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Numerical model of a parallel flow minichannel evaporator with new flow boiling heat transfer correlation

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ABSTRACT

In this paper, a distributed parameter (DP) numerical model with the new proposed flow boiling heat transfer correlation was established for parallel flow minichannel (PFMC) evaporator. DP model validation was made by comparing the measured values obtained on experimental studies, which were conducted under refrigerant mass flow rate range of 34.6–245.6 kg h^{-1} and evaporation pressure of 200–500 kPa. The effects of four different flow boiling heat transfer correlations on DP model performance were investigated. Results showed that the new correlation predicted 99% of experimental data in ± 30% error bands. Moreover, the DP model with the new correlation yielded the mean absolute error (MAE) of 1.5%, 9.1%, 18.8%, 14.2% and 19.8% in prediction of cooling capacity, outlet air temperature, refrigerant superheat, air side and refrigerant side pressure drop, respectively. The presented DP model can be implemented to evaluate the performance of PFMC evaporator, and therefore can save efforts on component and system design and optimization.

Modèle numérique d’un évaporateur à mini canaux à écoulement parallèles avec une nouvelle corrélation du transfert de chaleur par ébullition en écoulement

Mots clés : Paramètre distribué ; Transfert de chaleur par écoulement en ébullition ; Nouvelle corrélation ; Modèle numérique ; Mini canaux à écoulement parallèle ; Évaporateur

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Nomenclature

A	area, m^2
Bo	boiling number
Co	confinement number
c_p	specific heat capacity, $Jkg^{-1}\ K^{-1}$
D_h	hydraulic diameter, mm
d	humidity, $g\ kg^{-1}$
E	enhancement factor
F_d	fin width, mm
F_f	fluid-surface parameter
F_h	fin height, mm
F_p	fin pitch, mm
Fr	Froude number
f	friction factor
G	mass flux, $kg\ m^{-2}\ s^{-1}$
g	gravitational acceleration, ms^{-2}
h	specific enthalpy, $kJ\ kg^{-1}$
i	latent heat of evaporation, $kJ\ kg^{-1}$
j	j factor
k	liquid or vapor
L_l	louver length, mm
L	element length, m
L_p	louver pitch, mm
M	mole mass, $gmol^{-1}$
m	mass flow rate, $kg\ h^{-1}$
n	data number
Pr	Prandtl number
p	pressure, kPa
p_c	critical pressure, kPa
$\triangle p$	pressure drop, Pa or kPa
Q	cooling capacity, W
q	heat flux, Wm^{-2}
Re	Reynolds number
T_l	tube length, m
T_p	tube pitch, m
t	temperature, °C
We	Weber number

X_{tt}	Lockhart–Martinelli parameter
S	suppression factor
u	velocity, ms^{-1}
x	refrigerant quality
α	heat transfer coefficient, $Wm^{-2}\ K^{-1}$
δ	thickness, mm
δf	fin thickness, mm
ζ	data value
θ	angle, degree
λ	thermal conductivity, $Wm^{-1}\ K^{-1}$
μ	viscosity, Pas
ξ	moisture separation coefficient
ρ	density, $kg\ m^{-3}$
σ	surface tension, Nm^{-1}
φ	two-phase multiplier
Ψ	refrigerant state factor

Subscript

a	air side
ac	acceleration
cb	convective boiling
exp	experimental
fr	friction
in	inlet
liq	liquid
nb	nucleate boiling
new	new proposed
out	outlet
pre	predicted
r	refrigerant side
sat	saturated
sp	single phase
spec	specific
tp	two-phase
vap	vapor
w	tube wall

1. Introduction

Compared with conventional evaporators, parallel flow minichannel (PFMC) evaporators with hydraulic diameter in 1 mm range attract much attention because of their superior thermal performance, compact structure, and reduction of refrigerant charge (Qi et al., 2009; Shao et al., 2010). Refrigerant heat transfer characteristics in high surface-to-volume ratio minichannels, especially for the two-phase flow boiling region, are quite different from those in traditional channels (Jokar et al., 2006; Kandlikar, 2002; Thome et al., 2004).

During flow boiling process, the refrigerant quality increases, and flow boiling occurs until refrigerant reaches the superheated state. In general, the flow boiling heat transfer mechanism in minichannels is simplified as a combination of nucleate boiling and convective boiling. The nucleate boiling heat transfer is more prominent than convective flow boiling heat transfer at low qualities while the heat transfer process is dominated by forced convection flow boiling at high qualities, where one function is independent of another one. However, the flow mechanisms can coexist as refrigerant quality increases. Ong and Thome (2011) stated that the nucleate and convective boiling contributions can be superimposed by a very complex mechanism. According to Bertsch et al. (2009b), flow boiling heat transfer coefficients increased with heat flux increase and decreased with hydraulic diameter increase. The increase of saturation pressure led to heat transfer increase (Saitoh et al., 2005). Saitoh et al. (2007) suggested that refrigerant dry out initially occurred on the upper tube due to gravity effect.

Numerous correlations for flow boiling heat transfer prediction have been proposed, which can be divided into four categories: superposition model, selection model, fitting model, and phenomenological model (Bertsch et al., 2009a; Kaew-On et al., 2011; Quibén et al., 2009; Saisorn et al., 2010; Wojtan et al., 2005; Zhang et al., 2004). As for the superposition model, flow