

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	Archimedes number [-]
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 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 _B	Chisholm parameter for bubbly flow transition [-]
B _c	baffle cut [%]
B _d	Bond number [-]
B _F	Chisholm parameter for spray flow transition [-]
B _f	empirical constant of Rose [-]
B _o	boiling number [-]
BR	boiling range (or temperature glide) [K]
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 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 [-]
C_2	constant [-]
$C_{\delta o}$	empirical correction factor [-]
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, also Ca_L [m]
Cap	capillary number [-]
Co	confinement 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_{crit}	critical tube 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_{ref}	reference tube diameter [m]
d_p	droplet detachment diameter [m]
dT_{bub}	rise in bubble point temperature [K]

d_{th}	threshold diameter [m]
E	convection enhancement factor [-]
E_2	stratified flow correction factor [-]
E_{mf}	microfin factor [-]
E_{new}	new convection enhancement factor [-]
E_o	Eötvös number [-]
E_{RB}	microfin convection factor [-]
e	empirical constant [-]
e	fin or rib or obstruction height [m]
e	surface roughness [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_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_e	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_L	liquid Froude number [-]
Fr_{so}	Soliman liquid Froude number [-]
F_{pf}	pressure correction factor [-]
F_{round}	correction factor to Grönnerud correlation [-]
F_s	fraction of fin flank area covered by condensate wedge [-]
F_S	Shah factor [-]
F_{sbp}	ratio of bypass area to cross flow area [-]
F_{sf}	surface fluid empirical factor [-]
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 [-]
f	Fanning friction factor [-]
f	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_p	frequency of bubble pair or triplet [1/s]
fpm	fins per meter [m^{-1}]
f_{tp}	two-phase friction factor [-]
f_{trans}	friction factor for transition flow [-]
f_{turb}	friction factor for turbulent flow [-]
G	total mass velocity [kg/m^2s]
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 [-]
g	acceleration due to gravity [$9.81 m/s^2$]
g	empirical exponent [-]
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_{sub}	liquid enthalpy difference with respect to saturation [J/kg K]
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_1	dimensionless parameter [-]
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]
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_{cap}	capillary length [m]
L_{dev}	developing length [m]
L_{dry}	length of dry zone [m]
L_{film}	length of liquid film trapped by bubble [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	length of bubble including any dry zone [m]
L_G	chordal length through vapor phase [m]
L_G	axial length of bubble [m]
L_h	heated length of channel [m]
L_L	length of liquid slug [m]
L_L	chordal length through liquid phase [m]
L_p	length of pair or triplet in elongated bubble flow [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_{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]
M	mass flow rate [kg/s]
M	molecular weight [kg/kmol]
M_L	mass of liquid evaporated [kg]
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 [$\text{kg/m}^2 \text{ s}$]
\dot{m}	mass velocity of fluid at maximum cross-section of bundle [$\text{kg/m}^2 \text{ s}$]
\dot{m}	total mass velocity of liquid and vapor [$\text{kg/m}^2 \text{ s}$]
\dot{m}_{bubbly}	bubbly flow transition mass velocity [$\text{kg/m}^2 \text{ s}$]
\dot{m}_e	equivalent mass velocity [$\text{kg/m}^2 \text{ s}$]
\dot{m}_{dryout}	mass velocity at onset of dryout [$\text{kg/m}^2 \text{ s}$]
\dot{m}_G	mass velocity of vapor [$\text{kg/m}^2 \text{ s}$]
\dot{m}_{high}	mass velocity at transition from annular to stratified-wavy flow [$\text{kg/m}^2 \text{ s}$]
\dot{m}_L	mass velocity of liquid [$\text{kg/m}^2 \text{ s}$]
\dot{m}_{low}	mass velocity at transition from stratified-wavy to stratified flow [$\text{kg/m}^2 \text{ s}$]
\dot{m}_{min}	minimum value of mist flow transition mass velocity [$\text{kg/m}^2 \text{ s}$]
\dot{m}_{mist}	mass velocity at transition from mist flow [$\text{kg/m}^2 \text{ s}$]
\dot{m}_{ref}	reference mass velocity [= 500 $\text{kg/m}^2 \text{ s}$]
\dot{m}_{strat}	mass velocity at transition from stratified-wavy to stratified flow [$\text{kg/m}^2 \text{ s}$]
\dot{m}_{total}	total mass velocity of liquid plus vapor [$\text{kg/m}^2 \text{ s}$]
\dot{m}_w	window mass velocity of fluid [$\text{kg/m}^2 \text{ s}$]
\dot{m}_{wavy}	mass velocity at transition from annular to stratified-wavy flow [$\text{kg/m}^2 \text{ s}$]
$\dot{m}_{\text{wavy(new)}}$	new wavy flow transition mass velocity [$\text{kg/m}^2 \text{ s}$]
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_D	Nusselt number based on droplet diameter [-]
Nu_G	Nusselt number of vapor [-]
Nu_L	liquid Nusselt number [-]
Nu_{mf}	microfin Nusselt number [-]
Nu_D	mean Nusselt number based on tube diameter [-]
Nu_{nb}	nucleate boiling Nusselt number [-]
Nu_r	liquid film Nusselt number [-]
$Nu_{r,lam}$	laminar liquid film Nusselt number [-]
$Nu_{r,sub}$	subcooled liquid film Nusselt number [-]
$Nu_{r,turb}$	turbulent liquid film Nusselt number [-]
Nu_{strat}	local Nusselt number for stratified flow [-]
$Nu(x)$	local Nusselt number [-]
$Nu(z)$	local film Nusselt number [-]
Nu_{D-B}	Dittus-Boelter Nusselt number [-]
Nu_{ft}	internally finned tube Nusselt number [-]
Nu_{tt}	twisted tape Nusselt number [-]
$Nu_{y=\infty}$	twisted tape Nusselt number without twist [-]

