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Single-phase and two-phase flow pressure drop in the vertical header of microchannel heat exchanger

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ARTICLE INFO

Article history:
Received 25 February 2014
Received in revised form
23 April 2014
Accepted 12 May 2014
Available online 27 May 2014

Keywords:
Two-phase flow
Pressure drop
Vertical header
Microchannel heat exchanger

ABSTRACT

Refrigerant maldistribution among parallel microchannel tubes deteriorates the performance of microchannel heat exchanger because it creates unwanted superheated region that has lower heat transfer. Besides phase separation in the header, the pressure drop in the header causes the pressure drop in the microchannel tube to be different between each tube, also resulting in flow rate maldistribution. This paper experimentally investigates the pressure drop of single-phase and two-phase flow in the vertical header of a multi-pass microchannel heat exchanger. The overall pressure drop in the header includes four components: acceleration, gravitation, friction, and minor pressure drop due to microchannel tube protrusion. The gravitation and minor pressure drops are dominant for single-phase liquid flow and at low qualities of two-phase flow, whereas the acceleration and minor pressure drops are dominant for single-phase vapor flow and at high qualities of two-phase flow. The model to predict the overall pressure drop in the header for single-phase and two-phase flow is proposed based on the experimental results.

Chute de pression monophasique et diphasique dans le collecteur vertical de l'échangeur de chaleur à microcanaux

Mots clés : Ecoulement diphasique ; Chute de pression ; Collecteur vertical ; Echangeur de chaleur à micro-canaux

1. Introduction

The outdoor microchannel heat exchanger (MCHX) of a reversible system, usually having vertical headers and horizontal tubes, is widely used in automotive and residential air-conditioning systems, for its advantages in higher heat transfer, compactness, and possible charge reduction. In heat pump (HP) mode, the outdoor MCHX functions as an evaporator and refrigerant maldistribution creates unwanted superheated region, as shown by Song et al. (2002) and Dschida and Hrnjak (2008), where the heat transfer is lower than the two-phase region due to the lower heat transfer coefficient of superheated vapor and less temperature difference between refrigerant and air (due to the higher superheated refrigerant temperature than the saturation refrigerant temperature).

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http://dx.doi.org/10.1016/j.ijrefrig.2014.05.007
0140-7007/Published by Elsevier Ltd.

Nomenclature

A_{min}	cross-section area in the header at tube protrusion [m^2]
D_h	hydraulic diameter in the header at tube protrusion [m]
f	friction loss coefficient [–]
G	mass flux [$kg\,m^{-2}\,s^{-1}$]
h_{out}	enthalpy at header outlet [$J\,kg^{-1}$]
h_{sup}	enthalpy at header/superheated point[$J\,kg^{-1}$]
i	index number
l	tube pitch (distance between two microchannel tubes) [m]
m	mass flow rate [$kg\,s^{-1}$]
n	number of tubes [–]
P	pressure [Pa]
P_{header}	average pressure in the header [Pa]
Q	power of heaters [W]
Re	Reynolds number [–]
S	perimeter [m]
T	temperature [°C]
T_{header}	saturation temperature in the header [°C]
v	velocity [$m\,s^{-1}$]
X_{tt}	turbulent–turbulent Martinelli parameter [–]
x	quality [–]
y	parameter [–]
ΔP	pressure drop [Pa]
α	void fraction [–]
δU	uncertainty [–]
ζ	minor pressure loss coefficient due to tube protrusion
μ	viscosity [$kg\,m^{-1}\,s^{-1}$]
ρ	density [$kg\,m^{-3}$]
φ_v	two-phase friction pressure drop multiplier (vapor) [–]
$\varphi_{pro,v}$	two-phase protrusion pressure drop multiplier (vapor) [–]

Subscripts

acc	acceleration pressure drop
con	contraction pressure drop
exp	expansion pressure drop
fri	friction pressure drop
gra	gravitation pressure drop
i	branch number
in	in the middle of the header and at the smallest area of the last inlet tube
l	liquid
M	main pipe (header)
meas	measured
out	out of the header
pred	predicted
pro	minor pressure drop in the header due to tube protrusion
sup	superheated point
sub	subcooled point
t	microchannel tube
tp	two-phase
v	vapor

Thus, refrigerant maldistribution deteriorates the MCHX performance, and consequently reduces system efficiency. Byun and Kim (2011) presented R410A maldistribution in a two-pass outdoor MCHX under HP mode caused the cooling capacity reduced up to 13.4% compared to the uniform distribution case. Zou et al. (2014) showed capacity degradation of 30% and 5% for R410A and R134a maldistribution in a two-pass outdoor MCHX under HP mode, respectively.

Previous studies mainly focused on the effects of two-phase flow regime in the header on refrigerant distribution. Fei and Hrnjak (2004), Vist and Pettersen (2004), Webb and Chung (2005), Bowers et al. (2006), and Hwang et al. (2007) presented the two-phase flow and distribution in the horizontal headers, which usually appeared in the indoor MCHX. Watanabe et al. (1995), Cho and Cho (2004), and Lee (2009) investigated the two-phase flow in the inlet vertical headers, while Byun and Kim (2011) and Zou and Hrnjak (2013a,b, 2014) examined the two-phase flow in the intermediate vertical headers, which were commonly used in the outdoor MCHX. All of the above studies showed that refrigerant distribution was a very complex problem that was affected by numerous parameters, such as header geometries and inlet flow conditions. The two-phase flow regime in the header, which was affected by the above parameters, had a strong influence on refrigerant distribution among parallel tubes.

However, refrigerant distribution is not only affected by the two-phase flow regime in the header but also by the distribution of pressure drop in the heat exchanger. Because of several parallel microchannel tubes, there are numerous flow paths in the heat exchanger. Each flow path starts from the inlet of the heat exchanger and ends at the outlet of the heat exchanger; thus, the pressure drop along each flow path is equal. For example, if along one path the pressure drop in the header is greater than along another flow path, the pressure drop in the tube must be lower, resulting in the lower mass flow rate in that tube. This situation affects refrigerant distribution in addition to quality distribution in the header at the entrance of each tube (mainly a result of two-phase flow regime in the header). Hence, refrigerant distribution in the header with multiple parallel microchannel tubes is caused by two factors: header induced pressure drop and quality distribution.

Even in single-phase flow, maldistribution existed due to the pressure drop in the header, though there was no phase separation, as discussed by Bajura and Jones (1976), Datta and Majumdar (1980), and Yin et al. (2002). Tuo and Hrnjak (2013) presented that such single-phase maldistribution due to pressure drop in MCHX with horizontal headers also affected the heat exchanger and system performance. Yin et al. (2002) developed a single-phase pressure drop model for the whole microchannel heat exchanger based on the experimental results with nitrogen. Ren et al. (2014) examined the pressure drop of single-phase compressed air in the horizontal header and improved the pressure drop model of Yin et al. (2002) based on their results.