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ABSTRACT

A microchannel heat exchanger applied to air conditioners has advantages because of its high heat transfer performance. However, there are some challenges to utilize its maximum performance. One of the most important challenges is refrigerant maldistribution resulting in heat transfer deterioration when it is used as an evaporator. The authors proposed a refrigerant distribution header that can be applied to variable capacity air conditioners, named "Refrigerant loop header." In this paper, the "Refrigerant loop header", which enables to equally distribute in a wide range of capacity, is introduced. In addition, high distribution performance is experimentally confirmed at different refrigerant mass flow rates.

1. INTRODUCTION

In order to avoid global warming, the regulation for the reduction of CO_2 emissions has become stricter. For air conditioners, an improvement of energy efficiency is required. In order to improve efficiency of air conditioners, a heat exchanger needs to be required to acquire larger capacity at a small temperature difference between air and refrigerant. To design a heat exchanger for higher efficiency, the volume of the heat exchanger becomes larger. Therefore, the compact heat exchanger with higher performance is desired. The conventional heat exchanger employed in air conditioners is a finned tube heat exchanger composed of aluminum fin and copper tube. In this type of heat exchangers, a lot of researchers investigated to improve their performance (Biswas *et al*., 1994) (O'Brien and Sohal, 2005) (Stone, 1996) (Yu and Ho, 2009) (Zhang *et al*., 1997). Recently, a microchannel heat exchanger has much attention because of its higher heat transfer performance compared to the conventional heat exchanger. On the air side, because the boundary layer separation area, which occurs in the downstream of a circular tube for a finned tube heat exchanger, is decreased by the flat tube, the heat transfer coefficient is higher. On the refrigerant side, the inner heat transfer surface area is largely increased because the multiport extrude tube is employed. In addition, the heat resistance at the contact between fin and tube is much smaller by brazing. As shown in Fig. 1 some outdoor units mounted with a microchannel heat exchanger have been released.

However, there are challenges to apply the microchannel heat exchanger to air conditioners. One of the most important challenges is the reduction of refrigerant maldistribution especially when it is used as an evaporator (Fujino *et al*., 2014). In microchannel heat exchangers applied to air conditioners, the drainage performance on fins is important because the water contained air is condensed on fins resulting in increasing pressure drop on the air side. In addition to that, during defrosting operation, the improvement of drainage of melted frost on fins is demanded for higher efficiency. From these points of view, the plate type fin with a drainage guide is employed shown in Fig. 2. That is why the flat tubes are stacked in the gravitational direction. On the other hand, when the refrigerant is equally distributed to vertically stacked tubes in its header, the two-phase refrigerant is separated by gravity, resulting in maldistribution. That is the challenge to maximize the performance of microchannel heat exchangers applied to air conditioners. To reduce the maldistribution in the header, a lot of investigation both in experiments and simulations (Lee, 2010) (Zou and Hrnjak, 2013a) (Zou and Hrnjak, 2013b) (Zou and Hrnjak, 2014) (Zou *et al*., 2014). However, although the conventional distribution header has high distribution performance at a mass flow rate, the microchannel heat exchanger applied to air conditioners is demanded at various mass flow rates because variable capacities are operated by an inverter. In order to solve this challenge, the authors developed a "Refrigerant loop header" to realize the stable refrigerant distribution at different refrigerant flow rates. In this paper, the structure of "Refrigerant loop header" is introduced and experiments to evaluate the performance of this refrigerant distribution header were conducted.

2. REFRIGERANT DISTRIBUTION IN MCHX

2.1 Challenges of maldistribution in MCHX at different refrigerant mass flow rates

Figure 3 (a) shows the structure of the conventional insertion type distribution header. the header is composed of a header and flat tube. In order to equally distribute to each flat tube in the vertical header, the two-phase refrigerant flows in the upward direction to supply the liquid refrigerant with upper flat tubes by inertia force. For the control of inertia force, the cross-section area is adjusted by changing the insertion depth of the flat tube. Fig. 3 (b) shows the infrared image captured from the face area of the heat exchanger. the blue area indicates the two-phase region and the red area indicates the superheated region. In order to maximize the performance of the heat exchanger, the same two-phase length at each tube is desired. The refrigerant velocity is defined as equation (1)

