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Saturated flow boiling of HFC134a and its low GWP substitute HFO1234ze(E) inside a 4 mm horizontal smooth tube

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A B S T R A C T

This paper presents the comparative analysis of HFO1234ze(E) and HFC134a during vaporisation inside a 4 mm smooth tube. The experimental tests were carried out at three different saturation temperatures (10, 15, and 20 °C) at increasing vapour quality up to incipient dryout to evaluate the specific contribution of heat flux, refrigerant mass flux, mean vapour quality, and saturation temperature (pressure). The heat transfer coefficients have a positive slope versus vapour quality and the slope increases with refrigerant mass flux and decreases with heat flux. Saturation temperature (pressure), refrigerant mass flux and mean vapour quality have a remarkable impact on the frictional pressure drop of both HFO1234ze(E) and HFC134a whereas the effect of heat flux appears marginal or negligible. Convective boiling seems to be the prevailing heat transfer regime in the present experimental tests. HFO1234ze(E) exhibits heat transfer coefficients similar to HFC134a and slightly higher frictional pressure drops.

Ébullition en écoulement saturé de HFC134a et de son substitut à faible GWP HFO1234ze(E) à l'intérieur d'un tube horizontal lisse

Mots clés : Ébullition ; GWP ; HFC134a ; HFO1234ZE(e)

1. Introduction

Nowadays, the substitution of HFC134a with low GWP refrigerants is one of the most important challenges for refrigeration and air conditioning. The possible substitutes include natural refrigerants, such as HC600 (Butane) and HC600a (Isobutane), and also synthetic refrigerants, such as HFO1234yf and HFO1234ze(E).

The HC refrigerants exhibit very low GWP, 3 and 4 for HC600a and HC600, respectively, good thermodynamic and transport properties, and pressure and volumetric performance very

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Nomenclature

A	heat transfer area of the measurement section [m^2]
d	tube diameter [m]
f.s.	full scale
G	refrigerant mass flux [kg $m^{-2}s^{-1}$]
h	heat transfer coefficient [W m^{-2} K^{-1}]
J	specific enthalpy [J kg^{-1}]
k	coverage factor
L	length of the measurement section [m]
p	pressure [Pa]
Q	heat flow rate [W]
q	heat flux [q = Q / A, Wm^{-2}]
R_a	arithmetic mean roughness (ISO4271/1) [μm]
R_p	roughness (DIN 4762/1) [μm]
T	temperature [K (°C)]
X	vapour quality [$X = (J - J_L) / \Delta J_{LG}$]

Greek symbols

Δ	difference
ΔJ_{LG}	latent heat of vaporisation [J kg^{-1}]

Subscripts

a	momentum
c	local
f	frictional
g	gravity
LG	liquid vapour phase change
m	mean value
r	refrigerant
sat	saturation
t	total

similar to HFC134a. The major drawback of HC refrigerants is their high flammability, being classified as class A3 according to ASHRAE (ASHRAE, 2013). Also, some HFO refrigerants present mild flammability, being classified as class A2L (ASHRAE, 2013). In fact, it is very difficult to find low GWP substitutes for traditional HFC refrigerants with no flammability, as a weak chemical stability and/or a large chemical reactivity are necessary to obtain low GWP.

In particular, HFO1234ze(E) seems to be a very promising substitute for HFC134a, showing a GWP lower than 1 together with pressure and volumetric properties close to those of HFC134a.

Boiling heat transfer performances of HFO1234ze(E) were already investigated in the open literature with reference to different types of heat exchangers and heat transfer surfaces. Hossain et al. (2013) analyzed HFO1234ze(E) saturated boiling inside a 4.35 mm horizontal smooth tube with a saturation temperature from 5 to 10 °C, a refrigerant mass flux varying from 150 kg m^{-2} s^{-1} to 445 kg m^{-2} s^{-1} over the vapour quality range from 0.00 to 1.00. Refrigerant HFO1234ze(E) was compared against HFC32, HFC410A and the zeotropic mixture HFO1234ze(E)/HFC32 (55/45 mass %).

Vakili-Farahani et al. (2013) carried out experimental measurements on upward flow boiling in a flat aluminium multiport tube with a hydraulic diameter of 1.4 mm comparing HFO1234ze(E) to HFC245fa.

Grauso et al. (2013) investigated HFO1234ze(E) and HFC134a local heat transfer coefficients, frictional pressure drops and flow regimes during vaporisation inside a 6 mm smooth tube. The saturation temperatures were varied between −2.9 °C and 12.1 °C, the mass fluxes between 146 and 520 kg m^{-2} s^{-1} and heat fluxes between 5.0 and 20.4 kW m^{-2}.

Kondou et al. (2013) studied HFO1234ze(E), HFC32 and the zeotropic mixture HFO1234ze(E)/HFC32 flow boiling in a 5.21 mm microfin tube at a saturation temperature of 10 °C with heat fluxes of 10 and 15 kWm^{-2}, and mass fluxes from 150 to 400 kg $m^{-2}s^{-1}$.

Longo et al. (2014) investigated the performance of a heat pipe heat exchanger consisting of 12.7 mm microfin tubes operating with HFO1234ze(E) and HFC134a. The performance of the heat exchanger operated with the low GWP refrigerant HFO1234ze(E) is equivalent to that operated with the traditional refrigerant HFC134a.

Mancin et al. (2014) and Diani et al. (2015) reported an experimental study on HFC134a, HFO1234ze(E) and HFO1234yf flow boiling inside a 5 PPI copper foam. The experimental measurements were carried out at a constant saturation temperature of 30 °C with heat fluxes from 50 to 100 kWm^{-2}, refrigerant mass fluxes between 50 and 200 kg $m^{-2}s^{-1}$, and vapour quality from 0.2 to 0.95.

Diani et al. (2014) presented an experimental study of HFO1234ze(E) flow boiling inside a 3.4 mm ID microfin tube. The experimental measurements were performed at a constant saturation temperature of 30 °C, by varying the refrigerant mass velocity between 190 and 940 kg $m^{-2}s^{-1}$, the vapour quality from 0.2 to 0.99 at three different heat fluxes: 10, 25, and 50 kW m^{-2}.

Righetti et al. (2015) carried out the comparative performance analysis of the low GWP refrigerants HFO1234yf, HFO1234ze(E) and HC600a inside a commercial roll-bond evaporator for household refrigerators. Each of the low GWP refrigerants tested can be considered a good substitute for the traditional refrigerant HFC134a, provided that the compressor displacement is adjusted to deliver the proper refrigerant mass flow rate.

Longo et al. 2016b measured the heat transfer coefficients and pressure drops during HFO1234ze(E) vaporisation inside a small commercial BPHE and compared this refrigerant to HFO1234yf and HFC134a. HFO1234ze(E) exhibits heat transfer coefficients very similar to HFC134a and HFO1234yf and frictional pressure drops slightly higher than HFC134a and HFO1234yf.

This paper presents the comparative analysis of HFC134a and HFO1234ze(E) during saturated flow boiling inside a 4 mm horizontal smooth tube: the effects of heat flux, refrigerant mass flux, mean vapour quality and saturation temperature (pressure) are investigated separately to rank the superposed effects of different heat transfer regimes (nucleate boiling or/and forced convection boiling).

2. Experimental measurements and data reduction

The experimental facility, shown in Fig. 1, consists of three different loops: one for refrigerant and two for the secondary fluids