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Two-phase refrigerant distribution in a two row/four pass parallel flow minichannel heat exchanger

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ABSTRACT

R-410A distribution was experimentally studied for an evaporator having two row/four pass configuration. The evaporator has inlet, intermediate and top (or bottom) row-crossing headers. Tests were conducted for the mass flux from 70 to 130 kg m^{-2} s^{-1} with inlet quality 0.2 and exit superheat 5 °C. Flow distribution at the inlet header generally follows the well-known trend. For downward configuration, more liquid flows into upstream channels. For upward configuration, more liquid flows into downstream channels. At the intermediate header, flow distribution is dependent on the direction of the tubes. When tubes are heading upward, more liquid is supplied into upstream. When tubes are heading downward, on the contrary, more liquid is supplied into downstream channels. Flow distribution at the top row-crossing header is entirely different from that at the bottom row-crossing header. Thermal degradation by flow mal-distribution is much larger for top row-crossing header configuration than for bottom row-crossing header configuration. Correlations are developed to predict the fraction of liquid or gas taken off by downstream channel as a function of header gas Reynolds number. Header pressure drops are obtained by subtracting flat tube pressure drops and other minor pressure drops from measured pressure drops.

1. Introduction

Brazed aluminum heat exchangers, which consist of flat minichannel tubes and louver fins, 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 are in the category of parallel flow heat exchangers because a number of tubes are grouped to one pass using a header, and form a parallel flow configuration. 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 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. [1] the performance degradation by flow mal-distribution could be as large as 20%.

In many cases, brazed aluminum evaporators have multi-row/multi-pass configuration to match the cooling requirement of the refrigeration system, with two row/four pass configuration most widely-used. Fig. 1 shows two different configuration (top row-crossing header and bottom row-crossing header) for two row/four pass evaporators. For top row-crossing header configuration shown in Fig. 1(a), refrigerant enters into the inlet header, flows downward, and then is supplied to intermediate header, flows upward, passes row-crossing header to the rear row. At the rear row, refrigerant from the row-crossing header flows downward, and then is supplied to intermediate header, flows upward, and exits from the outlet header. For bottom row-crossing header configuration shown in Fig. 1(b), refrigerant enters into the inlet header, flows upward, and then is supplied to intermediate header, flows downward, passes row-crossing header to the rear row. At the rear row, refrigerant from row-crossing header flows upward, and then is supplied to intermediate header, flows downward, and exits from the outlet header. Also shown in the figure are estimated vapor qualities for given inlet and exit quality of 0.2 and 1.0.

The literature reveals that most of the studies on two-phase distribution in a header-branch configuration have been conducted on a single row/single pass configuration. For a single row/single pass configuration, refrigerant is divided into channels at the inlet header. Webb and Chung [2], Hrnjak [3], Lee [4] and Ahmad et al. [5] provided recent reviews on this configuration. For single row/multi-pass configuration, refrigerant is first divided into channels of the first pass. Refrigerant out of the first pass is combined at

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Nomenclature

c_p	specific heat (J kg^{-1} K^{-1})
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
$\dot{m}$	mass flow rate (kg s^{-1})
N	number of channel
P	pressure (Pa)
P_c	critical pressure (Pa)
R	function of measured variable
Q	supplied heat (W)
Re	Reynolds number
SD	standard deviation
T	temperature (K)
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 multiplier
ρ	density (kg m^{-3})
σ	surface tension (N m^{-1})

Subscripts

a	acceleration
avg	average
c	critical
ch	channel
cont	contraction
deg	degradation
exp	expansion
f	friction factor or friction
ft	flat tube
g	gas or gravitation
go	all gas
H	header or homogeneous
head	header
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
rt	round tube
sat	saturation
T	tube
w	cooling water

the intermediate header, and then divided to the second pass. The process continues to the last pass. It is expected that flow distribution characteristics at the intermediate header will be significantly different from that at the inlet header. However, literature shows very limited investigations on refrigerant distribution in an 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. [6] 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 distribution was highly dependent on mass flux and quality. Vist and Pettersen [7] 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. 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. [8] investigated the effect of tube protrusion depth for a horizontal round header (9 mm I.D.) – six vertical flat tube configuration using R-134a. Mass flux was fixed at 130 kg m^{-2} s^{-1}, and quality was varied up to 0.4. Tests were conducted for downward configuration. Protrusion depth was systematically varied, and optimum configuration was found to be with front two tubes protruded to the center of the header and remaining four tubes flush-mounted. Better liquid distribution was obtained at a lower vapor quality. Bowers et al. [9] investigated the effect of entrance length for a downward configuration using R-134a. Their test section composed of horizontal round header (20 mm I.D.) and fifteen vertical flat tubes. Mass flux was varied from 46 to 107 kg m^{-2} s^{-1}, and quality was varied up to 0.35. The apparatus was equipped an expansion valve, and expanded two-phase mixture was supplied to the test section through entrance tubes. For a short entrance length of 89 mm, liquid distribution was relatively uniform with minor influence of protrusion depth, mass flux or quality. For a long entrance length of 267 mm, however, better distribution was obtained as mass flux or protrusion depth increased.

Hwang et al. [10] investigated the effect of inlet configuration for a round header-thirty flat tube configuration using R-410A for upward flow. Two inlet configurations – parallel and normal – were tested, and better flow distribution was obtained for a normal inlet configuration. Kim et al. [11] and Kim and Byun [12] also investigated the effect of flow inlet direction for a round header (17 mm I.D.) – ten flat tube (D_h = 1.32 mm) configuration using R-134a for downward and upward flow. For downward flow, normal or vertical inlet yielded approximately similar liquid distribution, although slightly better results were obtained for normal inlet at high mass fluxes or high qualities. For upward flow vertical inlet yielded the best flow distribution.

Compared with many studies on refrigerant distribution in a single pass configuration, very limited information is available for refrigerant distribution in a multi-pass configuration. Byun and Kim [13] investigated the refrigerant distribution in a