change due to wall heat flux from inlet to outlet [K]
ΔT_{ref}	reference temperature rise [K]
ΔT_{sat}	wall superheat (= T_{wall}-T_{sat}) [K]
ΔT_{visc}	bulk temperature rise due to viscous heat dissipation from inlet to outlet [K]
t	time [s]
t	fin thickness [m]
t	mean thickness of fin [m]
t	twisted tape thickness [m]
t_{root}	thickness at root of fin [m]
t_{tip}	thickness at tip of fin [m]
t_{wall}	wall thickness of channel [m]
U	flow velocity [m/s]
U	overall heat transfer coefficient [W/m^2 K]
$<U>$	cross-sectional averaged drift velocity [m/s]
U_G	superficial velocity of vapor [m/s]
$<U_G>$	cross-sectional averaged vapor drift velocity [m/s]
U_{GL}	drift flux [m/s]
$<U_{GL}>$	cross-sectional average vapor drift flux velocity relative to U_L [m/s]
U_{GU}	vapor phase drift velocity [m/s]
$\bar{U}_{GU}$	weighted mean drift velocity [m/s]
U_L	superficial velocity of liquid [m/s]
U_{LU}	liquid phase drift velocity [m/s]
U_S	swirl fluid velocity [m/s]
u	velocity in x-direction [m/s]
u^*	friction velocity [m/s]

u_D	droplet velocity [m/s]
u_d	droplet deposition velocity [m/s]
u_G	vapor velocity [m/s]
$\bar{u}_G$	weighted mean velocity of vapor [m/s]
$<u_G>$	cross-sectional average of vapor velocity [m/s]
u_{Gs}	modified Baker parameter based on superficial vapor velocity [m/s]
u_H	homogeneous velocity [m/s]
u_i	suction velocity at interface [m/s]
u_k	velocity of phase k [m/s]
u_L	liquid velocity [m/s]
u_{LG}	superficial velocity of vapor with respect to liquid [m/s]
u_{Ls}	modified Baker parameter based on superficial liquid velocity [m/s]
u_y	velocity in y-direction [m/s]
u_∞	free stream velocity in z-direction [m/s]
V_G	volume of vapor phase [m^3]
V_L	volume of liquid phase [m^3]
v	velocity in y-direction [m/s]
v	specific volume [m^3/kg]
v_G	specific volume of vapor [m^3/kg]
v_H	homogeneous specific volume [m^3/kg]
v_i	velocity of interface in z-direction [m/s]
v_L	specific volume of liquid [m^3/kg]
W	dimensionless factor [-]
W	ratio in Katto and Ohno correlation [-]
We	Weber number [-]
We_D	droplet Weber number [-]
We_G	vapor Weber number [-]
We_L	Weber number of liquid [-]
w	local oil mass fraction [kg/kg]
w_{inlet}	inlet oil mass fraction [kg/kg]
X	mass fraction of mixture in liquid phase [kg/kg]
X_{tt}	Martinelli parameter with both phases turbulent [-]
x	exponent in Rohsenow correlation [-]
x	vapor quality [-]
x_a	actual local vapor quality [-]
x_B	vapor quality at transition to bubbly flow [-]
x_{crit}	vapor quality at location of critical heat flux [-]
x_{di}	vapor quality at onset of dryout [-]
x_{de}	vapor quality at end of dryout zone [-]
x_e	local equilibrium vapor quality [-]
x_{exit}	exit vapor quality at the critical heat flux [-]
x_F	vapor quality at transition to spray flow [-]
x_{IA}	vapor quality at transition from intermittent to annular flow [-]
x_{max}	vapor quality at the intersection of annular flow and mist flow transition curves [-]
x_{min}	vapor quality at minimum of mist flow transition equation [-]
x_S	vapor quality at transition to stratified flow [-]
Y	Greoneveld multiplying factor [-]
Y	ratio of vapor to liquid frictional pressure gradient [-]
Y	mass fraction of mixture in vapor phase [kg/kg]
Y	twist ratio [-]
y	exponent in Rohsenow correlation [-]

y	length [m]
y	length scale [m]
y	twist ratio for 180° turn [-]
y	parameter [-]
y^+	dimensionless length scale [-]
Z	dimensionless factor [-]
Z	heated length of tube to diameter ratio [-]
Z_G	ratio of sensible cooling duty for vapor to total condensing duty [-]
z	distance along y-axis [m]
z	distance from entrance [m]
z	length from top [m]
z	length around perimeter of tube from top [m]
z^*	dimensionless length from top [m]
z^*	Graetz length parameter [-]
z_a	length from inlet where liquid is actually completely evaporated [m]
z_{di}	length from inlet where dryout occurs [m]
z_e	length from inlet where liquid is completely evaporated under equilibrium conditions [m]
z_{eh}	hydrodynamic entrance length of developing flow [m]
z_{et}	thermal entrance length of developing flow [m]

