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Upward branching of two-phase refrigerant in a parallel flow minichannel heat exchanger

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ABSTRACT

Brazed aluminum heat exchangers are recently 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. In this study, R-134a flow distribution was experimentally studied for a round header-ten flat tube test section simulating a brazed aluminum heat exchanger. Three different inlet orientations (parallel, normal, vertical) were investigated. Tests were conducted with upward flow for the mass flux from 70 to 130 kg m^{-2} s^{-1} and quality from 0.2 to 0.6. Tubes were protruded to center of the header. Results show that better distribution (both for liquid and gas) is obtained for vertical inlet configuration. Possible explanation is provided based on flow visualization results. Efforts were made to develop correlations to predict the liquid or gas distribution in a header with limited success. Refined correlations should consider both geometric and operating variables. Header pressure drop data are also provided.

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 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 reduction by flow mal-distribution could be as large as 20%.

For a brazed aluminum evaporator, vertical tube configuration is preferred (with headers in horizontal position), because it facilitates the air-side condensate drainage. Refrigerant may be supplied from three different directions – parallel to the header, normal to the header or vertical to the header, as illustrated in Fig. 1. The outlet may be located at the same side of the heat exchanger with the inlet or it may be located at opposite side of the heat exchanger. In Fig. 1, the outlet and inlet are located at the same side of the heat exchanger. In addition to inlet direction, many parameters, both flow and geometric, affect the flow distribution in a parallel flow heat exchanger. Webb and Chung [2], Hrnjak [3], Lee [4], Ahmad et al. [5] provided recent reviews on this subject.

In-depth literature survey on two-phase distribution in a header-branch configuration is available in authors' previous publications [6,7], and only literatures related with the two-phase distribution of refrigerants will be reviewed. Existing investigations are summarized in Table 1. Watanabe et al. [8] 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. Tubes were flush-mounted. 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 [9] investigated a round header (8 mm and 16 mm I.D.) – ten round tube (4 mm I.D.) configuration using R-134a. Tubes were flush-mounted and the flow was supplied parallel to the header. Both upward and downward flows were tested. 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

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Nomenclature

A	cross-sectional area, m^2
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} or protrusion depth, m
L	length, m
LFR	liquid flow ratio
m	mass flow rate, kg s^{-1}
N	number of channel
NLFR	normalized liquid flow ratio
P	pressure, Pa
Q	supplied heat, W
P_c	critical pressure, Pa
Re	Reynolds number
SD	standard deviation
RMSE	root mean square error
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

exp	expansion or experimental
exit	*exit*
f	friction factor or friction
ft	flat tube
g	gas or gravitation
go	all gas
H	header or homogeneous
header	header
i	inlet or *i*th
l	liquid
lo	all liquid
meas	measured
minor	minor
o	outlet
p	preheater
pred	prediction
r	refrigerant
rt	round tube
T	tube
w	cooling water

the rear part of the header. The liquid distribution improved as quality decreased. Little difference in two-phase flow distribution was noted between the two diameter headers (8 mm and 16 mm I.D.).

Koyama et al. [10] investigated the effect of tube protrusion depth for a horizontal round header (9 mm I.D.) – six vertical flat tube configuration using R-134a. The flow was supplied parallel to the header. 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, and the flow at header inlet was identified as intermittent. 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. [11] investigated the effect of tube protrusion depth as well as 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

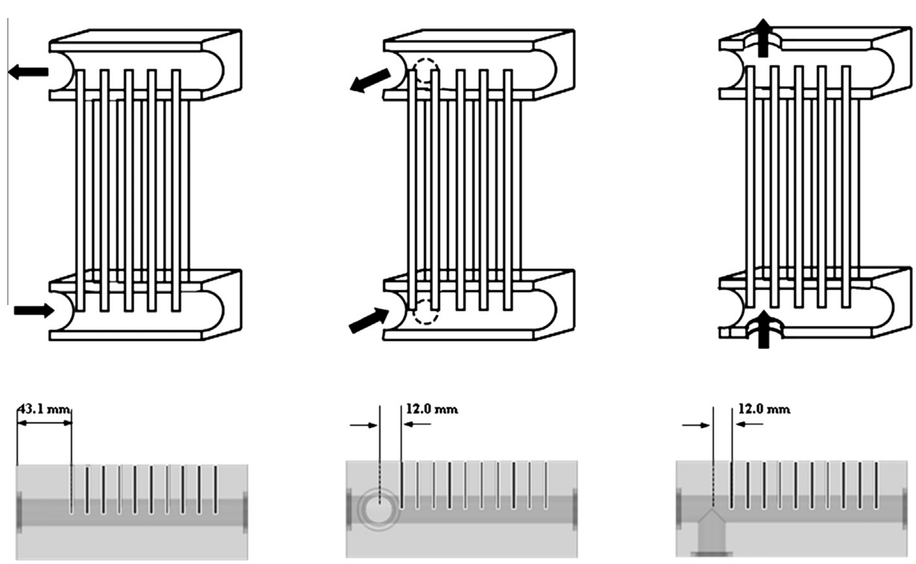

Fig. 1. Flow inlet configurations.