INTERNATIONAL JOURNAL OF REFRIGERATION 33 (2010) 1356–1369

available at www.sciencedirect.com

journal homepage: www.elsevier.com/locate/ijrefrig

Flow condensation pressure drop characteristics of R410A–oil mixture inside small diameter horizontal microfin tubes

Xiangchao Huang [a], Guoliang Ding [a,*], Haitao Hu [a], Yu Zhu [a], Yifeng Gao [b], Bin Deng [c]

[a] Institute of Refrigeration and Cryogenics, Shanghai Jiaotong University, Shanghai 200240, China
[b] International Copper Association Shanghai Office, Shanghai 200020, China
[c] Institute of Heat Transfer Technology, Golden Dragon Precise Copper Tube Group Inc., Shanghai 200135, China

ARTICLE INFO

Article history:
Received 15 November 2009
Received in revised form
22 May 2010
Accepted 29 May 2010
Available online 9 June 2010

Keywords:
Heat exchanger
Condenser
Microfin tube
Mixture
R410A
Oil
Pressure drop
Coefficient
Friction

ABSTRACT

Flow condensation pressure drop characteristics of R410A–oil mixture inside small diameter (5.0 mm and 4.0 mm O.D.) horizontal microfin tubes were investigated experimentally covering nominal oil concentrations from 0% to 5%. The research results indicate that, comparing with the frictional pressure drop of pure R410A, the frictional pressure drop of R410A–oil mixture may decrease by maximum of 18% when the vapor quality is lower than 0.6, and increase by maximum of 13% when the vapor quality is higher than 0.6. A new frictional pressure drop correlation for R410A–oil mixture flow condensation inside microfin tubes is developed based on the refrigerant–oil mixture properties, and can agree with 94% of the experimental data within a deviation of −30% to +30%.

Caractéristiques de chute de pression lors de la condensation en écoulement d’un mélange de R410A et d’huile à l’intérieur de tube à micro-ailettes de faible diamètre

Mots clés : Échangeur de chaleur ; Condenseur ; Tube microailеté ; Mélange ; R410A ; Huile ; Chute de pression ; Coefficient ; Frottement

* *Corresponding author*. Tel.: +86 21 34206378; fax: +86 21 34206814.
E-mail address: glding@sjtu.edu.cn (G. Ding).

0140-7007/$ – see front matter
doi:10.1016/j.ijrefrig.2010.05.019

Nomenclature

b	coefficient in Eq. (16)
Cp	isobaric specific heat (J kg^{-1} K^{-1})
d	tube diameter (m)
f	frictional coefficient
g	gravitational acceleration
G	mass flux (kg m^{-2} s^{-1})
h	specific enthalpy (J kg^{-1})
i_{fg}	latent heat of condensation (J kg^{-1})
L	length of test tube (m)
m	mass flow rate (kg s^{-1})
n	coefficient in Eq. (16)
δP	pressure drop (Pa)
PF	penalty factor for pressure drop
Q	heat flow rate (W)
Re	Reynolds number
s	specific gravity
T	temperature (°C)
x	vapor quality
X_{tt}	Martinelli parameter

Greek symbols

ε	void fraction
λ	thermal conductivity (W m^{-1} K^{-1})
μ	dynamic viscosity (Pa s)
ρ	density (kg m^{-3})
σ	surface tension (N m^{-1})
ω	oil concentration
Φ	two-phase frictional multiplier

Subscripts

a	pure refrigerant in microfin tube
a′	refrigerant–oil mixture in microfin tube
frict	frictional
Goto	Goto et al. correlation
h	hydraulic
ho	homogeneous
in	inlet
L	liquid
lo	liquid phase with total flow rate
local	local
m	mixing chamber
M–H	Müller-Steinhagen and Heck correlation
mom	acceleration
no	nominal
o	oil
out	outlet
pre	pre-condenser
r	refrigerant
s	pure refrigerant in smooth tube
test	test section
total	total
tp	two-phase
V	vapor

1. Introduction

For room air conditioners produced in recent years, microfin tubes with 9.52 mm O.D. or larger diameters are not widely applied as before, and 7.0 mm O.D. microfin tubes become the most commonly used tubes. However, in order to reduce material cost, charge inventory and refrigerant leakage, there is a trend to use smaller diameter tubes in air conditioners. Tubes with diameters of less than 7.0 mm O.D. have been utilized in room air conditioners, e.g. 5.0 mm O.D. microfin tubes have been widely employed and 4.0 mm O.D. microfin tubes are starting to be used. It can be imagined that 5.0 mm O.D. tubes will become the most commonly used tubes for room air conditioners in the next few years and the application of 4.0 mm O.D. tubes will also become conventional in the near future. In the room air conditioners using 5.0 mm O.D. and 4.0 mm O.D. tubes, R410A is the mainly employed refrigerant; meanwhile, a certain amount of oil is needed for lubricating and sealing the compressor, and circulates with the refrigerant inevitably, meaning the working fluids flowing inside the tubes are refrigerant–oil mixture. For the sake of achieving good designs for room air conditioners using 5.0 mm O.D. or 4.0 mm O.D. tubes, pressure drop characteristics of refrigerant–oil mixtures flow condensation inside the tubes should be known.

Many researchers have reported pressure drop characteristics of pure R410A (containing no oil) flow condensation inside microfin tubes, such as Eckels and Tesene (1999), Goto et al. (2001), Han and Lee (2005), Kedzierski and Goncalves (1999), Miyara et al. (2000) and Wijaya and Spatz (1995), with an inside diameter range of 4–14.61 mm. These researches show that the diameter of tube has influence on the transition of flow pattern during condensation process, i.e., the smaller the diameter is, the earlier the annular flow regime appears, resulting in the discrepancy of pressure drop characteristics among different diameter tubes.

For R410A–oil mixture, the researches of pressure drop characteristics inside microfin tubes only focus on flow boiling conditions (Hu et al., 2008; Ding et al., 2009). The research results of flow boiling pressure drop characteristic indicate that the presence of oil always increases flow boiling frictional pressure drop of R410A. The maximum pressure drop enhancement can reach 120% for 5.0 mm O.D. microfin tube. However, there are no research results on the influence of oil on flow condensation pressure drop.

Flow condensation pressure drop characteristics of other refrigerant–oil mixtures inside microfin tubes have been studied on R12–oil mixture (Eckels and Pate, 1991), R113–oil mixture (Sur and Azer, 1991), R22–oil mixture and R407C–oil mixture (Cho and Tae, 2001), R134a–oil mixture (Eckels and Pate, 1991; Eckels et al., 1994, 1998) and R404A–oil mixture (Infante Ferreira et al., 2003) inside 8.0–17.91 mm I.D. tubes. These researches show that tube diameters and properties of refrigerant–oil mixtures play an important role in affecting the flow condensation pressure drop characteristics of refrigerant–oil mixtures. The tube diameter affects the transition of flow pattern; while the presence of oil may increase the condensation pressure drop (Eckels et al., 1994; Cho and Tae,