Greek symbols:

α	heat transfer coefficient [W/m^{2}K]
α	mean film heat transfer coefficient on tube array [W/m^2 K]
α	local perimeter averaged heat transfer coefficient inside a tube [W/m^2 K]
$\alpha(N)$	heat transfer coefficient on Nth tube [W/m^2 K]
$\alpha(N=1)$	heat transfer coefficient on top tube [W/m^2 K]
$\alpha(x)$	local perimeter averaged heat transfer coefficient inside a tube at vapor quality x [W/m^2 K]
α_{array}	falling film heat transfer coefficient on single-row tube array [W/m^2 K]
α_b	heat transfer coefficient on bottom of finned tube retaining condensate [W/m^2 K]
α_{bundle}	local bundle boiling heat transfer coefficient [W/m^{2}K]
α_{bundle}	local bundle boiling heat transfer coefficient for falling film evaporation [W/m^{2}K]
α_c	convective condensation heat transfer coefficient [W/m^{2}K]
α_{cb}	convective boiling heat transfer coefficient [W/m^2 K]
α_{ct}	corrugated tube turbulent heat transfer coefficient [W/m^2 K]
α_D	convective heat transfer coefficient from vapor-to-droplet [W/m^{2}K]
α_{dry}	falling film heat transfer coefficient on dry fraction of tube [W/m^2 K]
α_{dryout}	heat transfer coefficient in dryout zone [W/m^{2}K]
α_{eff}	effective condensing coefficient for condensable mixture [W/m^2 K]
α_f	mean film heat transfer coefficient [W/m^2 K]
α_f	local film condensing coefficient around non-stratified top perimeter of tube [W/m^2 K]
α_f	helix angle of microfins [degrees]
$\alpha_f(z)$	local film heat transfer coefficient [W/m^2 K]
$\alpha_f^+(z)$	dimensionless local film heat transfer coefficient [W/m^2 K]
$\alpha_f(\beta)$	local film heat transfer coefficient at angle β from top of tube [W/m^2 K]
$\alpha_f(x)$	local condensing coefficient at vapor quality x [W/m^2 K]
α_{fin}	heat transfer coefficient on fin [W/m^2 K]
α_{ft}	finned tube turbulent heat transfer coefficient [W/m^2 K]

