INTERNATIONAL JOURNAL OF REFRIGERATION 36 (2013) 2366–2378

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Flow boiling of non-azeotropic mixture R32/R1234ze(E) in horizontal microfin tubes

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ARTICLE INFO

Article history:
Received 30 April 2013
Received in revised form
9 July 2013
Accepted 11 July 2013
Available online 24 July 2013

Keywords:
Flow boiling
Heat transfer
Pressure drop
Microfin tube
Non-Zeotropic mixture
GWP

ABSTRACT

Flow boiling of a potential refrigerant R32/R1234ze(E) in a horizontal microfin tube of 5.21 mm inner diameter is experimentally investigated. The heat transfer coefficient (HTC) and pressure drop are measured at a saturation temperature of 10 °C, heat fluxes of 10 and 15 kW m^{-2}, and mass velocities from 150 to 400 kg m^{-2} s^{-1}. The HTC of R1234ze(E) is lower than that of R32. Degradation in the HTC of the R32/R1234ze(E) mixture is significant; the HTC is even lower than that of R1234ze(E). The HTC is minimized at the composition 0.2/0.8 by mass, where the temperature glide and the mass fraction distribution are maximized. A predicting correlation based on Momoki et al. (1995) associated with the correction methods of Thome (1981) to consider the mass transfer resistance and Stephan (1992) to consider the additionally required sensible heat is proposed and validated with the experimental results.

Écoulement en ébullition d’un mélange non-azéotropique de R32 et de R1234ze dans des tubes horizontaux à micro-ailettes

Mots clés : Écoulement en ébullition ; Transfert de chaleur ; Chute de pression ; Tube micro aileté ; Frigorigènes non-azéotropiques ; GWP

1. Introduction

R1234ze(E), trans-1,3,3,3-tetrafluoro-1-propene, is anticipated to be an environment-friendly refrigerant for air conditioners because of its zero ozone depletion potential (ODP) and extremely low (less than 10) global warming potential (GWP). However, in recent studies, it was found that the coefficient of performance (COP) and the capacity of heat pump cycles using

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http://dx.doi.org/10.1016/j.ijrefrig.2013.07.009

Nomenclature

A_{act}	actual interior surface area (m^2)
C_{ir}	empirical constant related to interfacial resistance (-)
Cp	isobaric heat capacity (J kg^{-1} K^{-1})
D_{12}	mutual diffusion coefficient (m^2 s^{-1})
D_{be}	bubble departure diameter (m)
D_o	outer diameter (m)
F	Reynolds number factor (m)
G	mass velocity based on (kg m^{-2} s^{-1})
Ja^*	modified Jacob number (–)
N_{Sn}	Scriven number (–)
P	pressure (Pa)
Pr	Prandtl number (–)
Q	heat transfer rate (W)
La	Laplace constant (–)
Re	Reynolds number (–)
T	temperature (°C)
V	volumetric flow rate (m^3 s^{-1})
W	mass flow rate (kg s^{-1})
X	mass fraction in liquid phase or circulation composition by mass (–)
$\tilde{X}$	mole fraction in liquid phase (–)
$\tilde{Y}$	mole fraction in vapor phase (–)
a	thermal diffusivity (m^2 s^{-1})
d_{eq}	equivalent inner diameter (m)
h	specific enthalpy (J kg^{-1})
q	heat flux (W m^{-2})
x	thermodynamic vapor quality (–)

Greek symbols

X_{tt}	Lockhart–Martinelli parameter for turbulent flow (–) $= [(1-x)/x]^{0.9}(\rho_V/\rho_L)^{0.5}(\mu_L/\mu_V)^{0.1}$
ΔZ	tube length (m)
Δh_{LV}	latent heat of vaporization (J kg^{-1})
α	heat transfer coefficient (W m^{-2} K^{-1})
β	lead angle (rad)
ε	bias (–)
η_A	surface enlargement ratio (–)
λ	thermal conductivity (W m^{-1} K^{-1})
μ	viscosity (Pa•s)
ρ	density (kg m^{-3})
σ	surface tension (N m^{-2})
σ_{dev}	standard deviation (–)

Subscripts

1	the more volatile component, R32
2	the less volatile component, R1234ze(E)
AH	after heater
DP	distance between pressure taps
H_2O	water
L	liquid
R32	R32
TP	two phase
TS	test section
V	vapor
max	maximum
min	minimum
act	actual
bub	bubble point, or bubble
cal	calculation
cv	forced convection contribution
dew	dew point
eq	equivalent
exp	experiment
i	inlet
loss	heat loss to ambient
mix	mixture
nb	nucleate boiling contribution
o	outlet
pb	pool boiling
r	refrigerant
sat	saturation
tube	test tube
wi	interior tube wall
wo	exterior tube wall
α	active heat transfer length

R1234ze(E) are significantly lower than those of the most widely used refrigerant, R410A. The main causes are the small latent heat and vapor density of R1234ze(E). To improve the COP and capacity, in the latest literature (e.g., Koyama et al., 2010a), it was attempted to blend R1234ze(E) into another refrigerant, R32. Because of its large latent heat and relatively low GWP of 675, R32 was selected as a second component to be blended with R1234ze(E). As the result of their drop-in test with R32/R1234ze(E) 0.5/0.5 by mass, Koyama et al. (2010a) concluded that the tested binary mixture achieved a superior COP at some operating conditions, and this binary mixture is the most promising candidate to replace R410A.

As mentioned in many previous studies (e.g., Jakobs and Kruse, 1978; McLinden and Radermacher, 1987), exergy loss in heat exchangers can be minimized by utilizing the temperature glide of zeotropic mixtures. Whereas, as investigated in numerous heat transfer studies, there is severe degradation in the heat transfer coefficient (HTC) due to the volatility difference.

For instance, the flow boiling HTC of binary mixtures R152a/R13B1, R22/R114, and R12/R152a in a horizontal smooth tube of 9 mm inner diameter (ID) were experimentally provided by Ross et al. (1987), and Jung et al. (1989a, 1989b). Similarly, other binary mixtures R846/R12 and R116/134a were tested with a smooth tube of 14 mm ID by Niederkrüger et al. (1992, 1994), and Wettermann and Steiner (2000). Furthermore, HTC data of R32/R134a and R290/R600a in a smooth tube of 7.7 mm ID were reported by Shin et al. (1997). Thus, abundant variations of the combinations were tested for horizontal smooth tubes. The experimental results showed a drastic decrease in the HTC of the zeotropic binary mixtures compared with the components. The cause of this heat transfer degradation is typically called mass transfer resistance. As the discussion for the roles of the temperature glide and the concentration distribution in the mass transfer resistance advanced, a heat transfer model was developed. Murata and Hashizume (1993), Niederküger and Steiner (1994), Jung and Radermacher (1993), Takamatsu et al. (1993a, 1993b),