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Improvement of two-phase refrigerant distribution in a parallel flow minichannel heat exchanger using insertion devices

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HIGHLIGHTS

- Refrigerant distribution in a parallel flow heat exchanger.
- Methods sought to improve flow distribution.
- Both upward and downward configuration investigated.
- Insertion of perforated tube significantly improves the flow distribution.
- Optimum perforated tube configuration depends on the direction of flow.

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ABSTRACT

In this study, various insert devices (wire mesh, perforated plate, perforated tube) were investigated to obtain an improved flow distribution in a round header/ten flat tube test section using R-134a. To simulate an actual brazed aluminum heat exchanger, tubes were protruded to center of the header. Tests were conducted both for downward and upward flow for the mass flux from 70 to 130 kg m^{-2} s^{-1} and quality from 0.2 to 0.6. Of the investigated insert devices, perforated tube significantly improved the flow distribution both for downward and upward flow when the holes were located facing tubes. Preferred hole geometry was dependent on the flow direction. For downward flow, non-uniform hole configuration with decreasing hole sizes in flow direction yielded better flow distribution than uniform hole configuration. For upward flow, however, uniform hole configuration yielded better flow distribution. Possible reason was provided based on flow visualization results. Header pressure drop was obtained from the measured pressure drop by subtracting appropriate pressure drops. For no-insert configuration, header pressure drops were mostly negative, which implied that the pressure was recovered in the header. With insertion of the perforated tube, however, the header pressure drop increased significantly. Other insert devices (wire mesh, perforated plate) were not effective in improving the flow distribution.

1. Introduction

Brazed aluminum heat exchangers, which consist of flat minichannel tubes of 1–2 mm hydraulic diameter 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. In a brazed aluminum heat exchanger, a number of tubes are grouped to one pass using a header (parallel flow configuration) to manage the otherwise excessive tube-side pressure drop induced by the small-sized channel. Recently, brazed aluminum heat exchangers are considered as evaporators of automotive or residential air conditioners. For an evaporator, it is very important to distribute the two-phase refrigerant (especially liquid) evenly into each tube. Otherwise, the thermal performance is significantly deteriorated due to uneven dryout between channels. According to Kulkarni et al. [1], the performance reduction by flow mal-distribution could be as large as 20%.

For evaporator usage of the brazed aluminum heat exchanger, vertical tube configuration is preferred (with headers in horizontal position), because it facilitates the air-side condensate drainage. The refrigerant may be supplied to bottom header (upward flow), or to top header (downward flow). Previous studies show that liquid distribution in a parallel flow heat exchanger is highly

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Nomenclature

A	cross-sectional area [m^2]
C_C	contraction coefficient [−]
c_p	specific heat [J kg^{-1} K^{-1}]
CFR	channel flow ratio [−]
d	tube inner diameter [m]
f	friction factor [−]
Fr	Froude number [−]
G	mass flux [kg m^{-2} s^{-1}]
h	enthalpy [J kg^{-1}] or protrusion depth [m]
L	length [m]
$\dot{m}$	mass flow rate [kg s^{-1}]
N	number of channel [−]
P	pressure [Pa]
P_c	critical pressure [Pa]
Re	Reynolds number [−]
SD	standard deviation [−]
T	temperature [K]
v	specific volume [m^3 kg^{-1}]
We	Weber number [−]
x	quality [−]

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

cont	contraction
exp	expansion
exit	exit
f	friction factor or friction
ft	flat tube
g	vapor or gravitation
go	all vapor
H	homogeneous
header	header
i	inlet
l	liquid
lo	all liquid
meas	measured
minor	minor
o	outlet
r	refrigerant
rt	round tube
T	tube
w	cooling water

uneven. 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.

The literature reveals several studies on two-phase distribution in a header/branch tube configuration. Existing investigations are summarized in Table 1. Watanabe et al. [6] conducted a flow distribution study for a round header (20 mm ID)/four round tube (6 mm ID) 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. Tompkins et al. [7] tested a rectangular header/

Table 1
Previous studies on the distribution in header/tube configuration.

