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An experimental study and development of new correlation for condensation heat transfer coefficient of refrigerant inside a multiport minichannel with and without fins

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ABSTRACT

This paper is dedicated to the experimental study and development of new correlation for condensation heat transfer in horizontal rectangular multiport minichannel with and without fins using R134a. A new experimental apparatus has been fabricated in order to obtain explicit local condensation heat transfer coefficient measurements over a range of test conditions. The test section is an 852 mm long horizontal rectangular multiport minichannel with and without fins having 20 channels with a hydraulic diameter of 0.64 mm and 0.81 mm. The measurements were done over a range of saturation temperature from 30 to 35 °C with mass fluxes ranging from 50 to 200 kg/m^2 s. The effects of vapor quality, mass fluxes, channel geometry, and saturation temperature on the heat transfer coefficient have been clarified and analyzed. The experimental results were compared with the well-known condensation heat transfer models available in the open literature. All of the existing correlations were failed to capture the present experimental heat transfer coefficient with a high degree of accuracy. As a consequence, a new condensation heat transfer correlation was developed based on the present experimental data and validated with 750 data points collected from the available journal.

1. Introduction

In recent decades, the multiport mini-channels are widely being used in heat exchangers in an encyclopedic variety of applications. They are very commonly used in refrigeration, air conditioning and heat pump equipment. Multiport mini-channels are a particular target of advanced research due to their higher heat transfer, reduced weight, reduced air side pressure drop and substantial refrigerant charge reduction as well as their space, energy, and material savings potential when compared to conventional tube heat exchangers for the same capacity. Minimizing charge is decisive in the present day refrigeration system, air conditioning system, heat pumps and some other industrial application because of the great impact of HCFC and HFC refrigerants on the direct greenhouse effect [1].

Many researchers have been proposed a few classifications of channels based on different criteria such as application, type of flow, effects of gravity and surface tension, and so on. The most widely used one is proposed by Kandlikar [2] and Kandlikar and Grande [3] based on flow of gases but they also recommended if for condensing and boiling flows, according to which $d \geq 3$ mm as conventional channels, $200\ \mu m \leq d < 3$ mm as minichannels, and $10\ \mu m < d < 200\ \mu m$ as microchannel.

Several researchers extensively investigated the condensation heat transfer characteristics in single and multiport tubes with different shaped minichannels experimentally and theoretically. Thome et al. [4] developed a new flow pattern based model for condensation heat transfer in the horizontal tube of diameter ranging from 3.1 to 21.4 mm. The model predicted experimental database, contained 4621 data points from 15 fluids of different flow regimes reasonably. Koyama et al. [5] experimentally measured the condensation heat transfer coefficients of HFC134a in two multiport tubes having eight channels and nineteen channels with 1.1 mm and 0.8 mm hydraulic diameters at the saturation temperature 60 °C. They proposed a correlation for heat transfer

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Nomenclature

Bo	Bond number
d	diameter [m]
l	length of a subsection [m]
w	width of the test section
Δz	distance between wall thermocouple
t	test section wall thickness [m]
Fr	Froude number
Pr	Prandtl number
Nu	Nusselt number
f	friction factor
G	mass flux [kg/m^2 s]
g	gravitational acceleration [m/s^2]
h	heat transfer coefficient [kW/m^{2}K]
h'	enthalpy of refrigerant [J/kg]
h''	enthalpy of cooling water [J/kg]
N_{conf}	confinement number
p	pressure [Pa]
Re	Reynolds number
Su	Suratman number
Ga	Galileo number
Ja	Jakob number
T	temperature [°C]
v	specific volume [m^3/kg]
Δv	specific volume difference between saturated vapor and saturated liquid [m^3/kg]
We	Weber number
x	vapor quality
w	wetted perimeter of tested tube [m]
z	effective heat transfer length [m]

Greek symbols

Φ	two-phase frictional multiplier
k	thermal conductivity [W/m K]
λ	channel geometry constant
β	aspect ratio
ρ	density [kg/m^3]
μ	viscosity [Pa s]
ν	kinetic viscosity [m^2/s]
σ	surface tension [N/m]
α	void fraction
X	Lockhart-Martinelli parameter

Subscripts

F	forced convection term
B	gravity controlled convection term
tp	two-phase
r	reduced pressure
$pred$	predicted
exp	experimental
cr	critical
c	coolant
LO	liquid only
VO	vapor only
h	hydraulic diameter
R	refrigerant
sat	saturation
s	subsection
U	upper side water flow
L	bottom side water flow
in	inlet
out	outlet
l	saturated liquid
v	saturated vapor
tt	turbulent liquid-turbulent vapor
wi	inner wall
wo	outer wall

coefficient by combining convective and film condensation term. Agarwal et al., [6] carried out experiments of HFC134a condensation heat transfer in six non-circular horizontal multiport tubes whose hydraulic diameter ranged from 0.424 to 0.839 mm. They developed correlation for heat transfer during condensation and suggested to use annular flow based model for square, barrel-shaped and rectangular channels, while the mist-flow based model for channels with sharp corners. Gross et al. [7] studied the convective condensation of R134a inside eight horizontal and parallel tubes with 0.77 mm diameter. Their results show that mass velocity and vapor quality have an important influence on the heat transfer coefficient. Park and Hrnjak [8] investigated the CO_2 flow condensation heat transfer in multiport tubes of 0.89 mm hydraulic diameter. Yang and Webb [9] conducted experiments of condensation heat transfer using R12 in a flat extruded aluminum plain tube of hydraulic diameter 2.63 mm and micro fin tube of hydraulic diameter of 1.56 mm. The authors propose that the heat transfer coefficients in a micro fin tube are slightly greater than that of plain tubes due to the surface tension drainage force becomes effective and provide additional enhancement, which is apparently additive to the effect caused by vapor shear. Sakamatapan et al. [10] conducted experiments of condensation heat transfer characteristics of R134a in multiport minichannels have fourteen channels with a 1.1 mm hydraulic diameter and eight channels with a 1.2 mm hydraulic diameter. They found when the hydraulic diameter is decreased; the heat transfer coefficients increased up to 15%. Gomez et al. [1] measured and investigated the flow condensation heat transfer coefficients of R1234yf and R134a in a minichannel multiport tube of 1.16 mm hydraulic diameter. Test results showed that the thermal conductivity, density ratio and viscosity ratio are playing an important role in the variation of the heat transfer coefficient. Recently, Jige et al. [11] performed the experimental study of condensation heat transfer characteristics of refrigerants R134a, R32, R1234ze (E), and R410A in a horizontal rectangular multiport minichannel of hydraulic diameter 0.85 mm. The author clarified the effects of mass velocity, vapor quality, saturation temperature, refrigerant properties and hydraulic diameter of a rectangular channel on condensation. The authors also proposed a model for condensation heat transfer in rectangular minichannels considering the flow patterns and effects of vapor shear and surface tension.

The different review above discovered that most of the research has been done and developed their correlation for minichannel without fins. However, clear information on the condensation heat transfer phenomena in rectangular multiport minichannels with fins is still limited and is not clarified sufficiently. In the present study, the condensation heat transfer coefficients of R134a in horizontal multiport minichannels with and without fins are measured experimentally and compared the measurements with some models available in the literature. In addition, a new correlation has been proposed to predict condensation heat transfer coefficient.