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Developing Two-Phase Flow Distribution in Horizontal Headers With Downward Minichannel-Branches

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ABSTRACT

When a two-phase flow is within in the header, the phases are distributed unequally into the branches. A maldistribution will lead to a performance deterioration of these heat exchangers mostly evaporators. This paper presents an experimental study on two-phase flow in minichannel-branch headers for evaporators. The test section consists of a 9 mm i.d. horizontal header and 6 vertically branching conduits. Each branch has 6 x 0.85 mm i.d. minichannels. The headers are examined with R134a as a test fluid at saturation temperature of about 21^{o}C, mass velocity of about 130 kg/(m^{2}s), and average vapor quality in the header inlet of about 0.1, 0.2, 0.3 and 0.4. The vapor-liquid phase mass flows enter into the branches are measured and the flow regimes at each branch inlet in the headers are presented.

1. INTRODUCTION

High performance and compactness are requested for designing heat exchangers, which are widely used in small size air conditioning and refrigeration systems. Therefore, a multi-pass heat exchanger equipped by a header with many branching conduits to distribute refrigerant is commonly used. When a two-phase flow is within in the header, the phases are distributed unequally into the branching conduits due to phase separation in the header. Imperfect distribution to each channel causes a performance deterioration of these heat exchangers mostly evaporators.

Experimental studies to investigate the phase distribution in the header and to develop a header with small maldistribution are required. Many experimental studies reporting on phase distribution in single T-junctions have been published (Honan and Lahey, 1981; Zetzmann, 1982; Azzopardi and Whalley, 1982; Saba and Lahey, 1984; Lahey, 1986). These research efforts have shown that, in general, the phases are not distributed evenly at the junction. The phase distributions at branching junction are dependent on a large number of variables such as the inlet flow regime, inlet quality, inlet mass flow rate, branch-to-inlet diameter ratio, fluid properties, and junction geometry. Only a few authors have investigated distribution of two-phase flow in the headers (Watanabe *et al.*, 1995; Osakabe *et al.*, 1999; Horiki *et al.*, 2004; Vist and Pettersen, 2004). These have reported that all measurement showed severe maldistribution both the vapor and phases.

In the previous study, Koyama *et al*. (2005) have developed two-phase flow distribution for upward and downward flows in two headers configured by six minichanel-branches with and without insertion separately. They have reported that the existence of insertions affected the headers to provide a bit better result, however, all experimental results showed significant maldistribution in the vapor and liquid phases.

To develop the reduced maldistribution, the headers configured by compound of minichanel-branches with and without insertion are examined in the present study. Experimental data of two-phase distribution of R134a in minichannel-branch headers are obtained for systematically changed values of vapor quality in the header inlet. The vapor-liquid phase mass flows enter into the branches are measured and the flow regimes at each branch inlet in the headers are presented.

2. EXPERIMENTAL APPARATUS AND METHOD

The experimental apparatus is shown schematically in Figure 1. It consists of a test fluid circulation loop and three cooling brine circulation loops. The refrigerant liquid which is driven by a pump (1) flows through the Coriolis mass flow meter (2), the evaporator inlet mixing chamber (3), the electrically heated evaporator (4), the evaporator outlet mixing chamber (3') and then enters the test section that consists of a header (5) and minichannel-branches (6). Afterwards, the two-phase mixture flows through vapor-liquid separators (7). The separated liquid phase from each branching conduit passes through an icebox (8) to provide a subcooled condition and then the liquid phase flows through the corresponding turbine mass flow meter (L), sight glass (10) and the liquid receiver (12). Meanwhile, the separated vapor phase from branching conduits enters heaters (9) to obtain a superheated condition and then the vapor phase flows through thermal mass flow meters (V), sight glasses and the condenser (11). The vapor is completely condensed in the condenser and the condensate flows sequentially through the liquid receiver (12), sub-cooler (13), sight glass (10') and then returns to the refrigerant pump (1). The test loop is covered by insulating materials. The vapor quality in the inlet of test section is regulated to a specific value. In order to maintain the fixed pressure in the header inlet, the temperatures in the condenser, the liquid receiver and the sub-cooler are kept at constant by using a constant temperature brine bath (14).