Figure 1: Outdoor unit mounted with MCHX

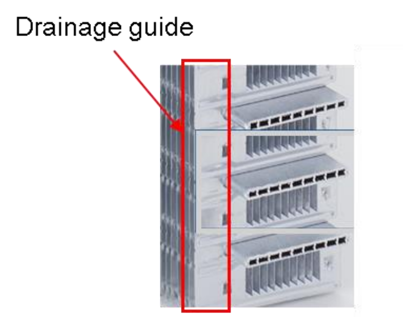
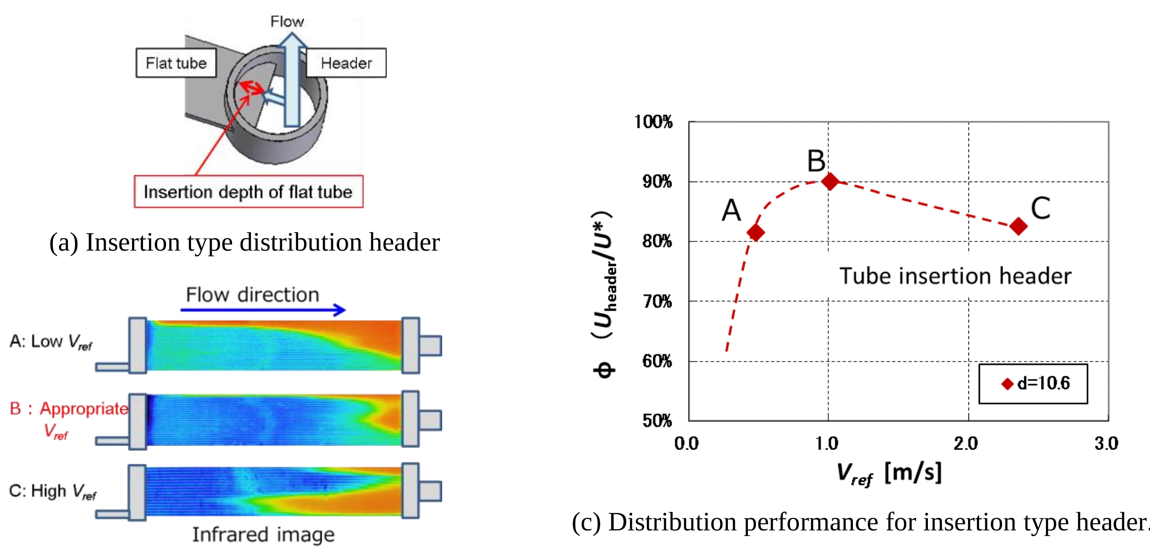


Figure 2: Microchannel heat



(a) Insertion type distribution header

(b) Infrared image at different mass flow rates

(c) Distribution performance for insertion type header.

Figure 3: Distribution characteristics for an insertion header (Inoue *et al*., 2018).

$$V_{ref} = Gr / (\rho_{ave}\, S). \tag{1}$$

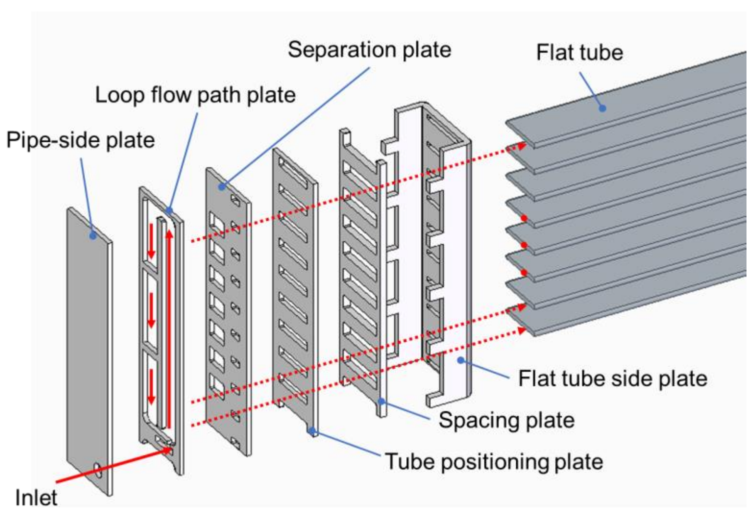
where ρ_{ave}: averaged density (homogeneous), S: cross-sectional area of the upward path. At low V_{ref}, the superheated region is observed in the upper region. With increasing V_{ref}, the superheated region is moved lower. At appropriate V_{ref}, the distribution performance is the highest among these 3 points. From these results, the insertion type distribution header still has a challenge to be applied at various refrigerant mass flow rates