α_{FZ} Forester-Zuber nucleate boiling heat transfer coefficient [W/m^2 K]
α_G turbulent heat transfer coefficient of vapor [W/m^2 K]
α_{Gt} forced convection heat transfer coefficient with total flow as vapor [W/m^2 K]
α_{grav} gravity-dominated film heat transfer coefficient [W/m^2 K]
α_I ideal heat transfer coefficient [W/m^2 K]
α_I ideal boiling heat transfer coefficient [W/m^2 K]
α_I ideal tube bank heat transfer coefficient [W/m^2 K]
α_{id} ideal heat transfer coefficient [W/m^2 K]
α_{invert} heat transfer coefficient in inverted annular flow regime [W/m^{2}K]
α_L liquid only heat transfer coefficient [W/m^2 K]
α_{Lt} forced convection heat transfer coefficient with total flow as liquid [W/m^2 K]
α_{mean} mean heat transfer coefficient [W/m^2 K]
α_{mf} microfin convective boiling heat transfer coefficient [W/m^2 K]
α_{mist} mist flow heat transfer coefficient [W/m^{2}K]
α_{nb} nucleate boiling heat transfer coefficient [W/m^2 K]
α_{nom} nominal heat transfer coefficient [W/m^2 K]
α_{nb} nucleate boiling heat transfer coefficient [W/m^2 K]
$\alpha_{nb,I}$ ideal nucleate pool boiling heat transfer coefficient of mixture [W/m^{2}K]
$\alpha_{nb,o}$ standard nucleate boiling heat transfer coefficient [W/m^2 K]
α_o reference nucleate pool boiling heat transfer coefficient [W/m^{2}K]
α_{pt} plain tube turbulent heat transfer coefficient [W/m^2 K]
α_Γ falling film heat transfer coefficient [W/m^2 K]
$\alpha_{\Gamma,dev}$ developing region falling film heat transfer coefficient [W/m^2 K]
$\alpha_{\Gamma,lam}$ laminar falling film heat transfer coefficient [W/m^2 K]
$\alpha_{\Gamma,lturb}$ turbulent falling film heat transfer coefficient [W/m^2 K]
$\alpha_{ref\text{-}oil}$ flow boiling heat transfer coefficient of refrigerant-oil mixture [W/m^2 K]
α_{sh} shear-dominated film heat transfer coefficient
α_{ss} shell-side single-phase heat transfer coefficient [W/m^2 K]
α_{strat} mean film heat transfer coefficient around bottom of tube in stratified flow [W/m^2 K]
α_{tp} two-phase flow boiling heat transfer coefficient [W/m^2 K]
α_{tt} twisted tape turbulent heat transfer coefficient [W/m^2 K]
α_{tt} twisted tape two-phase flow boiling heat transfer coefficient [W/m^2 K]
α_{vapor} vapor phase heat transfer coefficient [W/m^2 K]
α_{wet} wetted wall heat transfer coefficient [W/m^2 K]
α_{wet} falling film heat transfer coefficient on wetted fraction of tube [W/m^2 K]
β angle of surface with respect to the horizontal [rad]
β angle around perimeter of tube with respect to top [rad]
β coefficient of thermal expansion [K^{-1}]
β condensate retention angle from bottom of tube [rad]
β contact angle [deg]
β helix angle of corrugation or fin [°]
β value used for calculation of Ω [-]
β volumetric quality [-]
$\langle\beta\rangle$ cross-sectional averaged volumetric quality [-]
β_L liquid mass transfer coefficient [= 0.0003 m/s]
β_{ct} constant for corrugated tube [-]
β_{ft} constant for finned tubes [-]
β_{mL} mass transfer coefficient in liquid [0.0003 m/s]

β_{rib} profile contact angle [°]
$\Delta\delta$ interfacial roughness [m]
δ liquid film thickness [m]
δ thickness of twisted tape [m]
δ^* non-dimensional liquid film thickness [m]
δ^+ turbulent dimensionless film thickness [-]
ε void fraction of vapor [-]
$<\varepsilon>$ cross-sectional averaged void fraction of vapor [-]
ε_c void fraction of vapor at centreline of channel [-]
$\varepsilon_{c\text{-}s}$ cross-sectional void fraction of vapor [-]
$\varepsilon_{chordal}$ chordal void fraction of vapor across channel [-]
ε_H homogeneous void fraction [-]
ε_{IA} void fraction evaluated at x_{IA} [-]
ε_{local} local void fraction of vapor at a point or small volume [-]
ε_r void fraction of Rouhani drift flux model [-]
ε_q Rose low finned tube enhancement ratio at same q [-]
$\varepsilon_{\Delta T}$ Rose low finned tube enhancement ratio at same ΔT [-]
ε_{vol} volumetric void fraction of vapor [-]
ε_w void fraction of vapor at wall [-]
ϕ angle from top of tube [rad]
ϕ_d angle at end of developing region [rad]
ϕ_f angle at end of stagnation flow region [rad]
ϕ_i angle at end of impingement region [rad]
ϕ_L liquid two-phase friction multiplier [-]
Φ_{fr} Friedel two-phase multiplier (and others with respective subscripts) [-]
Φ_G two-phase multiplier factor for the vapor phase [-]
Φ_L two-phase multiplier factor for the liquid phase [-]
Γ condensate flow rate per unit width of wall [kg/ms]
Γ_{evap} liquid flow that has been evaporated when reaching the bottom of the array [kg/m s]
Γ_{feed} liquid flow rate of liquid applied to the top of the array [kg/m s]
Γ_L liquid flow rate per unit length on plate or one side of tube [kg/m s]
$\Gamma(\beta)$ condensate flow rate per unit width at angle β from top [kg/ms]
$\Gamma(N)$ condensate flow rate (on one side) per unit length off bottom of tube N [kg/ms]
$\Gamma_{bottom}(N)$ condensate flow rate (from one side) per unit length off bottom of tube N [kg/ms]
$\Gamma_{top}(N)$ condensate flow rate (from one side) per unit length onto top of tube N [kg/ms]
$\Gamma(z)$ condensate flow rate per unit width at distance z from top [kg/ms]
γ constant for finned tubes [-]
η similarity variable [-]
η_{fin} fin efficiency [-]
$\eta_{surface}$ surface efficiency [-]
φ bulk-to-wall property correction ratio [-]
φ one-half of apex angle of a trapezoidal fin [rad]
κ ratio of droplet heat flux to total heat flux [-]
κ ratio of the temperature rises due to viscous heating and wall heat flux [-]
κ_{lim} limit of ratio of temperature rise [-]
Λ correction factor [-]
λ Baker gas-phase parameter [-]
λ wavelength between bubble departures from interface [m]