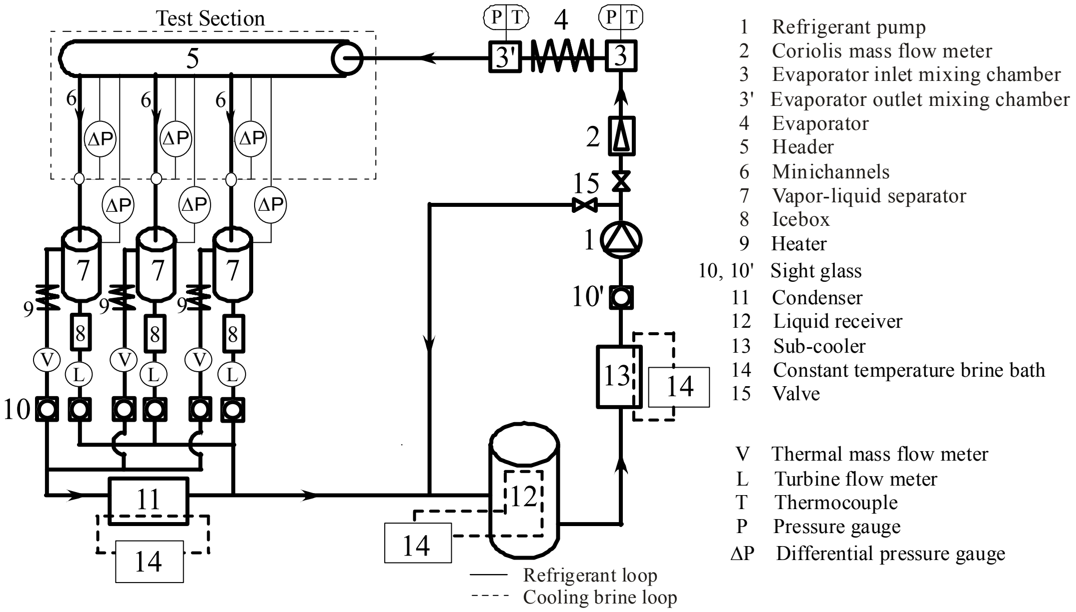

Figure 1: Schematic of experimental apparatus

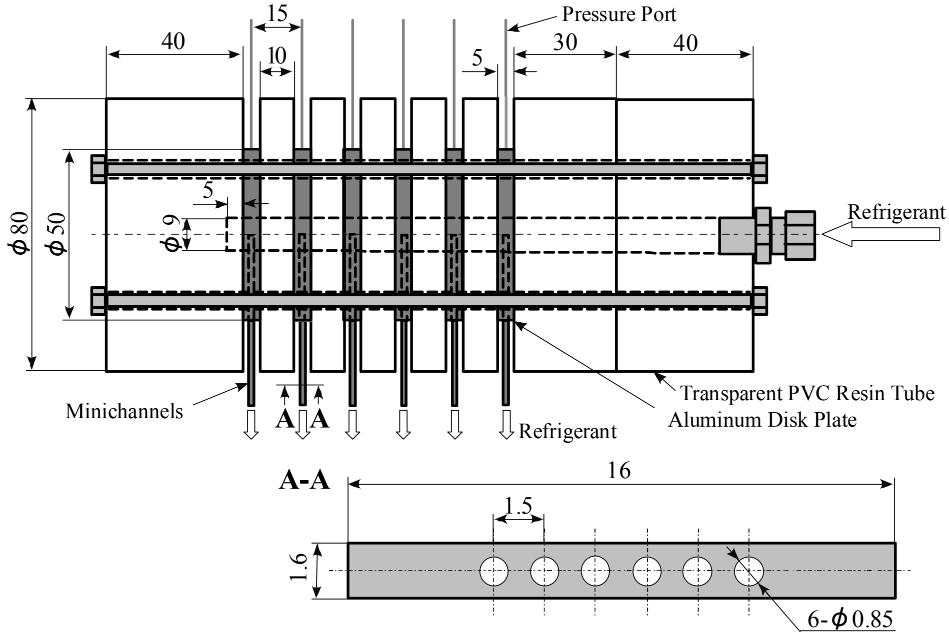

Figure 2: Schematic of test section

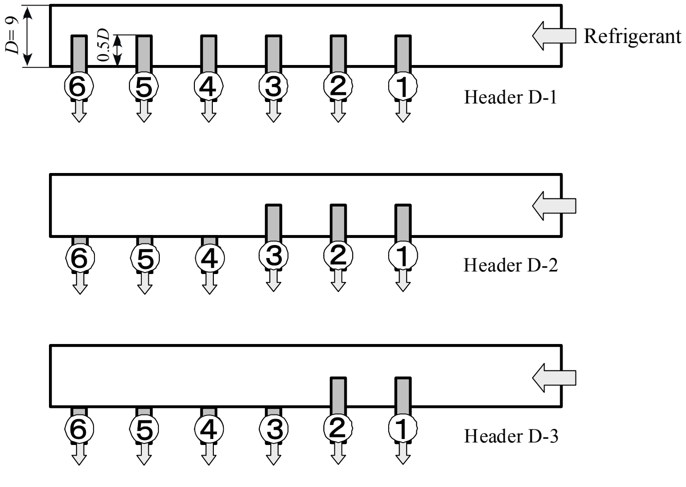

Figure 3: Configurations of headers

Figure 2 shows the schematic diagram of the test section. The test section consists of a 9 mm i.d. horizontal header and 6 downward branching conduits. The header is made of transparent PVC resin for the visualization the refrigerant flow regime. Each conduit is composed of an aluminum disk plate and an aluminum minichannel-branch. Each branch has 6 x 0.85 mm i.d. minichannels. Two pressure ports are installed at the disk plate to measure pressure difference in the minichannel-branch. Figure 3 shows the configurations of the test headers. The header D-1 consists of six branches with insertion 50%. The header D-2 is configured by three branches with insertion 50% at front side of the header and other three branches without insertion at rear side of the header. The header D-3 is configured by two branches with insertion 50% at the front side and remaining four branches without insertion.

One K-type sheath thermocouple of 0.5 mm diameter was installed at each mixing chamber for the measurement of local refrigerant temperature. Prior to the installment, all thermocouples were calibrated within an error of ±0.05K. The temperatures of cooling brine were controlled within an accuracy of $\pm 0.1^{o}C$ by three constant temperature brine baths. The static pressures in the mixing chambers at the inlet and outlet of the evaporator are measured by gauge pressure transducers with an accuracy of ±0.1%. The pressure difference in each branching conduit was measured by a differential pressure transducer with an accuracy of ±0.3%. The flow rate of refrigerant was measured by a Coriolis mass flow meter within an accuracy of ±0.43%. The flow rates of the vapor phase were measured by thermal mass flow meters and each thermal mass flow meter has an accuracy of ±0.7%. The flow rates of the liquid phase were measured by turbine mass flow meters and each turbine mass flow meter has an accuracy of ±0.1%. The power input to the evaporator was measured by a wattmeter with an accuracy of ±0.5%. The outputs of the thermocouples, gauge pressure transducers and evaporator were read and recorded consecutively 10 times by a programmable Keithley data logger.

Experiments are conducted at saturation temperature of about 21°C, refrigerant mass flow rate of about 30 kg/h which corresponds to mass velocity of about 130 kg/(m^{2}s) in the 9 mm header, and average vapor quality in header inlet x of about 0.1, 0.2, 0.3 and 0.4. The vapor quality is defined as the ratio of the vapor flow rate over the total flow rate:

$$x = \frac{w_v}{w_v + w_l} \tag{1}$$

The vapor quality in the inlet of the test header is executed from an enthalpy balance using measured temperature, mass flow rate and electrical heat input of the evaporator. The thermodynamic and transport properties of refrigerant R-134a are determined by the program package REFPROP 7.0 (McLinden et al., 2002).

Flow regimes at each branch inlet are defined to describe the phase separation in the header according to the flow pattern map developed by Wojtan et al. (2005) which divides flow regimes into stratified (S), stratified-wavy (SW), slug (Slug), slug/stratified-wavy (Slug+SW), intermittent (I) and annular flow (A). The map is presented in vapor quality as the abscissa versus mass velocity as the ordinate that facilities observation of the evolution of flow regime transitions along the header at fixed mass velocity with increasing vapor quality.

3. EXPERIMENTAL RESULTS

Figures 4, 5 and 6 show the experimental results of the vapor-liquid distribution in the branching conduits separately for the headers D-1, D-2 and D-3, respectively. For all conduits, the liquid phase distributes most easily to the first branch of the header and the vapor phase is directed to the downstream of the header. This is probably due to that the inertia effect in the downstream direction is more pronounced than the gravity effect. The inertia and gravity act in different directions for downflows.

All the figures show that the vapor quality in the header inlet influences the vapor phase and liquid phase distributions. Increasing the vapor quality in the header inlet gives better distribution of the vapor phase for all branches. Contrary to the improved vapor distribution at higher header inlet vapor quality, the liquid phase distribution is better in the low vapor quality experiments.

As can be seen from Figures 4, 5 and 6, the headers configured by compound of the branches with and without insertion offer the significant reduced maldistribution both the vapor and liquid phases. The header D-1 provides severe maldistribution both the phases. The header D-1 distributes the vapor and the liquid phases unevenly. However, the headers D-2 and D-3 distribute the phases almost evenly. The insertion in the upstream of the header affect more liquid enables to proceed until approaching the downstream of the header. It is probably due to that that the insertions influence the local inertia change inside the header.