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_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]
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 ($p_r = p_{\text{sat}}/p_{\text{crit}}$) [-]
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_{bl}	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_{sat}	wall to bulk saturation pressure difference [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]
$(dp/dz)_{\text{frict}}$	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	exponent [-]
q _o	reference heat flux [W/m^2]
q _b	heat flux through base area [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 _G	heat flux resulting from wall-to-droplet evaporation [W/m^2]
q _L	heat flux resulting from droplet evaporation [W/m^2]
q _{max}	highest heat flux theoretically achievable in evaporation process [W/m^2]
q _o	reference heat flux [W/m^2]
q _{ONB}	heat flux at onset of nucleate boiling [W/m^2]
q _r	radiation heat flux [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	ideal gas constant [8.3143 J/K mol]
R	exponent [-]
R _c	mixture resistance [$\text{m}^2\text{K/W}$]
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 _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* _{Γ}	modified liquid Reynolds number of film [-]

$Re_{\Gamma,trans}$	transition liquid film Reynolds number [-]
Re_{nb}	nucleate boiling Reynolds number [-]
Re_s	swirl Reynolds number [-]
Re_{SG}	vapor superficial Reynolds number [-]
Re_{SL}	liquid superficial Reynolds number [-]
Re_{tp}	two-phase Reynolds number [-]
Ri	Richardson number [-]
r	constant [-]
r	external radius of tube [m]
r	radius from centreline [m]
r	radius of bubble [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	boiling suppression factor
S	velocity ratio [-]
S	vertical pitch between centerline of tubes [m]
S	exponent [-]
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]
ΔT	wall-to-fluid temperature difference [K]
ΔT	wall superheat [K]
ΔT_{bp}	boiling range or temperature glide of mixture [K]
ΔT_{glide}	temperature glide of a zeotropic mixture [K]
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 [-]
ΔT_f	temperature difference across film ($= T_{sat} - T_w$) [K]
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]

