Available online at www.sciencedirect.com

SCIENCE DIRECT®

International Journal of Heat and Mass Transfer 48 (2005) 3804–3816

International Journal of HEAT and MASS TRANSFER

www.elsevier.com/locate/ijhmt

Experimental study on condensation heat transfer enhancement and pressure drop penalty factors in four microfin tubes

D. Han [a], Kyu-Jung Lee [b,*]

[a] Institute of Advanced Machinery Design, Korea University, Seoul 136-713, Korea

[b] Department of Mechanical Engineering, Korea University, 5ka-1 Anam-dong, Sungbuk-gu, Seoul 136-713, Korea

Received 2 August 2004; received in revised form 23 November 2004

Abstract

Heat transfer and pressure drop characteristics of four microfin tubes were experimentally investigated for condensation of refrigerants R134a, R22, and R410A in four different test sections. The microfin tubes examined during this study consisted of 8.92, 6.46, 5.1, and 4 mm maximum inside diameter. The effect of mass flux, vapor quality, and refrigerants on condensation was investigated in terms of the heat transfer enhancement factor and the pressure drop penalty factor. The pressure drop penalty factor and the heat transfer enhancement factor showed a similar tendency for each tube at given vapor quality and mass flux. Based on the experimental data and the heat–momentum analogy, correlations for the condensation heat transfer coefficients in an annular flow regime and the frictional pressure drops are proposed.

Keywords: Microfin tube; Condensation; Heat transfer; Pressure drop; Correlations

1. Introduction

Since Fujie et al.'s [1] invention, microfin tubes have received a lot of attention because they ensure a large heat transfer enhancement (80–180%) with a relatively small increase in pressure drop (20–80%). Microfin tubes are typically made of copper and have an outside diameter between 4 and 15 mm, have a single set of 50–70 spiral fins with spiral angle between 6° and 30°, and a fin height between 0.1 and 0.25 mm. The heat transfer enhancement is caused by the increase in the surface heat transfer area, the mixing induced by fin in the liquid film, and the surface tension effect on the condensate drainage in microfin tubes.

Numerous researchers [2–10] have proposed condensation heat transfer and pressure drop correlations for microfin tubes. Newell and Shah [11] reviewed the characteristic of two-phase heat transfer, pressure drop, and the effect of void fraction in microfin tubes. García-Valladares [12] reported that additional work was needed to develop a generalized heat transfer correlation for microfin tubes. Wang and Honda [13] evaluated the existing condensation heat transfer correlations for microfin tubes with their collected experimental heat transfer data. They reported that the Yu and Koyama

* Corresponding author. Tel.: +82 23290 3359; fax: +82 2928 9768.

E-mail address: kjlee@korea.ac.kr (K.-J. Lee).

0017-9310/$ - see front matter
doi:10.1016/j.ijheatmasstransfer.2005.02.041

Nomenclature

A	heat transfer surface area [m^2]
c_p	specific heat of fluid at constant pressure [J/kg K]
D	tube diameter [mm]
dP	pressure drop [N/m^2]
dz	distance along the flow direction [m]
e	fin height [mm]
e^+	roughness Reynolds number [dimensionless] ($=eu_t/v$)
Eh	heat transfer enhancement factor [dimensionless] ($=h_m/h_s$)
f	friction factor [dimensionless]
g	acceleration due to gravity [m^2/s]
G	mass flux [kg/m^2 s]
h	heat transfer coefficients [W/m^2 K]
h_t	heat transfer coefficients in the groove [W/m^2 K]
i	enthalpy [J/kg]
k	thermal conductivity of fluid [W/mK]
L	test section length [m]
m	mass flow rate [kg/s]
n	number of fins [dimensionless]
N	total number of data [dimensionless]
Nu	Nusselt number [dimensionless] ($=hD_i/k$)
p	axial fin pitch [mm] ($=\pi D_i/n\tan\beta$)
PF	pressure drop penalty factor [dimensionless] ($=dP_m/dP_s$)
Pr	Prandtl number [dimensionless] ($=v/\alpha$)
Pr_t	turbulent Prandtl number [dimensionless] ($=\varepsilon_m/\varepsilon_h$)
Q	heat transfer rate [W]
T	temperature [°C]
t_w^+	temperature difference in the groove [dimensionless] ($=\rho c_p u_t/h_t$)
u	fluid time average axial velocity [m/s]
u_t	turbulent friction or shear velocity [m/s] ($=\tau^{0.5}/\rho^{0.5}$)
x	vapor quality [dimensionless]
X_{tt}	Lockhart–Martinelli parameter [dimensionless]
y	distance measured from the duct wall [m]
y^+	wall coordinate [dimensionless] ($=yu_t/v$)

Greek symbols

α	thermal diffusivity [m^2/s]
β	spiral angle [°]
δ	liquid film thickness [m] ($=(1-\lambda)D_i/4$)
Δ	difference [dimensionless]
ε_h	eddy thermal diffusivity for turbulent flow [m^2/s]
ε_m	eddy kinematic viscosity for turbulent flow [m^2/s]
Φ	two-phase frictional multiplier [dimensionless]
λ	void fraction [dimensionless]
v	kinematic fluid viscosity [m^2/s]
θ	apex angle of a fin [°]
ρ	density [kg/m^3]
τ	shear stress [N/m^2] ($=D_i(dP/dz)_{fr}/4$)

Subscripts

exp	experimental
f	refrigerant
fr	frictional
g	gas phase
i	inside
in	inlet
l	liquid phase
lo	liquid only
m	microfin tube
o	outside
out	outlet
pre	pre-heater
pred	predicted value
s	smooth tube
sat	saturation
ts	test section
w	wall or water

[9] correlation gave the best prediction of performance among the empirical correlations. Wang et al. [14] compared the condensation frictional pressure drop correlations for microfin tubes and reported that the Goto et al. [8] correlation showed the best results even though it does not consider any geometrical effects.

The characteristics of smaller diameter tubes must be investigated to develop information for compact size heat exchangers. Although the extensive studies on two-phase heat and flow characteristics in microfin tubes has been done, more research on the characteristics of microfin tubes less than 6 mm in diameter is needed. Although a relatively large number of correlations have been proposed for microfin tubes, the existing correlations need to be evaluated with the experimental data of smaller diameter tubes. Without considering of geometrical effects, heat transfer enhancement cannot be ensured even if smaller size diameter tubes are introduced. Therefore, the heat transfer and frictional pressure drop characteristics of smaller microfin tubes must be