λ	friction factor multiplier [-]
λ_{crit}	critical wavelength [m]
λ_d	dangerous wavelength [m]
λ_T	Taylor wavelength [m]
μ	dynamic viscosity [Ns/m^2]
μ_{bulk}	dynamic viscosity at bulk temperature [Ns/m^2]
μ_G	vapor dynamic viscosity [Ns/m^2]
μ_L	liquid dynamic viscosity [Ns/m^2]
μ_{oil}	dynamic viscosity of pure oil [Ns/m^2]
μ_{ref}	dynamic viscosity of pure refrigerant [Ns/m^2]
$\mu_{ref\text{-}oil}$	dynamic viscosity of local refrigerant-oil mixture [Ns/m^2]
μ_{wall}	dynamic viscosity at wall [Ns/m^2]
μ_{water}	dynamic viscosity of water [Ns/m^2]
ν	kinematic viscosity [m^2/s]
ν_L	liquid kinematic viscosity [m^2/s]
$\xi(\pi-\beta)$	function in Rose low finned tube method [-]
θ	similarity variable [-]
θ_{crit}	critical angle of deflection for tube array [radians]
θ_{ctl}	centerline angle around top perimeter of tube [degrees]
θ_{def}	maximum angle of deflection of condensate flowing from tube to tube [radians]
θ_{dry}	dry angle around top perimeter of tube [radians]
θ^*_{dry}	dimensionless dry angle [-]
θ_{ds}	baffle cut angle on shell diameter [degrees]
θ_{max}	dry angle at x_{max} [radians]
θ_{strat}	stratified angle around upper perimeter of the tube to stratified liquid level [radians]
θ^*_{strat}	dimensionless stratified angle [-]
$\Delta\theta$	bubble point temperature rise at interface relative to bulk [K]
$\Delta\theta_{bp}$	boiling range or temperature glide of a mixture [K]
ρ	density [kg/m^3]
ρ	liquid density of refrigerant-oil mixture [kg/m^3]
ρ_{air}	density of air [kg/m^3]
ρ_G	vapor density [kg/m^3]
ρ_G^*	fictitious vapor density [kg/m^3]
ρ_{gc}	density of gas core [kg/m^3]
ρ_H	homogeneous density of fluid [kg/m^3]
ρ_k	density of phase k [kg/m^3]
ρ_L	liquid density [kg/m^3]
ρ_{man}	liquid density of oil according to manufacturer [kg/m^3]
ρ_{oil}	liquid density of oil [kg/m^3]
ρ_{ref}	liquid density of refrigerant [kg/m^3]
ρ_V	vapor density [kg/m^3]
ρ_{water}	density of water [kg/m^3]
σ_{SB}	Stephan-Bolzmann constant [W/m^{2}K^4]
σ	surface tension [N/m]
σ	parameter for aspect ratios of rectangular channels [-]
σ_{water}	surface tension of water [N/m^2]
τ_i	interfacial shear stress [N/m^2]
τ_i^*	dimensionless interfacial shear stress [N/m^2]

τ_i^+	dimensionless interfacial shear stress [N/m^2]
Ω	geometrical function [-]
Ω	intertube spacing factor [-]
ξ_{Ph}	friction factor [-]
χ	dimensionless factor in hydrodynamic developing flow [-]
ψ	correlating parameter of Groeneveld and Delorme [-]
ψ	similarity variable [-]
ψ	surface tension parameter [-]

Subscripts :

1,2…	subscripts of empirical constants
D	droplet
G	vapor
H	homogeneous
k	phase
L	liquid
a	actual
b	bottom of tube
c	centerline
e	equilibrium
f	evaluated at film temperature
fin	fin
top	top of tube
w	wall