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Condensation of refrigerants in a multiport tube with rectangular minichannels

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ABSTRACT

This study investigated the condensation heat transfer and pressure drop characteristics of refrigerants R134a, R32, R1234ze(E), and R410A in a horizontal multiport tube with rectangular minichannels, in the mass velocity range of 100–400 kg m^{-2} s^{-1} and saturation temperature set at 40 and 60 °C. The effect of mass velocity, vapor quality, saturation temperature, refrigerant properties, and hydraulic diameter of rectangular channels on condensation characteristics is clarified. A new correlation is proposed for predicting the frictional pressure drop for condensation flow in minichannels. A heat transfer model for condensation heat transfer in rectangular minichannels is developed considering the flow patterns and effects of vapor shear stress and surface tension. Then, based on this model, a new heat transfer correlation is proposed. The proposed correlations successfully predict the experimental frictional pressure drop and heat transfer coefficients of the test refrigerants in horizontal rectangular minichannels.

Condensation de frigorigènes dans un tube multi-ports à minicanaux rectangulaires

Mots clés : Condensation ; Transfert de chaleur ; Chute de pression ; Tube multi-ports ; Minicanal ; Canal rectangulaire

1. Introduction

Compact heat exchangers composed of multiport tubes and fins have been widely used as condensers in automotive air-conditioning systems. Introducing these compact heat exchangers into residential air-conditioning systems is expected in order to improve the heat exchange performance and reduce the charge amount of refrigerant. Most of multiport tubes used as heat transfer tubes in compact heat exchangers have

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Nomenclature

A	total cross-sectional area [m^2]
a^*	aspect ratio
c_p	specific heat capacity [J kg^{-1} K^{-1}]
d	diameter [m]
f	friction factor
G	mass velocity [kg m^{-2} s^{-1}]
Ja	Jakob number
L	length [m]
Nu	Nusselt number
Oh	Ohnesorge number
P	pressure [Pa]
Pr	Prandtl number
Pr_L	liquid Prandtl number = $\mu_L c_{pL}/\lambda_L$
q	heat flux [W m^{-2}]
Q	heat transfer rate [W]
r_c	radius of curvature [m]
Re	Reynolds number
Re_L	liquid Reynolds number = $Gd(1-\chi)/\mu_L$
S	wetted perimeter length [m]
t	length of thin condensate film region [m]
T	temperature [°C]
T_s	refrigerant temperature [°C]
v	velocity [m s^{-1}]
w	velocity [m s^{-1}]
x	coordinate of the perpendicular to the tube wall [m]
y	coordinate along the tube wall in the circumferential direction [m]
z	coordinate along the tube wall in the vapor mainstream direction [m]

Greek symbols

α	heat transfer coefficient [W m^{-2} K^{-1}]
χ	quality
δ	film thickness [m]
Δh	latent heat [J kg^{-1}]
ΔP	pressure drop [Pa]
ΔP_F	frictional pressure drop [Pa]
ΔZ	measuring length [m]
Φ	two-phase multiplier
λ	thermal conductivity [W m^{-1} K^{-1}]
μ	viscosity [Pa s]
ρ	density [kg m^{-3}]
σ	surface tension [N m^{-1}]
τ_i	interfacial vapor shear stress [Pa]
ξ	void fraction

Subscripts

An	annular
cal	calculation
e	abrupt contraction and expansion
exp	experiment
F	forced convection dominant
h	hydraulic diameter
i	inner surface of tube
L	liquid phase
Lo	liquid phase with total flow
Ls	liquid slug
m	momentum change
o	outer surface of tube
S	surface tension dominant
single	single phase flow
V	vapor phase
Vo	vapor phase with total flow
Vp	vapor plug
W	tube wall

multiple rectangular minichannels with less than 2 mm hydraulic diameter. However, the heat transfer characteristics and flow patterns in multiple rectangular minichannels are suspected to be different from those of conventional large-diameter round tubes having an inner diameter greater than 3 mm.

Several researchers have investigated the condensation in multiport tubes and single tubes with rectangular minichannels experimentally and theoretically. Koyama et al. (2003a) carried out experiments of R134a condensation flow in multiport tubes whose hydraulic diameters ranged from 0.81 to 1.06 mm, and they proposed a correlations of the frictional pressure drop and the heat transfer coefficient. Kim et al. (2003) conducted experiments of condensation heat transfer using R410A and R22 in a smooth multiport tube with 1.56 mm hydraulic diameter and in a micro-finned multiport tube with 1.41 mm hydraulic diameter and compared their results with several heat transfer correlations. Cavallini et al. (2005a) investigated the pressure drop and condensation heat transfer characteristics of R134a and R410A in a multiport tube with 1.4 mm hydraulic diameter. Park and Hrnjak (2009) investigated the CO_2 flow condensation heat transfer and pressure drop in a multiport tube at saturation temperatures −15 and −25 °C. Agarwal et al. (2010) measured the condensation heat transfer coefficients of R134a in six noncircular multiport tubes of 0.42–0.84 mm hydraulic diameter. Jige and Koyama (2011) carried out experiments of R744 in a horizontal multiport tube of 0.36 mm hydraulic diameter at a pressure of 5–7 MPa. Wang and Rose (2005) investigated the condensation heat transfer in horizontal non-circular minichannels theoretically. They proposed a theoretical model to predict the film condensation heat transfer. In this model, the effects of the interfacial shear stress, surface tension, and gravity on the condensate surface are taken into account. Wang and Rose (2011) also proposed a heat transfer correlation that considered the effect of the surface tension only, and reported that this correlation is in agreement with the data in the surface tension dominated regime. However, the local condensation heat transfer characteristics in the rectangular mini channel are not clarified sufficiently yet.

In this study, the condensation heat transfer and pressure drop characteristics of refrigerants R134a, R32, R1234ze(E), and R410A in a horizontal multiport tube with rectangular