2.2 Refrigerant loop header

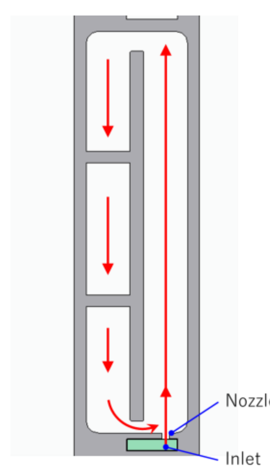
In order to solve this challenge, a distribution header is proposed. The structure of the distribution header, named "Refrigerant loop header" is shown in Fig. 4(a). This header is composed of 6 plates. The two-phase refrigerant flows through the inlet hole in a "pipe-side plate", which is connected to the inlet pipe. In a "loop flow path plate", the refrigerant flows up to supply its liquid with upper flat tubes. As shown in Fig. 3, in the insertion type distribution header, if the refrigerant velocity is increased, the liquid supply to the upper flat tubes is increased because the inertia force is much larger than gravity, resulting in maldistribution. To keep the appropriate distribution, the loop flow path is introduced to return the liquid to the region just above the inlet. In addition, in order to return to the upstream, a nozzle to suck the refrigerant from the return path is located. A "Separation path plate" plays a role in connecting between the loop flow path and the path for flat tubes. By a "Tube positioning plate," a "Spacing plate," and a "Flat tube side plate", the header and flat tubes are assembled by brazing.

3. EXPERIMENTAL APPARATUS

For evaluation of the distribution performance of "Refrigerant loop header", experiments using a heat exchanger are conducted. Fig.5 shows the experimental setup. On the refrigerant side (Fig.5 (b)), a closed test loop is employed. Refrigerant flow rate is controlled by a pump and measured by a Coriolis flow meter. In order to adjust inlet quality, a pre-heater is located at upstream of the test section. Another heater is located in the downstream of the test section because outlet quality is evaluated by this heater input, superheated temperature at the outlet of this heater, and refrigerant mass flow rate. Refrigerant outlet pressure is controlled by a cooling heat exchanger and a subcooler. On the air side (Fig.5(b)), a test section is located on the side of an air chamber. To adjust air flow velocity, a blower power is controlled while measuring the pressure drop at a nozzle, which is located in the air chamber. The dry bulb and wet bulb at both inlet and outlet are measured by Pt temperature sensor in the air samplers. The heat exchanger surface temperature distribution is measured by an infrared camera. The uncertainties are ±0.06 K in the temperature



(a) Overall structure.

