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Two-phase refrigerant distribution in an intermediate header of a parallel flow minichannel heat exchanger

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ABSTRACT

Refrigerant R-410A distribution in a two pass evaporator with intermediate header was investigated. The number of tubes was 10 for the first pass and 12 for the second pass. Tests were conducted for the mass flux from 73 to 143 kg m^{-2} s^{-1}, quality from 0.4 to 0.6. In the intermediate header, two-phase mixture out of the first pass is merged and then redistributed to the second pass. More liquid is forced downstream as mass flux or quality increases yielding better flow distribution. Effect of insertion device in the inlet header was also investigated. Efforts were made to develop correlations to predict the liquid or gas distribution in a header with limited success. Header pressure drop data are also provided.

Répartition de frigorigène diphasique dans un collecteur intermédiaire d'un échangeur de chaleur à écoulements parallèles de minicanaux

Mots clés : Répartition d'écoulement ; Echangeur de chaleur ; Collecteur ; Intermédiaire

1. Introduction

Brazed aluminum heat exchangers, which consist of flat minichannel tubes on the refrigerant-side and louver fins on the air-side, have long been used as condensers of automotive air conditioners due to superior thermal performance as compared with conventional fin-and-tube heat exchangers. Brazed aluminum heat exchangers may be categorized as parallel flow heat exchangers because a number of tubes are grouped to one pass using a header, and flows are parallel one another. Typical hydraulic diameter of the flat tube is 1–2 mm. Recently, brazed aluminum heat exchangers are considered as evaporators of automotive or residential air conditioners. In

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Nomenclature

c_p	specific heat, J kg^{-1} K^{-1}
CR	ratio of inlet and outlet channel number
d	tube inner diameter, m
D	header diameter, m
f	friction factor
Fr	Froude number
G	mass flux, kg m^{-2} s^{-1}
GFR	gas flow ratio
h	enthalpy, J kg^{-1}
L	length, m
LFR	liquid flow ratio
m	mass flow rate, kg s^{-1}
N	number of channels
P	pressure, Pa
P_c	critical pressure, Pa
R	function of measured variable
Q	rate of heat supply, W
Re	Reynolds number
T	temperature, K or tube
v	specific volume, m^3 kg^{-1}
w	uncertainty of parameter
We	Weber number
x	quality or measured variable

Greek notations

α	void fraction
ΔP	pressure drop, Pa
μ	viscosity, kg m^{-1} s^{-1}
Φ^2	two-phase flow multiplier
ρ	density, kg m^{-3}
σ	Surface tension, N m^{-1} or standard deviation

Subscripts

a	acceleration
avg	average
ch	channel
cont	contraction
deg	degradation
exp	expansion
f	friction
ft	flat tube
g	gas or gravitation
go	gas only
H	header or homogeneous
i	inlet or i_{th}
ideal	ideal
in	inlet
int	intermediate
l	liquid
lg	latent heat
lo	all liquid
meas	measured
minor	minor
o	outlet
out	outlet
p	preheater
r	refrigerant
ran	random
rt	round tube
sat	saturation
sys	systematic
T	tube
w	cooling water

this case, it is very important to distribute the two-phase refrigerant (especially the liquid) evenly into each tube. Otherwise, the thermal performance is significantly deteriorated. According to Kulkarni et al. (2004), the performance reduction by flow mal-distribution could be as large as 20%.

In general, brazed aluminum evaporators consist of more than twenty tubes to match the cooling requirement of the refrigeration system. Fig. 1 shows an example of refrigerant-side circuiting (one, two and four passes). Also shown in the figure are estimated vapor qualities for given inlet and exit quality of 0.2 and 1.0. Improved flow distribution is expected with increased number of refrigerant passes. The pressure drop will, however, also be increased.

The literature survey reveals that most of the studies on two-phase distribution in a header-branch configuration have been conducted on a single pass configuration (Fig. 1a). For a single pass configuration, refrigerant is divided into channels at the inlet header, and is combined at the outlet header. Webb and Chung (2004), Hrnjak (2004), Lee (2006), Ahmad et al. (2009) provided recent reviews on this subject. For multi-pass configuration, refrigerant is first divided into channels at the inlet header. Refrigerant out of the first pass is combined, and then divided into channels in the intermediate header of the second pass. The process continues to the last header. It is expected that flow distribution characteristics in the intermediate header will be significantly different from that in the inlet or outlet header. However, literature shows very limited investigations on refrigerant distribution in the intermediate header. The literature survey will first briefly review the two-phase distribution in a single pass configuration, and then available studies on multi-pass configuration will be discussed.

Watanabe et al. (1995) conducted a flow distribution study for a round header (20 mm I.D.) – four round tube (6 mm I.D.) upward flow configuration using R-11. Mass flux (based on the header cross sectional area) was varied from 40 to 120 kg m^{-2} s^{-1}, and inlet quality was varied up to 0.4. The flow at the inlet was stratified, and was supplied parallel to the header. The flow distribution was highly dependent on mass flux and quality. Vist and Pettersen (2004) investigated a round header (8 mm and 16 mm I.D.) – ten round tube (4 mm I.D.) configuration using R-134a. Mass flux was varied from 12 to 21 kg m^{-2} s^{-1}, and quality was varied up to 0.5. The flow in the header inlet was mostly intermittent with some annular at high mass fluxes. For downward flow configuration, most of the liquid flowed through frontal part of the header. For upward configuration, on the contrary, most of the liquid flowed through the rear part of the header. Koyama et al. (2006) investigated the effect of tube protrusion depth for a horizontal round header (9 mm I.D.) – six