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Characterisation of the hydraulic maldistribution in a heat exchanger by local measurement of convective heat transfer coefficients using infrared thermography

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ABSTRACT

A methodology was developed to characterise the heat exchangers' performance decrease due to two-phase flow maldistribution. It consists in measuring the spatial distribution of the local heat transfer coefficients with a rapid, non-invasive and fluid independent method. The method is based on the infrared (IR) thermography measurement of the temperature response to an oscillating heat flux. The amplitude of the measured temperatures is compared to the solution of an analytical model. The problem is solved iteratively to obtain the heat transfer coefficients. This method has been applied to evaluate the uneven phase distribution of an air–water mixture in a compact heat exchanger. The exchanger is composed of seven multiport flat tubes, a vertical downward header and horizontal channels. Experiments were performed for mass flux from 29 kg m^{-2} s^{-1} to 116 kg m^{-2} s^{-1} and for quality from 0.10 to 0.70.

Caractérisation de la mauvaise distribution hydraulique dans un échangeur de chaleur par mesure locale des coefficients de transfert de chaleur utilisant la thermographie infrarouge

Mots clés : Microcanal ; Echangeur de chaleur ; Distribution de l'écoulement ; Expérimentation ; Coefficient de transfert de chaleur local ; Thermographie infrarouge

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Nomenclature

a	thermal diffusivity $a = k/(\rho\, c_p)$, $m^2\ s^{-1}$
c_p	specific heat capacity, $J\ kg^{-1}\ K^{-1}$
D_h	hydraulic diameter, m
f	frequency, Hz
f	friction factor
G	mass flux, $kg.m^{-2}\ s^{-1}$
H	height, m
h	heat transfer coefficient, $W.m^{-2}\ K^{-1}$
I	intensity, A
j	imaginary number such that $j^2 = -1$
k	thermal conductivity, $W.m^{-1}\ K^{-1}$
L	length, m
$\dot{m}$	mass flowrate, $kg\ s^{-1}$
N	number of tubes
Nu	Nusselt number $Nu = h\, D_h/k$
P	heat flowrate, W
Pr	Prandtl number $Pr = \mu\, c_p/k$
$\dot{q}$	heat generation by unit of volume, $W.m^{-3}$
Re	Reynolds number $Re = \rho\, v\, D_h/\mu$
S	surface, m^2
T	temperature, K
th	thickness, m
t	time, s
U	voltage, V
V	volume, m^3
W	width, m
x	quality
ε	minimisation criterion
θ	reduced temperature, K
μ	dynamic viscosity, Pa.s
ρ	density, $kg.m^{-3}$
φ	phase delay, rad
ω	angular pulsation $\omega = 2\pi f$, rad s^{-1}

Subscripts

alt	alternating
c	continuous part
ch	channel
f	fluid
in	inlet
meas	measured
t	tube
w	wall
ω	angular excitation frequency

1. Introduction

Compact brazed aluminium heat exchangers are essential components of refrigerating machines. They are composed of flat tubes on the refrigerant side and louver fins on the air side. The flat tubes are inserted in a header and the heat exchanger is designed for parallel flow. These kinds of heat exchangers are widely used in air-conditioning, due to their higher heat transfer coefficients and their charge reduction compared to conventional heat exchangers. Evaporators, contrary to condensers, are supplied with a two-phase fluid. The phases are unevenly distributed in the channels. According to Mueller and Chiou (1988), and Kitto Jr. and Robertson (1989), the maldistribution in heat exchangers is caused by:

- mechanical design, such as header and channel design, and manufacturing tolerance,
- self-induced maldistribution due to heat transfer,
- difficulties to distribute two-phase flow because of phase separation and flow instability,
- formation of fouling and corrosion.

According to Kulkarni et al. (2004), a bad distribution may result in a performance reduction of up to 20%. Indeed, the presence of little liquid in a channel can promote a dry-out phenomenon, which will reduce drastically the heat transfer performance.

The investigation of maldistribution requires a complex experimental facility, especially if quantitative information has to be obtained. Moreover, most of the available measurement methods are invasive and may alter the measured values. Some authors (Webb and Chung, 2005) underlined that the investigation of geometrical parameters influence on distribution should imply the use of a non-invasive measuring method.

Microchannel heat exchangers are composed of many parallel tubes with reduced sections. These exchangers are already widely used and have the advantage of reducing refrigerant charge, system size, refrigerant pressure drops, air pressure drops, and of enhancing heat transfer. However, in these exchangers, flow distribution is operated by cylindrical headers distributing a large number of parallel channels (Hrnjak, 2002). The efficiency of these heat exchangers, and especially of evaporators, highly depends on the uniformity of the two-phase distribution through the channels.

The most common method to characterise distribution, consists in measuring quality and mass flowrate over the whole heat exchangers. Here, the authors are interested in investigating a new method.

1.1. *Direct methods*

Several experimental studies have been carried out to characterise two-phase flow distribution in microchannel heat exchangers in order to provide essential information for a better design. Bernoux (2000), and later Ahmad et al. (2009), used a heavily instrumented experimental loop. It was composed of eight coriolis flow meters and eight differential pressure transducers to study the distribution of two-phase R-113 and HFE-7100 in eight channels. This configuration requires a modified heat exchanger without outlet header and is only suited for a few channels. The same protocol has also been used by Poggi et al. (2009) for two-phase HFE-7100.