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ABSTRACT

Micro channel heat exchanger (MC-HEX) is more effective for a performance enhancement than a conventional fin and tube heat exchanger (F&T). MC-HEX was applied to the automotive HVAC system at first, then it was applied to a residential air-conditioner recently. Because MC-HEX helps to reduce refrigerant quantities in air-conditioner systems, we apply MC-HEX to not only cooling cycles but also heat pump cycles for residential air-conditioners. It means that our MC-HEX could solve the issue of frost in heating mode.

On the other hand, the heat pump cycle came to be applied to the automotive HVAC system for reducing consumption electricity of EV and HEV/PHEV. However, the typical automotive heat pump cycle is different from the heat pump cycle of a residential air-conditioner. Usually the heat pump cycle of a residential air-conditioner is consisted of two heat exchangers with a reverse cycle mode, but the automotive heat pump cycle consist of three heat exchangers without reverse cycle modes. Therefore, MC-HEX of a residential air-conditioner cannot be applied to an automotive HVAC system especially for outside heat exchangers.

In this paper, our MC-HEX for an outdoor unit of residential air-conditioner is modified to apply to an automotive heat pump cycle. The tube-pass design of our MC-HEX for an outdoor unit of residential air-conditioner gives priority to the performance in the evaporation condition (heating mode) because of improving annual efficiency. As a result, the condensation performance should decrease, because the most suitable tube-pass design of the condensation is different from the evaporation in MC-HEX. But MC-HEX for an automotive heat pump system has to give priority to the performance in the condensation condition (cooling mode) with high frost performance. This trade-off is solved by developing a variable circuit which applied the tube-pass arrangement that is different from a condensation condition and an evaporation condition. The inside structure of the header for controlling distribution which can correspond to the down flow of the refrigerant in the evaporation condition is also developed. As a result, our MC-HEX has the same condensation performance with an automotive HVAC system and the same evaporation performance and frost performance with a residential air-conditioner.

1. INTRODUCTION

Micro channel heat exchanger (MC-HEX) is more effective for a performance enhancement than a conventional fin and tube heat exchanger (F&T) in a residential air-conditioner. And MC-HEX helps to reduce refrigerant quantities in residential air-conditioner systems. MC-HEX is applied to the air-conditioner for almost all vehicles, but it had not been used a lot in residential air-conditioners except Samsung air-conditioner, According to Samsung air-conditioner, we applied MC-HEX (PFC) to the outdoor unit of the residential air-conditioner (cooling only model) since 2006. And we developed the MC-HEX (PFE) to the indoor unit of the residential air-conditioner in 2011, which modified the heat exchanger for the automotive HVAC system. Also in order to solve the frost and de-frost problem in the heat pump outdoor unit, we developed a new MC-HEX (FMC) which changed the fin design from corrugate type to the flat type in 2012. Furthermore we developed the new type MC-HEX (FME) to apply to a heat pump indoor unit in 2013, which consists of perpendicular micro channel tubes and horizontal headers with flat type fins. Now we have 4 types of MC-HEX which are applicable to all of the residential air conditioner products (Fig. 1).
On the other hand, the heat pump cycle came to be applied to the automotive HVAC system for reducing consumption electricity of EV and HEV/PHEV. It means that MC-HEX is used as an evaporator at low temperature (outside). But the general condenser of MC-HEX for automotive HVAC system does not have drainage structure,

and frost is generated early by high fin efficiency and direct exposure of the tube. Though the general evaporator of MC-HEX for automotive HVAC system has drainage structure, the frost grows up for the same reason as earlier condenser. After de-frosting, freezing is generated on the surface of the evaporator, because condensation water is remained by a long drainage path (Fig.2).