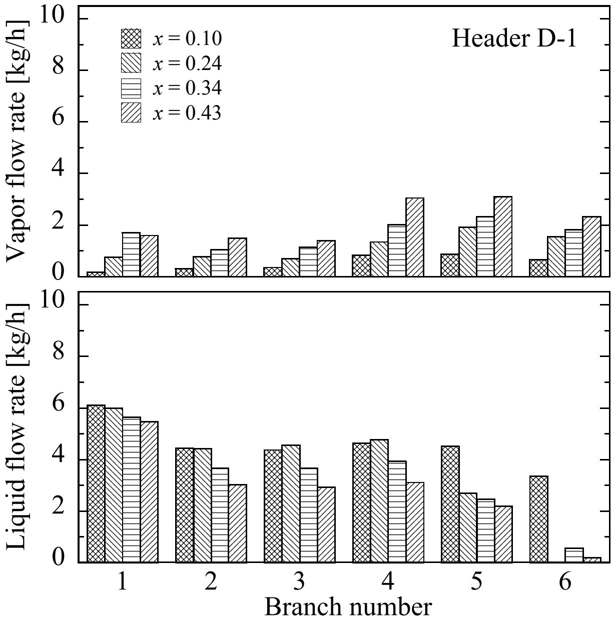

Figure 4: Vapor and liquid flow rates of header D-1

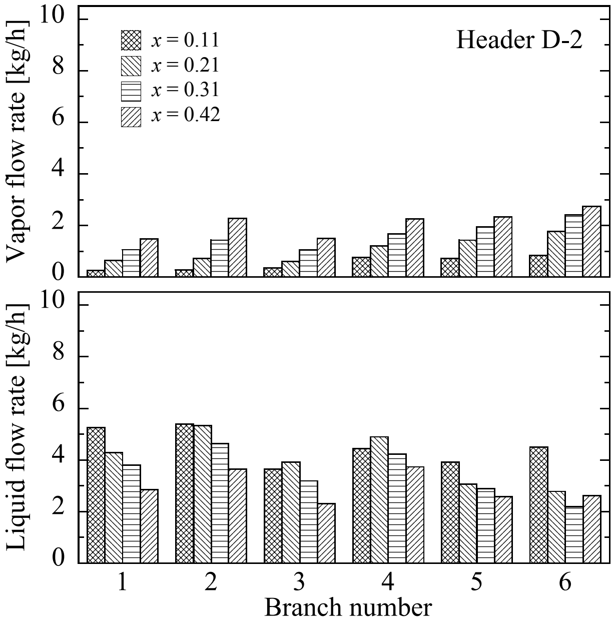

Figure 5: Vapor and liquid flow rates of header D-2

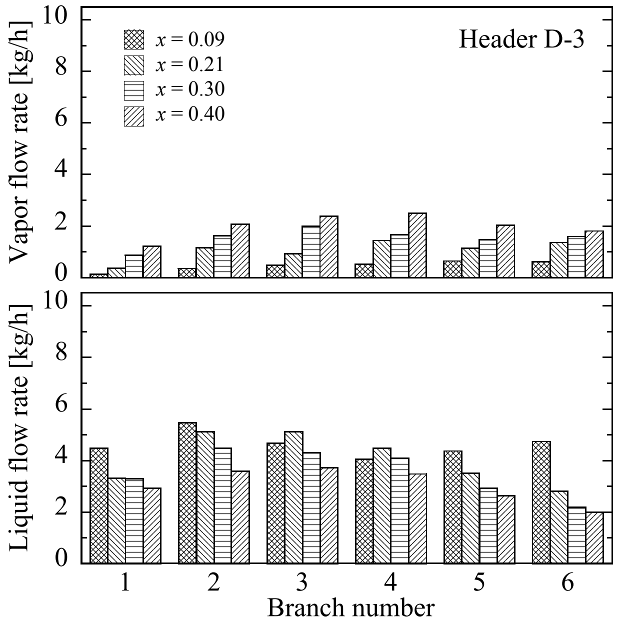

Figure 6: Vapor and liquid flow rates of header D-3

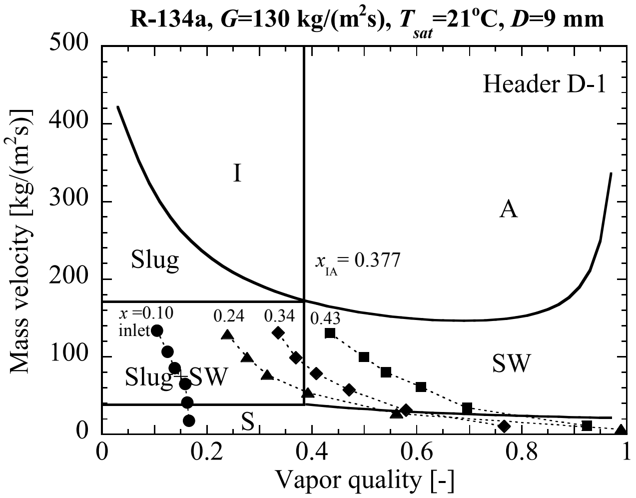

Figure 7: Phase separation in header D-1

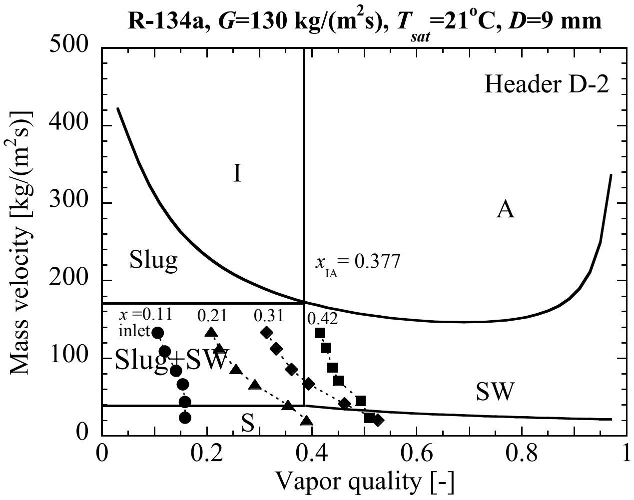

Figure 8: Phase separation in header D-2

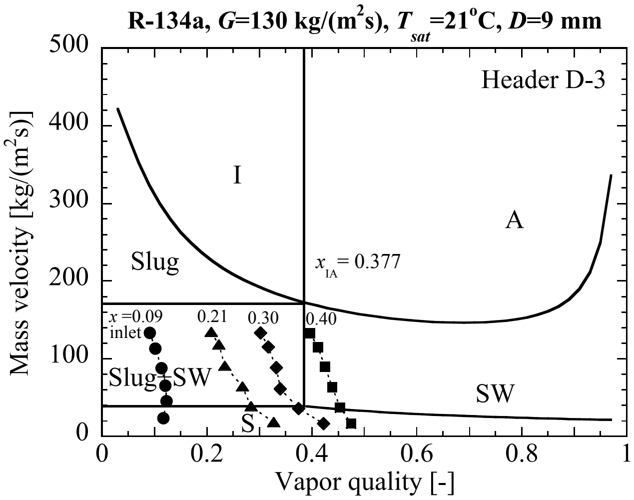

Figure 9: Phase separation in header D-3

Figures 7, 8 and 9 show the flow pattern map to explain the phase separation in the header D-1, D-2 and D-3, respectively. All figures reveal phase separation. The phase separation increases with the increase of maldistribution. No phase separation means that all vapor qualities from the header inlet to the downstream of the header is constant. The header D-1 provides serious phase separation. The headers D-2 and D-3 offers the significant reduced phase separation. The tendency of the phase separation goes on the downstream direction with higher vapor quality.

The headers configured by compound of branches with and without insertion give the better distribution of the two-phase flow. The insertions have no effect on the flow regime but only affect the liquid level in the rear side of the header. The header configurations influence the phase separation inside the headers. Although the experimental results do not provide complete uniform distribution, the significant reduced phase separation is provided by the headers D-2 and D-3. The header D-3 provides the lowest phase separation among all the headers studied here.

4. CONCLUSIONS

Experimental results are presented for better understanding the two-phase distribution in the headers with downward minichannel-branches. Three headers have been examined at various experimental conditions.

The liquid distributes most easily at the first branch and the vapor flows down directly the downstream of the header. The vapor quality in the header inlet influences the vapor phase and liquid phase distributions. Increasing the vapor quality in the header inlet gives better distribution of the vapor phase.

The existence of insertion improves the headers to distribute the phases more evenly. It is evident that the two-phase distribution strongly depends on the geometry and configuration of the headers. Although the experimental results do not provide a complete uniform distribution, the header D-3 provides the lowest phase separation.

NOMENCLATURE

D	header diameter	(mm)
G	refrigerant mass velocity	(kg/(m^{2}s))
T	temperature	(^{o}C)
h	insertion height	(mm)
x	vapor quality	(-)
w	refrigerant flow rate	(kg/h)

Subscripts

sat	saturation
l	liquid phase
v	vapor phase

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