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Research paper

An analysis of the effect of the footprint orientation on the thermal-hydraulic performance of a microchannels heat sink during flow boiling of R245fa

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HIGHLIGHTS

- Experimental analyses of a microchannels heat sink during flow boiling of R245fa.
- The footprint orientation effect on thermal-hydraulic performance was evaluated.
- HP provides highest heat transfer coefficient and VP lowest pressure drops.
- Images of the flow boiling showed thermal instabilities.
- One method for heat transfer coefficient had satisfactory prediction.

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ABSTRACT

The present study concerns an experimental investigation of flow boiling of R245fa in a 50 parallel rectangular 123.3 × 494.2 μm^2 microchannels heat sink. Heat transfer coefficient and pressure drop results were obtained for footprint heat fluxes up to 300 kW/m^2, mass velocities from 300 to 1000 kg/m^2 s, liquid subcoolings at the test section inlet of 5 and 10 °C and saturation temperature of 30 °C. The heat sink performance was evaluated for its footprint area horizontally positioned (HP), its footprint area vertically aligned with the microchannels horizontally positioned (VHP) and its footprint area vertically positioned with upflow through the microchannels (VP). Average footprint heat transfer coefficients up to 30 kW/m^2 °C were obtained. Moreover, for two-phase flow and fixed heat flux, the heat transfer coefficient increases with decreasing mass velocity and liquid subcooling, while the pressure drop increases with increasing mass velocity and decreasing liquid subcooling. The heat sink according to the HP orientation provides higher overall heat transfer coefficients. The highest and lowest pressure drops were observed for the VHP and VP orientations, respectively. The effect of the footprint orientation on the heat transfer coefficient increases with increasing mass velocity and liquid subcooling. Temperature oscillations with higher amplitude and frequency were observed for the VHP orientation. Images of the flow boiling process revealed that bubbles agglomerate in the lower part of the heat sink for the VHP orientation under conditions of high mass velocities. Reverse flows were observed only for HP and VHP footprint orientations. Discontinuities in the boiling curve just before the ONB have occurred simultaneously to bubble nucleation at the outlet plenum. Li and Wu [42] was the best method to predict the heat transfer coefficient data. For pressure drop, the Homogeneous Model using the two-phase viscosity given by Cicchitti et al. [46] presented the best prediction of the experimental results compare with the others predictive methods evaluated, but no one of pressure drop predictive methods evaluated in the present study was accurate enough to predict the R245fa database for flow boiling conditions.

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Nomenclature

A	area [m^2]
c_p	heat capacity [kJ/kg °C]
D_h	hydraulic diameter [m]
dp/dz	pressure drop gradient [kPa/m]
F	enhancement factor [dimensionless]
f	frictional factor [dimensionless]
G	mass velocity [kg/m^2 s]
g	gravitational acceleration [m/s^2]
HP	horizontally positioned [dimensionless]
H	microchannel depth [m]
h	heat transfer coefficient [W/m^2 °C]
i	enthalpy [kJ/kg]
i_{lv}	enthalpy of vaporization [kJ/kg]
k	thermal conductivity [W/mK]
L	length [m]
M	molar mass [kg/Mol]
$\dot{m}$	mass flux [kg/s]
p	absolute pressure [kPa]
p_r	reduced pressure [dimensionless]
$\dot{Q}$	dissipated energy [W]
q''	heat flux [W/m^2]
S	suppression factor [dimensionless]
T	temperature [°C]
$\bar{T}$	average temperature [°C]
t_{film}	liquid film time [s]
t_l	liquid slug time [s]
$t_{max,film}$	maximum liquid film time [s]
t_v	vapor slug time [s]
VHP	vertically oriented with horizontal channels [dimensionless]
VP	vertically positioned with vertical channels [dimensionless]
W	microchannel width [m]
x	vapor quality [dimensionless]
X	Lockhart–Martinelli parameter [dimensionless]
$\bar{x}$	average vapor quality [dimensionless]

Greek symbols

δ_0	liquid film thickness [m]
δ_{end}	final liquid film thickness [m]
δ_{min}	minimum liquid film thickness [m]
Δp	differential pressure [kPa]
ΔT_{sub}	liquid subcooling [°C]
$\Delta\bar{T}$	wall superheating [°C]
μ	dynamic viscosity [Pa s]
ν	kinematic viscosity [Pa s]
ρ	density [kg/m^3]
σ	surface tension [N/m]
τ	elongated bubble period [s]
ξ	fraction of data predicted within an error band of ±30% [%]
η	mean absolute error [%]

Subscripts

1ϕ	single-phase flow
2ϕ	two-phase flow
1	pre-heater inlet
acl	accelerational
adj	adjust
C	convective
ch	channel
cont	contraction
df	differential pressure measurement
eff	effective, effective contact with the fluid
elet	electrical power
end	end
env	environment
exp	expansion
fluid	fluid
ftp	footprint area
film	liquid film
heated	heated
homo	homogeneous model
in or 2	heat spreader inlet
l	liquid-phase
ll	viscous–viscous flow
lo	the two-phase mixture as liquid
NB	nucleate boiling
v	vapor-phase
vo	the two-phase mixture as vapor
real	real
out or 3	heat spreader outlet
plm	inlet and outlet plenum
sat	saturated state
TP	two-phase
wall	wall

Dimensionless numbers

BO	$BO = q''/G \cdot i_{lv}$ boiling number [dimensionless]
Bo	$Bo = g(\rho_l - \rho_g)D_h^2/\sigma$ bond number [dimensionless]
Co	$Co = 1/D_h\sqrt{\sigma/g\cdot(\rho_l-\rho_v)}$ confinement number [dimensionless]
Fr	$Fr = G^2/\rho_l \cdot g \cdot D_h$ Froude number [dimensionless]
Pr	$Pr = c_p \cdot \mu/k$ Prandtl number [dimensionless]
Re	$Re = G \cdot D_h/\mu$ Reynolds number [dimensionless]
Gz	$Gz = L/D_h/Re \cdot Pr$ Graetz number [dimensionless]

1. Introduction

During the last five decades, the electronic industry has experienced an exponential increase of the number of transistors in the microprocessors. This miniaturization process is associated with the need of dissipating extremely high heat fluxes from the microelectronic devices. These circumstances drove the electronic industry and the heat transfer academics to focus on the development of heat sinks capable of meeting such demands. Heat sinks based on single-phase flow through multi parallel micro-scale channels are currently available in the market for replacing air-cooling as a more energy-efficient solution. Besides, heat spreaders based on flow boiling mechanism inside micro-scale channels have been considered as a better alternative to dissipate the very high heat transfer rates from electronic devices because of their compactness and excellent heat transfer performance.

According to Ribatski et al. [1] and Qu and Mudawar [2], flow boiling in small diameter channels presents as advantage over conventional channels the combination of higher surface area in contact with the coolant per volume and superior heat transfer coefficients. Moreover, evaporation in microchannels minimizes temperature gradient along the heat sink length when compared against single-phase cooling. These characteristics allow