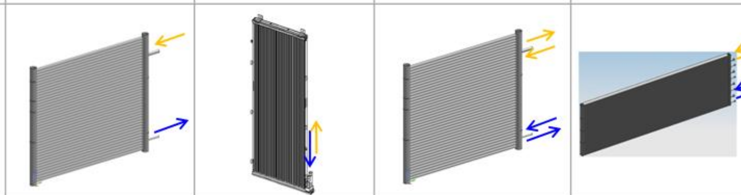
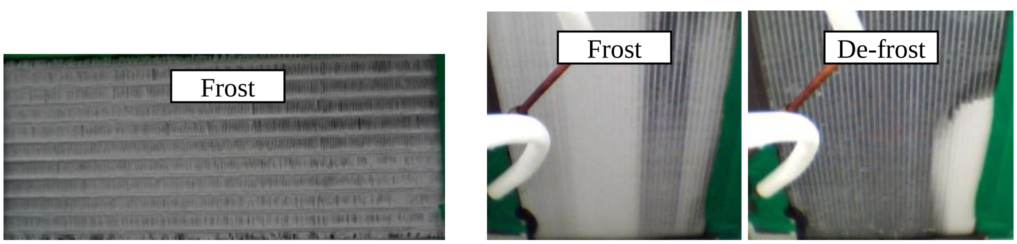
		Samsung MC-HEX			
		PFC Parallel Flow Condenser	PFE Parallel Flow Evaporator	FMC Fin & Micro channel Cond.	FME Fin & Micro channel Evap.
					
Charac teristic	Fin				
		W16 / 10mm	W26.8 / 19.3mm	W28mm	W26mm
	Tube				
		W16 / 10mm	W12 / 8mm	W20mm	W9.5+9.5mm
Material		All AL			
Application		Out door unit (Cooling model)	In door unit (Cooling model)	Out door unit (Heat pump)	In door unit (Heat pump)
Performance		120%	128%	117%	125%

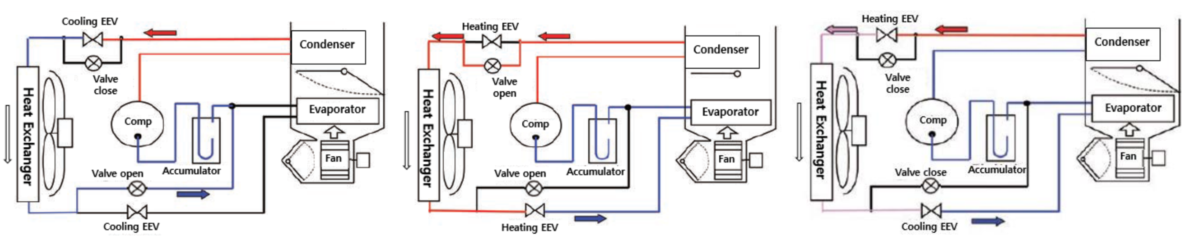
Figure 1: 4 types of MC-HEX in Samsung



(a) MC-HEC (Condenser) (b) MC-HEX (Evaporator)

Figure 2: State of the frost in conventional MC-HEX

Representative automotive heat pump cycle is consisted of three heat exchangers without a reverse cycle mode (Fig. 3). In other words, the refrigerant flow direction of condensation is the same as the evaporation in MC-HEX. Therefore, the tube-pass design that considered the volume ratio of refrigerant is usually applied for general automotive HVAC system, but it is difficult to design the most suitable tube-pass pattern because the refrigerant flow direction of condensation is the same as evaporation in the automotive heat pump system.



(1) Cooling mode (2) Heating mode (3) Dehumidifying and heating mode

Figure 3: Automotive heat pump cycle

The tube-pass design of our MC-HEX (FMC) for outdoor unit of residential heat pump air-conditioner gives priority to the performance in the evaporation condition (heating mode) because of improving annual efficiency. Air side fin shape and micro channel size is also designed for evaporation condition (heating mode) preferentially. As a result, the condensation performance should decrease, because the most suitable tube-pass design of the condensation is different from evaporation in MC-HEX (FMC). Comparison of operating conditions between the residential air-conditioner and the automotive heat pump system are summarized in Table 1. Large cooling capacity is necessary for heat load by the sun, and large heating capacity is necessary to heat low temperature fresh air directly for the automotive heat pump system.

