



Flow patterns and heat transfer in a square cross-section micro condenser working at low mass flux



G. El Achkar^{a,b}, M. Miscevic^{a,b,*}, P. Lavieille^{a,b}, J. Lluc^{a,b}, J. Hugon^c

^a Université de Toulouse, UPS, INPT, LAPLACE (Laboratoire Plasma et Conversion d'Energie), 118 route de Narbonne, F-31062 Toulouse cedex 9, France

^b CNRS, LAPLACE, F-31062 Toulouse, France

^c Thales Alenia Space, Cannes, France

ARTICLE INFO

Article history:

Received 14 December 2011

Accepted 21 November 2012

Available online 13 December 2012

Keywords:

Condensation

Two-phase flow

Narrow channel

Square cross-section

Flow patterns

Heat transfer

Isolated bubbles zone

Void fraction

Bubbles detachment

ABSTRACT

Flow patterns and heat transfer were investigated during condensation of *n*-pentane in an air-cooled square cross-section micro condenser. The test section consisted of a borosilicate square microchannel, of inner and outer edges 553 μm and 675 μm , respectively, and of a length 208 mm. The transparency of the microchannel walls allowed the visualization of the phases distribution and the different condensation flow regimes. Different mass velocities ranging between 3 and 15 $\text{kg m}^{-2} \text{s}^{-1}$ were imposed. Three main flow regimes were identified: annular regime, intermittent regime, and spherical bubbles regime. A specific experimental procedure was developed, based on bubbles tracking, in order to determine accurately the hydraulic and thermal parameters profiles in the isolated bubbles zone, such as the time-averaged void fraction profile $\bar{\alpha}(z)$ and the time-averaged vapour quality profile $\bar{x}(z)$, according to the axial position in the microchannel. Thanks to energy balance, the time-averaged liquid temperature profile $\bar{T}_l(z)$ in the isolated bubbles zone was determined. A significant temperature difference between the liquid and vapour phases was highlighted. Therefore, the latent and total heat fluxes released in this zone were quantified and compared to each other. Besides, the relationship between the void fraction and the vapour quality in the spherical bubbles zone was determined and compared to existing void fraction models. Finally, the bubbles detachment frequency was determined. A relationship between this frequency and the mass velocity was proposed.

© 2012 Elsevier Ltd. All rights reserved.

1. Introduction

The increase in the power dissipated in telecommunication satellites has gradually led to thermal control problems, which become critical nowadays. In a long-term perspective and to anticipate on the future challenges, one solution is to increase the radiation temperature by the use of a cooling cycle of evaporation, compression, condensation, and expansion. The conditions which under operate condensers affect significantly the performance and the stability of these two-phase systems. The gravitational field greatly influences the distribution of liquid and vapour in the condensers. In a space application context, it is important to

operate in condition of low impact of the gravity and for a wide range of mass velocity going from 0 to several hundreds of $\text{kg m}^{-2} \text{s}^{-1}$. A possible solution, in terrestrial environment, is to reduce the size of the channels [1].

Investigations available in the literature were widely concentrated on condensation flows at high mass velocities of several hundreds of $\text{kg m}^{-2} \text{s}^{-1}$, and particularly concerned flow regimes, heat transfer, and pressure drops. Three main flow regimes were identified for various channel diameters, shapes, and refrigerants: the annular regime, the intermittent regime or elongated bubbles regime, and the spherical bubbles regime [1–7].

The annular regime was mostly studied, particularly from a heat transfer point of view. Indeed, many experimental and numerical studies were conducted in order to determine the internal heat transfer coefficient between the refrigerant and the internal walls of the channel. Matkovic et al. [8], Del Col et al. [9], Wang Wei-Wen et al. [10], Koyama et al. [11], Baird et al. [12], and Kim et al. [13] measured experimentally the internal heat transfer coefficients using the energy balance, for different refrigerants, mass velocities, hydraulic diameters and shapes of the channel. Besides, numerical

* Corresponding author. Université de Toulouse, UPS, INPT, LAPLACE (Laboratoire Plasma et Conversion d'Energie), 118 route de Narbonne, F-31062 Toulouse cedex 9, France.

E-mail addresses: georges.elachkar@laplace.univ-tlse.fr (G. El Achkar), marc.miscevic@laplace.univ-tlse.fr (M. Miscevic), pascal.lavieille@laplace.univ-tlse.fr (P. Lavieille), jacques.lluc@laplace.univ-tlse.fr (J. Lluc), julien.hugon@thalesaleniaspace.com (J. Hugon).