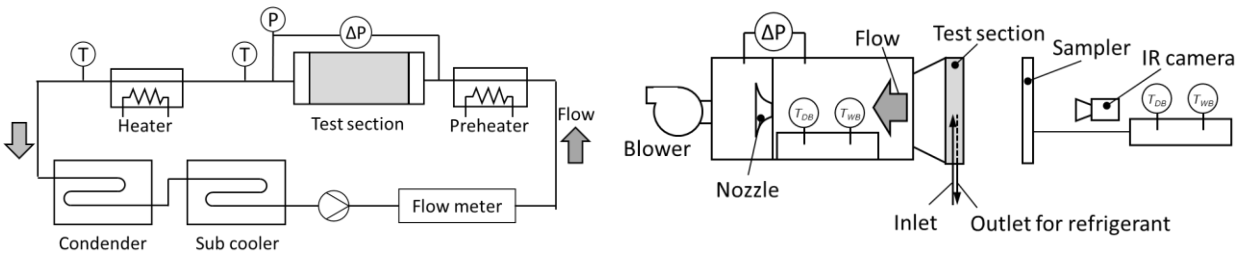


(b) Loop flow path plate

Figure 4: Refrigerant loop header

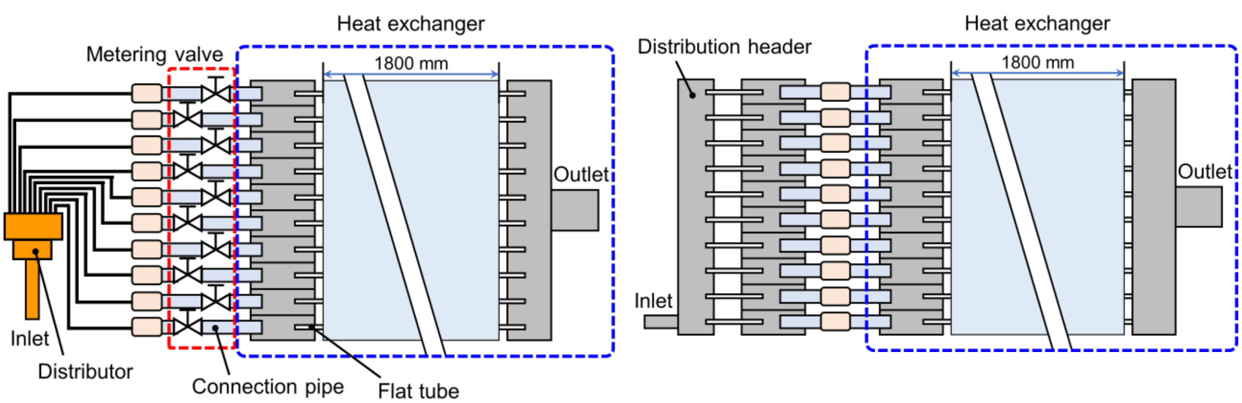
obtained by Pt thermometer, ±0.25%FS in pressure, and ±0.1%RD in refrigerant flow rate. The heat balance error between air side and refrigerant side is within ±3%.

The distribution performance is evaluated by the following method. First, the overall heat transfer coefficient of the heat exchanger under the equally distributed refrigerant condition U^* is evaluated. The equally distributed refrigerant condition is defined here as that when the temperature distribution along the refrigerant flow direction for each tube obtained by thermocouples located on the outer walls of each flat tube in the downstream is equal. Fig. 6(a) shows the configuration to acquire the equally distributed capacity. The flow rate in each tube is adjusted by using the distributor and the inlet valves. Next, to evaluate the distribution performance, the distribution header is connected



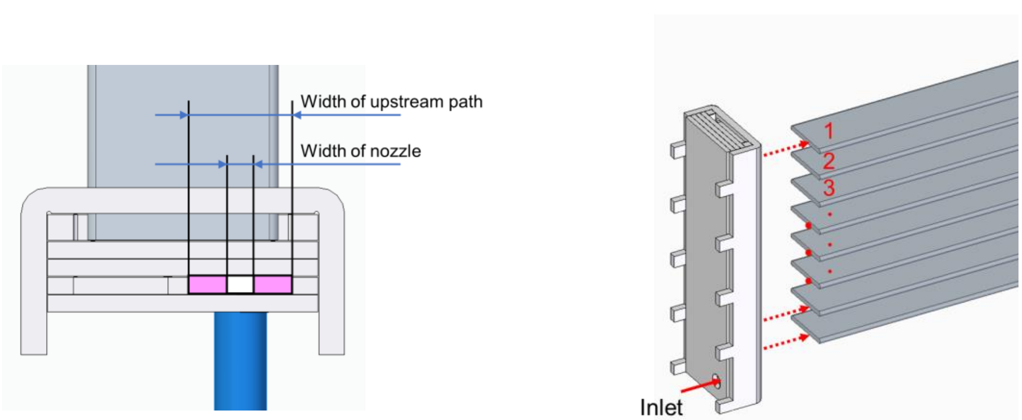
(a) Refrigerant loop (b) Air blow

Figure 5: Schematic diagram of test facility



(a) For base data (b) With distribution header

Figure 6: Configuration to evaluate distribution performance



(a) Cross section for upstream path (b) Number of steps

Figure 7: Definition of design parameter.