Table 1: Comparison between residential air-conditioner and automotive heat pump system

		Residential air-conditioner		Automotive heat pump system	
Refrigerant		R410A → R32		R134A → R1234yf	
Indoor temp.	Summer	30 ~ 40 ℃		50 ~ 70 ℃	
	Winter	5 ~ 10 ℃		-10 ~ 0 ℃	
Air velocity	Evap.	1.0 ~ 1.5 m/s		2.0 ~ 3.0 m/s	
	Cond	1.5 ~ 2.0 m/s		4.0 ~ 5.0 m/s	
Capacity	Cooling	20 m^2	2,200 W	Middle	5,000 W
	Heating		2,500 W		6,000 W

2. MODIFY THE DESIGN OF MC-HEX (FMC) TO APPLY TO AUTOMOTIVE HEAT PUMP CYCLE

In this section, our MC-HEX (FMC) for outdoor unit of residential air-conditioner is modified to apply to the automotive heat pump cycle. The design of a fin shape is changed in consideration of heat transfer performance at high air velocity and frost characteristics. A heat transfer area of the refrigerant side is increased by reducing micro channel size which give priority to condensation performance. The pressure drop of the refrigerant side on the evaporation condition is to rise by reducing the micro channel size is solved by a variable circuit. It helps constitute the suitable tube-pass design in both evaporation and condensation conditions. The inside structure of the header for controlling refrigerant distribution is applied for corresponding to the down flow of the refrigerant in the evaporation condition.

2.1 Modify the air-side performance

The fin shape of our MC-HEX (FMC) for outdoor unit of residential heat pump air-conditioner is designed for frost characteristics. A block of the air by the frost adhesion is controlled by the spread of the fin area at the upper flow. Even the fin width of MC-HEX (FMC) is larger than MC-HEX (PFC), therefore the pressure drop is lower because the number of louver is minimized. As a result, heat transfer performance in the high air velocity decreased compared to than MC-HEX (PFC) for the outdoor unit of the residential air-conditioner (Fig.4).

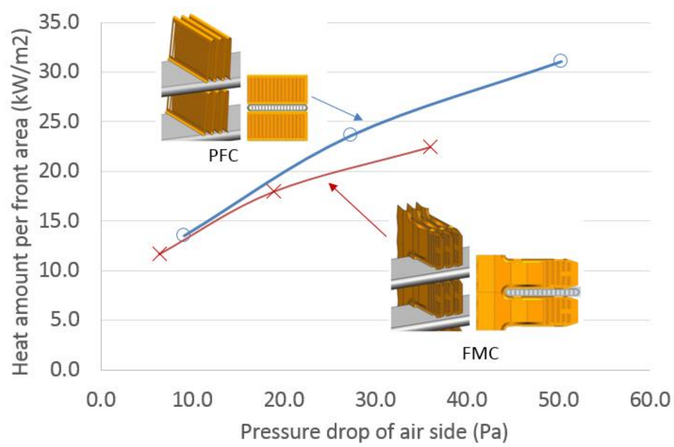


Figure 4: Comparison of performance between PFC and FMC

Design of the fin shape is modified for increasing heat transfer performance at high air velocity and frost characteristics. Because the production facility will have no big change, the fin width and the tube pitch is fixed, and only the fin shape, especially louver design, is considered with the limitation that pressure drop becomes less than MC-HEX (PFC) (Table 2). Performance increases about 9% at front velocity 2.0 (m/s) by increasing the number of the louvers (Case 1, 4). However, it is expected that frost characteristic turns worse, so the gap that air flow can bypass after generated frost is designed (Case 9~12). Finally performance of No. 9 fin shape increases about 7% and pressure drop increases about 69% more than original fin shape that is selected (Fig.5).