ΔT_I	ideal wall superheat for boiling of a 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 [$^{\circ}\text{C}$]
T_s	Rose low finned tube parameter for interfin root area [-]
T_{sat}	saturation temperature [K]
T_{sat}	saturation temperature of pure refrigerant [K]
ΔT_{sat}	wall superheat ($= T_{wall} - T_{sat}$) [K]
T_t	Rose low finned tube parameter for fin tips [-]
T_w	wall temperature [K]
T_{wall}	wall temperature [$^{\circ}\text{C}$]
T_{wall}	wall temperature [K]
T, t	time [s]
t	fin thickness [m]
t	mean thickness of fin [m]
t	twisted tape thickness [m]
t	bubble growth time [s]
t_{dry}	time period that local wall is dry [s]
$t_{dryfilm}$	time period to dryout the entire liquid film at location z [s]
t_{film}	residence time of liquid film at location z [s]
t_G	time period of vapor in bubble and dry zone passing by location z [s]
t_L	time period of liquid passing by location z [s]
t_{root}	thickness at root of fin [m]
t_{tip}	thickness at tip of fin [m]
U	flow velocity [m/s]
U	overall heat transfer coefficient [$\text{W}/\text{m}^2 \text{K}$]
$\langle U \rangle$	cross-sectional averaged drift velocity [m/s]
U_G	superficial velocity of vapor [m/s]
$\langle U_G \rangle$	cross-sectional averaged vapor drift velocity [m/s]
U_{GL}	drift flux [m/s]
$\langle U_{GL} \rangle$	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	velocity in x-direction [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]
$\langle u_G \rangle$	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	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 [-]
We_p	Weber number of pair [-]
We_{SG}	superficial vapor Weber number [-]
We_{SL}	superficial liquid Weber number [-]
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	Martinelli parameter with phases laminar or turbulent [-]
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 [-]
$x_{IB/CB}$	vapor quality at transition from intermittent to annular flow [-]
x_{IA}	vapor quality at transition from isolated bubble to coalesce dominated bubble flow [-]
$x_{CB/A}$	vapor quality at transition from coalesce dominated bubble flow 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	frictional pressure gradient ratio [-]
Y_{Shah}	parameter of Shah [-]
y	exponent in Rohsenow correlation [-]
y	length [m]
y	twist ratio for 180° turn [-]
y	parameter [-]
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_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]

Greek symbols:

α	heat transfer coefficient [$\text{W}/\text{m}^2\text{K}$]
α	mean film heat transfer coefficient on tube array [$\text{W}/\text{m}^2\text{K}$]
α	local perimeter averaged heat transfer coefficient inside a tube [$\text{W}/\text{m}^2\text{K}$]
$\alpha(N)$	heat transfer coefficient on Nth tube [$\text{W}/\text{m}^2\text{K}$]
$\alpha(N=1)$	heat transfer coefficient on top tube [$\text{W}/\text{m}^2\text{K}$]
$\alpha(x)$	local perimeter averaged heat transfer coefficient inside a tube at vapor quality x [$\text{W}/\text{m}^2\text{K}$]
α_b	heat transfer coefficient on bottom of finned tube retaining condensate [$\text{W}/\text{m}^2\text{K}$]
α_{bundle}	local bundle boiling heat transfer coefficient [$\text{W}/\text{m}^2\text{K}$]
α_c	convective condensation heat transfer coefficient [$\text{W}/\text{m}^2\text{K}$]
α_{cb}	convective boiling heat transfer coefficient [$\text{W}/\text{m}^2\text{K}$]
α_{ct}	corrugated tube turbulent heat transfer coefficient [$\text{W}/\text{m}^2\text{K}$]
α_D	convective heat transfer coefficient from vapor-to-droplet [$\text{W}/\text{m}^2\text{K}$]
α_{dryout}	heat transfer coefficient in dryout zone [$\text{W}/\text{m}^2\text{K}$]
α_{eff}	effective condensing coefficient for condensable mixture [$\text{W}/\text{m}^2\text{K}$]
α_f	mean film heat transfer coefficient [$\text{W}/\text{m}^2\text{K}$]
α_f	local film condensing coefficient around non-stratified top perimeter of tube [$\text{W}/\text{m}^2\text{K}$]
α_f	helix angle of microfins [degrees]
$\alpha_f(z)$	local film heat transfer coefficient [$\text{W}/\text{m}^2\text{K}$]
$\alpha_f^+(z)$	dimensionless local film heat transfer coefficient [$\text{W}/\text{m}^2\text{K}$]
$\alpha_f(\beta)$	local film heat transfer coefficient at angle β from top of tube [$\text{W}/\text{m}^2\text{K}$]
$\alpha_f(x)$	local condensing coefficient at vapor quality x [$\text{W}/\text{m}^2\text{K}$]
α_{film}	time averaged heat transfer coefficient of evaporating film [$\text{W}/\text{m}^2\text{K}$]
α_{fin}	heat transfer coefficient on fin [$\text{W}/\text{m}^2\text{K}$]
α_{ft}	finned tube turbulent heat transfer coefficient [$\text{W}/\text{m}^2\text{K}$]
α_{FZ}	Forester-Zuber nucleate boiling heat transfer coefficient [$\text{W}/\text{m}^2\text{K}$]
α_G	turbulent heat transfer coefficient of vapor [$\text{W}/\text{m}^2\text{K}$]
α_{Gt}	forced convection heat transfer coefficient with total flow as vapor [$\text{W}/\text{m}^2\text{K}$]
α_{grav}	gravity-dominated film heat transfer coefficient [$\text{W}/\text{m}^2\text{K}$]
α_I	ideal heat transfer coefficient [$\text{W}/\text{m}^2\text{K}$]
α_I	ideal boiling heat transfer coefficient [$\text{W}/\text{m}^2\text{K}$]
α_I	ideal tube bank heat transfer coefficient [$\text{W}/\text{m}^2\text{K}$]
α_{id}	ideal heat transfer coefficient [$\text{W}/\text{m}^2\text{K}$]
α_{invert}	heat transfer coefficient in inverted annular flow regime [$\text{W}/\text{m}^2\text{K}$]
α_L	liquid only heat transfer coefficient [$\text{W}/\text{m}^2\text{K}$]
α_{Lt}	forced convection heat transfer coefficient with total flow as liquid [$\text{W}/\text{m}^2\text{K}$]
α_{mean}	mean heat transfer coefficient [$\text{W}/\text{m}^2\text{K}$]
α_{mf}	microfin convective boiling heat transfer coefficient [$\text{W}/\text{m}^2\text{K}$]
α_{mist}	mist flow heat transfer coefficient [$\text{W}/\text{m}^2\text{K}$]

