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Flow pattern map, heat transfer and pressure drops during evaporation of R-1234ze(E) and R134a in a horizontal, circular smooth tube: Experiments and assessment of predictive methods

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ABSTRACT

This paper presents experimental results for local heat transfer coefficients, adiabatic frictional pressure gradients and two-phase flow regimes with the low-GWP refrigerant R-1234ze(E), compared to Hydro-Fluoro-Carbon refrigerant R-134a in the same conditions.

In particular the results refer to an experimental investigation carried out in a circular smooth tube of 6.00 mm of inner diameter, for saturation temperatures between −2.9 °C and 12.1 °C, mass fluxes between 146 and 520 kg m^{-2} s^{-1} and heat fluxes between 5.0 and 20.4 kW m^{-2}. These experimental results are compared to those for R-134a at the same operating conditions.

Moreover, an assessment of predictive methods is provided for local heat transfer coefficients and frictional pressure gradients; also a direct comparison of flow regimes visualizations for R-1234ze(E) with a flow pattern map available in literature is presented.

Configuration de l'écoulement, transfert de chaleur et chutes de pression pendant l'évaporation de R-1234ze(E) et de R134a à l'intérieur d'un tube lisse circulaire : expériences et évaluation des méthodes prévisionnelles

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Nomenclature

Latin letters

D	diameter (m);
G	refrigerant mass flux (kg m^{-2} s^{-1});
h	local heat transfer coefficient (W m^{-2} K^{-1});
k	thermal conductivity (W m^{-1} K^{-1})
i	specific enthalpy (J kg^{-1});
i_{lv}	specific latent heat of vaporization (J kg^{-1});
I	internal;
L	length of the tube
N_{acq}	number of acquisitions
p	pressure (bar);
q	heat flux (W m^{-2});
R	electrical resistance (Ω);
Q	thermal power (W);
sd	standard deviation (%);
t	temperature (°C);
T	temperature (K);
x	vapor quality;

Greeks

ε_n	error (%);
$\bar{\varepsilon}$	mean error (%);
$\lvert\bar{\varepsilon}\rvert$	mean absolute error (%);
$\lambda_{30\%}$	percentage of experimental points predicted within ±30%;
ρ	density (kg m^{-3});
μ	dynamic viscosity (Pa s);
σ	surface tension (N m^{-1})

Subscripts

ATS	referred to adiabatic test section;
bott	referred to bottom position;
critical	referred to critical point
DTS	referred to diabatic test section;
exp	experimental;
i	inner;
IA	intermittent/annular flow regimes transition;
l	referred to liquid phase;
left	referred to left position;
M	referred to measurement section M;
o	outer;
r	reduced;
right	referred to right position;
sat	saturation;
top	referred to top position
v	referred to vapor phase;
w	wall.

1. Introduction

The strong restriction concerning the use of chlorine and high-Global Warming Potential (GWP) refrigerants by the recent international regulations involved great effort by refrigerant industry to find suitable alternatives. In particular, the Regulation (EC) No. 842/2006 and the Directive 2006/40/EC state that air-conditioning of new vehicles must use refrigerants with GWP less or equal than 150.

One of the most promising alternatives are the Hydro-Fluoro-Olefines (HFO) refrigerants. This new generation of refrigerants is chlorine free (zero ODP) with very low GWP with respect to most of HFCs (e.g. R-134a with a GWP of 1300) and works at very lower pressures at typical saturation temperatures in refrigeration, air-conditioning and heat pump applications than other alternatives (like CO_2 or HFC mixtures).

Preliminary studies for R-1234ze(E) and o HFO refrigerants (R-1234yf) showed that they are less toxic and flammable than hydrocarbons (Brown et al., 2009; Takizawa et al., 2009; Zyhowski and Brown, 2011), hence their characteristics make them attractive not only for vehicle air-conditioning, but also for air-conditioning systems, refrigeration systems and heat pumps (Brown et al., 2009; Koyama et al., 2010; Lee and Jung, 2011; Zilio et al., 2011).

Most of the studies available in literature on R-1234ze(E) and other HFO refrigerants are about their thermodynamic properties (Akasaka et al., 2010; Tanaka and Higashi, 2010; Brown et al., 2010), showing that their characteristics are very similar to those of R-134a. Table 1 summarizes general characteristics, thermodynamic and transport properties of R-1234ze(E) and R-134a. While for R-134a, HFC mixtures and other alternative refrigerants (natural fluids and their mixtures), the heat transfer characteristics during flow boiling have been widely studied (see for example Greco and Vanoli, 2005a, 2005b, 2005c; Mastrullo et al., 2009, 2012; Grauso et al., 2011; Thome et al., 2008; Thome and Ribatski, 2005), for HFOs there are very few data available in literature. In particular, some works investigated the heat transfer characteristics during condensation for R-1234yf (Del Col et al., 2010; Park et al., 2011a; Hossain et al., 2012), and R-1234ze(E) in a vertical multiport tube (Park et al., 2011b), and others the nucleative boiling characteristics of R-1234yf (Park and Jung, 2010). Very few works can be found on flow boiling characteristics of R-1234yf (Saitoh et al., 2011) and of R-1234ze(E) (Tibiriçá et al., 2012), however those concern only small diameter tubes. In particular Tibiriçá et al. (2012) investigated the flow boiling characteristics (heat transfer coefficients, critical heat flux and flow pattern transitions) of R-1234ze(E) in circular channels of 1.0 and 2.2 mm of inner diameters for saturation temperatures varying from 25 °C to 35 °C over wide ranges of mass flux and heat flux.

Recently Padilla et al. (2011) presented a work with experiments reporting flow regimes and two-phase pressure