Nomenclature		y	vertical position in the channel (m)
		z	axial position in the channel (m)
		<i>Greek symbols</i>	
A	cross-section area of the channel (m ²)	α	void fraction
a	edge of the channel (m)	λ	thermal conductivity (W m ⁻¹ K ⁻¹)
Bo	Boiling number	ρ	density (kg m ⁻³)
c_p	specific heat (J kg ⁻¹ K ⁻¹)	τ	duration of the experiment (s)
e	wall thickness (m)		
G	mass velocity (kg m ⁻² s ⁻¹)	<i>Subscripts and superscripts</i>	
h	heat transfer coefficient (W m ⁻² K ⁻¹)	atm	atmospheric
l_v	latent heat of vaporisation (J kg ⁻¹)	av	averaged
L	length (m)	b	bubble
$\dot{m}$	mass flow rate (kg s ⁻¹)	ext	external
N	total number of bubbles	g	global
P	pressure (Pa)	i	variable
R	radius (m)	int	internal
S	velocity ratio	l	liquid
t	time (s)	sat	saturation
T	temperature (°C)	v	vapour
U	velocity (m s ⁻¹)	w	wall
V	volume (m ³)		
x	vapour quality		

models and theories were developed in order to predict the condensation heat transfer in mini- and microchannels [14–17]. These models and theories were based on the determination of the interface profiles (i.e. liquid films thicknesses), and encountered a wide range of refrigerants, mass velocities, hydraulic diameters and shapes of the channel.

Very few studies were conducted on the intermittent regime. Odaymet and Louahlia-Gualous [18] determined experimentally the local heat transfer coefficient between the elongated bubble and the internal walls of a silicon square microchannel of hydraulic diameter 350 μm . Garimella et al. [19] developed an experimentally validated model for two-phase flow pressure drops in the intermittent regime inside circular and non-circular microchannels.

A modest number of studies on the spherical bubbles regime is available in the literature. Most of them were conducted for vapour bubbles collapse process in academic situations (i.e. collapse in an infinite liquid medium, in a motionless or in a convective situation considering homogeneous liquid velocity). The bubble collapse was found to be controlled by two main mechanisms: the inertia and the heat transfer. On the one hand, with high liquid subcooling, bubbles rapidly collapse, satisfying the Rayleigh solution for the collapse of a spherical cavity in an infinite liquid in which the process is controlled by the inertia of the surrounding liquid [20]. On the other hand, if subcooling is relatively low, the bubble collapse period is longer and the process is controlled by the heat transfer in the vicinity of the interface [21–23]. However, it can be affected by many parameters, such as the motion of the bubble relative to the surrounding liquid and its initial radius and shape [24–29].

For much lower range of mass velocity of the order of several to tens of kg m⁻² s⁻¹, less studies have been conducted. Hence, investigations on condensation flows in microgravity for this range of mass velocity, for different shapes of the channel and refrigerants, are required. In this context, an experimental apparatus was designed and constructed [7,30]. This apparatus allowed the visualization of the phases distribution by a shadowgraph technique considering convective condensation flow inside a capillary channel at very low mass velocity. In such reduced size of channel, gravity effects are weak compared to capillary effects. The phases distribution is then nearly axisymmetric. In a first step, a circular cross-section microchannel of internal diameter 560 μm was used.

The purpose of the study was the determination of the different regimes taking place in such a capillary channel and the transitions between them, as well as the determination of the heat transfer laws involved in each of these regimes. In addition to the experimental approach, Miscevic et al. had developed a model providing a good simulation of the capillary regime (consisting of a single continuous interface) in the steady state [31]. The model was generalized to unsteady situations by Piaud et al. [32]. Later on, the experimental apparatus was enhanced. Thermal characterization and modeling of the isolated bubbles regime were then performed for the same circular channel [33]. Besides, thermal and hydraulic characterizations were experimentally conducted in a multi-channel condenser (consisted of 4 parallel circular channels having the same internal diameter 560 μm) at the same order of magnitude of mass velocity [34]. In a second step, and in order to highlight the effect of the surface tension on the flow regimes and heat transfers, the circular cross-section channel was replaced by a square cross-section channel of internal hydraulic diameter 553 μm . The purpose was to follow the same procedure considered for the circular channel.

A study conducted on the condensation inside the square cross-section microchannel is presented in this paper. A characterization and a quantification of the heat transfers in the isolated bubbles zone were achieved. The experimental results were then compared to prediction models available in the literature. Finally, the bubbles detachment frequency was determined.

2. Experiments

2.1. Experimental apparatus

2.1.1. Test rig

The test rig used was depicted in Fig. 1. It consisted of an entrance tank connected to a thermostated bath, a temperature controlled enclosure, a micrometric valve, a test section, a precision balance, a high-speed camera, an air-conditioning system, an exit tank, and a data acquisition system. Photographs of the main components of the experimental apparatus were reported in Fig. 2. Details of the setup are available in Ref. [34].

The entrance tank consisted of two coaxial cylinders. The internal one contained the fluid used as refrigerant (*n*-pentane,

Download English Version:

<https://daneshyari.com/en/article/7050156>

Download Persian Version:

<https://daneshyari.com/article/7050156>

[Daneshyari.com](https://daneshyari.com)