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]
$\alpha_{nb,l}$	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]
$\alpha_{\Gamma,turb}$	turbulent falling film heat transfer coefficient [W/m ² K]
$\alpha_{ref-oil}$	flow boiling heat transfer coefficient of refrigerant-oil mixture [W/m ² K]
α_{sh}	shear-dominated film heat transfer coefficient [W/m ² K]
α_{slug}	heat transfer coefficient of a liquid or vapor slug [W/m ² K]
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]
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 [°]
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 [-]
γ	gradient of the superficial bubble velocity [1/s]
$\Delta\delta$	interfacial roughness [m]

δ	liquid film thickness [m]
δ	thickness of twisted tape [m]
δ^*	non-dimensional liquid film thickness [m]
δ_{end}	liquid film thickness at end of bubble [m]
δ_{IA}	liquid film thickness at x_{IA} [m]
δ_{min}	minimum liquid film thickness at dryout [m]
δ_o	liquid film thickness at its formation at nose of bubble [m]
$\Delta\delta$	interfacial wave height [m]
ε	void fraction of vapor [-]
$\langle\varepsilon\rangle$	cross-sectional averaged void fraction of vapor [-]
ε_c	void fraction of vapor at centreline of channel [-]
ε_{c-s}	cross-sectional void fraction of vapor [-]
$\varepsilon_{\text{chordal}}$	chordal void fraction of vapor across channel [-]
ε_H	homogeneous void fraction [-]
ε_{IA}	void fraction evaluated at x_{IA} [-]
$\varepsilon_{\text{local}}$	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 [-]
η	similarity variable [-]
η_{fin}	fin efficiency [-]
η_{surface}	surface efficiency [-]
κ	ratio of droplet heat flux to total heat flux [-]
Λ	correction factor [-]
λ	flow parameter [-]
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_H	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]
$\mu_{\text{ref-oil}}$	dynamic viscosity of local refrigerant-oil mixture [Ns/m ²]
μ_{tp}	two-phase viscosity of vapor-liquid flow [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]
ξ_{Ph}	friction factor [-]
$\xi(\pi-\beta)$	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]
$\Delta\theta_{\text{bp}}$	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_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_{tp}	two-phase density of liquid-vapor flow [kg/m ³]
ρ_V	vapor density [kg/m ³]
ρ_{water}	density of water [kg/m ³]
σ_{SB}	Stephan-Boltzmann constant [W/m ² K ⁴]
σ	surface tension [N/m]
σ_{water}	surface tension of water [N/m ²]
ϕ	bulk-to-wall property correction ratio [-]
ϕ	one-half of apex angle of a trapezoidal fin [rad]
ϕ	flow parameter [-]
τ	time period of pair/triplet generation [s]
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]
Ψ	correlating parameter of Groeneveld and Delorme [-]
Ψ	similarity variable [-]
Ω	geometrical function [-]
Ω	intertube spacing factor [-]

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