Investigators	Header/Tube Conf.	Diameter/Area ratio	Protrusion depth	Flow direction	Fluids	Range of investigation
Watanabe et al. [6]	Horiz. Cir. Header/Vert. Cir. Tube	$D/d = 3.3$ $A_H/A_T = 2.8$	$h/D = 0.0$	Up	R-11	$40 \le G \le 120$ kg m^{-2} s^{-1} $0 \le x \le 0.4$
Tompkins et al. [7]	Horiz. Rect. Header/Vert. Minichannel Tube	N/A	$h/D = 0.0$	Down	Air/Water	$50 \le G \le 400$ kg m^{-2} s^{-1} $0 \le x \le 0.4$
Vist and Pettersen [8]	Horiz. Cir. Header/Vert. Cir. Tube	$D/d = 2, 4$ $A_H/A_T = 0.4, 1.6$	$h/D = 0.0$	Up & Down	R-134a	$12 \le G \le 21$ kg m^{-2} s^{-1} $0.1 \le x \le 0.5$ Insert devices
Lee and Lee [9]	Vert. Rect. Header/Horiz. Flat Tube	$D/d = 7.2$ $A_H/A_T = 2.4$	$0.0 \le h/D \le 0.5$	Horiz.	Air/Water	$54 \le G \le 134$ kg m^{-2} s^{-1} $0.2 \le x \le 0.5$
Koyama et al. [10]	Horiz. Cir. Header/Vert. Minichannel Tube	$D/d = 10.6$ $A_H/A_T = 3.1$	$0.0 \le h/D \le 0.5$	Down	R-134a	$G = 130$ kg m^{-2} s^{-1} $0.1 \le x \le 0.4$
Bowers et al. [11]	Horiz. Cir. Header/Vert. Minichannel Tube	N/A	$0.0 \le h/D \le 0.5$	Down	R-134a	$46 \le G \le 107$ kg m^{-2} s^{-1} $0 \le x \le 0.35$
Kim and Han [12]	Horiz. Cir. Header/Vert. Minichannel Tube	$D/d = 12.9$ $A_H/A_T = 1.9$	$0.0 \le h/D \le 0.5$	Up & Down	Air/Water	$70 \le G \le 130$ kg m^{-2} s^{-1} $0.2 \le x \le 0.6$
Cho et al. [13]	Horiz&Vert.Cir. Header/Vert&Horiz.Minichannel Tube	$D/d = 15.6$	$h/D = 0.5$	Up & Horiz.	R-22	$G = 60$ kg m^{-2} s^{-1} $0 \le x \le 0.3$
Hwang et al. [14]	Horiz. Cir. Header/Vert. Minichannel Tube	$D/d = 11.2$	$h/D = 0.5$	Up	R-410a	$106 \le G \le 212$ kg m^{-2} s^{-1}
Kim et al. [15]	Horiz. Cir. Header/Vert. Minichannel Tube	$D/d = 12.9$ $A_H/A_T = 1.9$	$h/D = 0.0$	Down	R-134a	$70 \le G \le 130$ kg m^{-2} s^{-1} $0.2 \le x \le 0.6$
Webb and Chung [2].	Horiz. D-Header/Vert. Minichannel Tube	$D/d = 24.9$ $A_H/A_T = 1.47$	$0.13 \le h/D \le 0.63$	Down	Air/Water	$0.3 \le G \le 0.8$ $G = 134$ kg m^{-2} s^{-1} Insert devices
Marchitto et al. [16]	Horiz. Cir. Header/Vert. Rect. Channel	$4.3 \le D/d \le 8.7$ $1.2 \le A_H/A_T \le 4.7$	$h/D = 0.0$	Up	Air/Water	$0 < x < 0.1$ $200 \le G \le 1200$ kg m^{-2} s^{-1} Insert devices
Present study	Horiz. Cir. Header/Vert. Minichannel Tube	$D/d = 12.9$ $A_H/A_T = 1.9$	$h/D = 0.5$	Up & Down	R-134a	$70 \le G \le 130$ kg m^{-2} s^{-1} $0.2 \le x \le 0.6$ Insert devices