Table 1: Experimental condition.

Dry−bulb temp. T_{DB}	**Wet-bulb temp.** T_{WB}	**Air velocity** V_a	**Refrigerant**	**Mass flow rate** Gr	**Inlet quality** x_{in}	**Outlet quality** x_{out}
7 °C	6 °C	1.5 m/s	R410A	21 – 44 kg/hr	0.08	0.98
14°C	11.5°C			80 kg/hr		

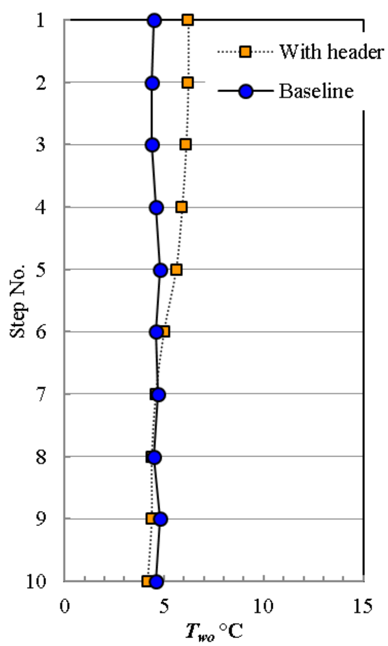
to the inlet of tubes. After adjusting inlet and outlet quality and mass flow rate by controlling outlet pressure, the overall heat transfer coefficient U is evaluated. From these two values, the distribution factor ϕ is defined as equation (2)

$$\phi = U / U^{*}. \tag{2}$$

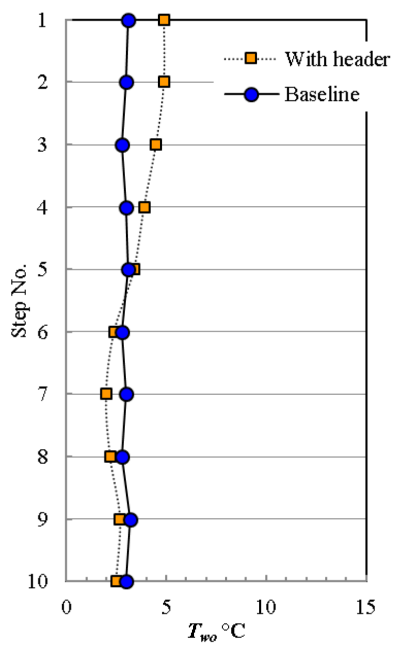
At the same time, temperature distribution at the outer wall of flat tubes is measured to observe the tendency of maldistribution. Fig. 7 shows the design parameters for "Refrigerant loop header." The width of the upward flow path is set to 6 mm, and that of the nozzle is set to 2 mm, respectively. The number of steps is fixed at 10. Table 1 shows the experimental conditions. The refrigerant is used R410A.

4. RESULTS AND DISCUSSION

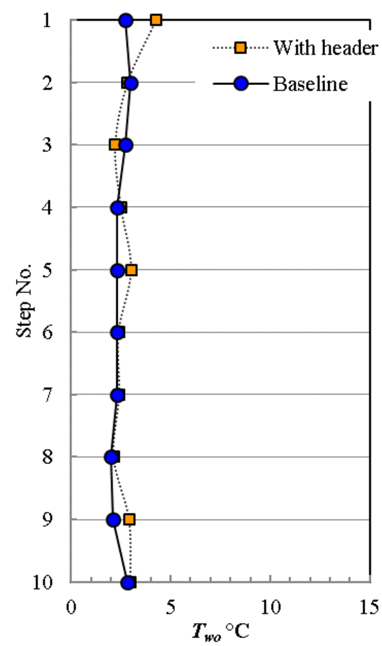
Figure 8 shows the flat tube outer wall temperature distribution in downstream. The temperature distribution under the equal distributed condition is defined as a baseline. At Gr = 20 and 43.6 kg/hr, the temperature is larger at the upper steps with the distribution header. This tendency indicates that the liquid flow is decreased at upper tubes. However, because the wall temperature is less than air temperature, the superheated length is not largely extended. At Gr = 79.6 kg/hr, the temperature distribution is similar. From these results, this distribution header enables to keep high distribution performance at different mass flow rates. Fig. 9 shows the comparison of the refrigerant factor



(a) Gr = 20.2 kg/hr



(b) Gr = 43.6 kg/hr



(c) Gr = 79.6 kg/hr

Figure 8: Wall temperature distribution at each tube outlet

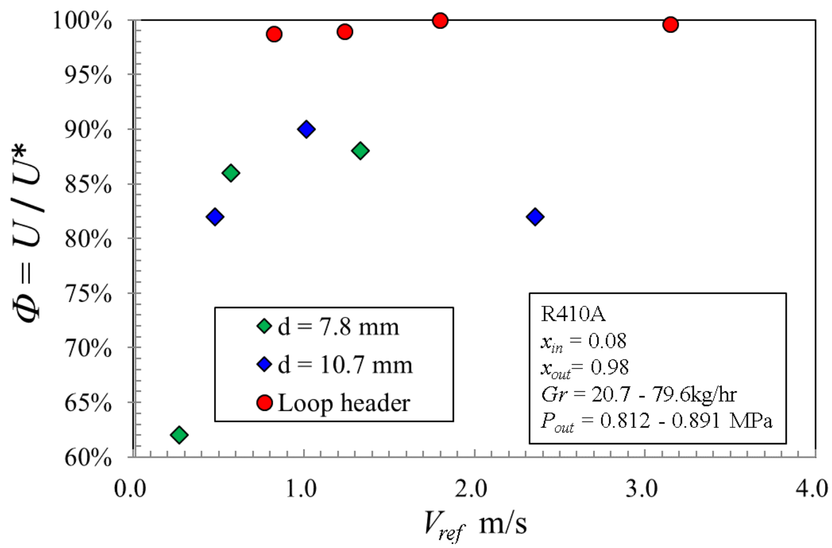


Figure 9: Distribution performance

ϕ between an insertion header and a refrigerant loop header. For an insertion header, the insertion flat tube depth is indicated by *d*. As explained above, for the insertion header, although the distribution factor has a maximum value at appropriate V_{ref}, the factor is decreased at different V_{ref}. On the other hand, for the refrigerant loop header, at low V_{ref}, the distribution factor is increased with increasing V_{ref}. In addition, the distribution performance is kept at more than 98% at moderate and higher V_{ref}. In this design point, the refrigerant velocity is enough to supply liquid with upper steps even at the smallest mass flow rate of 20 kg/hr. In addition to that, with increasing mass flow rate up to 4 times, the maldistribution resulting in the heat transfer deterioration does not occur because the refrigerant is circulated along the loop flow path in this distribution header. As a result, for the refrigerant loop header, even if the mass flow rate is increased 4 times, the distribution performance seems to be kept at more than 97%.

5. CONCLUSION

To solve the technical challenge of maldistribution for a microchannel heat exchanger applied to air conditioners, a distribution header named "Refrigerant loop header" is proposed. The structure and concept of this header is introduced. For the validation of distribution performance, experiments were conducted using a heat exchanger. From the experimental results, the high distribution performance can be kept even if the mass flow rate is increased up to 4 times. This technique has been applied to inverter air conditioners.

NOMENCLATURE

Φ	distribution factor	(%)
Gr	mass flow rate	(kg/hr)
P	pressure	(Pa)
T	temperature	(°C)
U	overall heat transfer coefficient	(W/m^2 K)
V	velocity	(m/s)
x	quality	(-)

Subscript

a	air
DB	dry bulb
in	inlet
o	outer

out	outlet
ref	refrigerant
w	wall
WB	wet bulb

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