Table 2: Parameter of fin shape

Case No.	Level			
	Louver pitch (mm)	Louver angle (°)	Fin pitch (mm)	Bypass gap (mm)
PFC	1.0	25	1.2	-
FMC	1.5	20	1.4	-
1	1.0	25	1.4	-
2	1.4	25	1.5	-
3	1.4	20	1.5	-
4	1.0	20	1.4	-
5	1.0	20	1.5	-
6	1.4	20	1.4	-
7	1.4	25	1.4	-
8	1.0	25	1.5	-
9	1.0	25	1.4	1.0 (center)
10	1.0	25	1.4	3.0 (center)
11	1.0	25	1.4	2.0 (side)
12	1.0	25	1.4	3.0 (side)

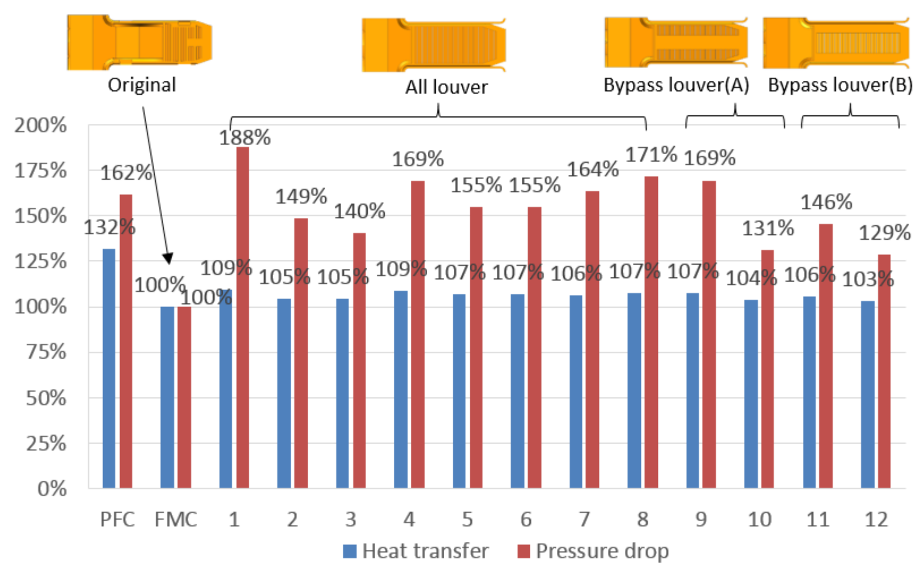


Figure 5: Results of the analysis for fin shape (STAR-CCM+11.02.009)

The experimental results of No.9 fin shape performance are shown in Figure 6. It is evaluated with water of 48.0 (Deg. C) as the refrigerant side and the air temperature is 35.0 (Deg. C). Heat amount per front area is increased about 10% and pressure drop is increased about 35%. The improvement of the heat amount accords with a calculation result. And it is supposed that the difference with the calculation result in the pressure drop is caused by the bar of the original fin edge part which is made by the abrasion of the die.

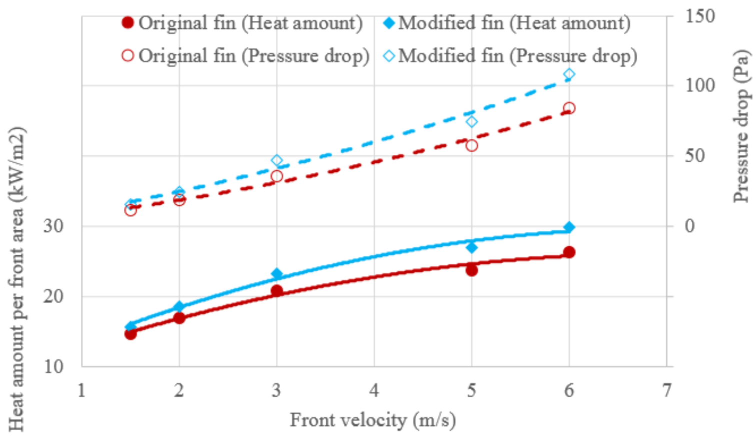


Figure 6: Experimental results of modified fin performance

2.2 Modify the refrigerant-side performance

Our MC-HEX (PFC) has a MC-Tube which has a hydraulic diameter of 0.82(mm). On the other hand, our MC-HEX (FMC) has a MC-Tube of 16 holes which the hydraulic diameter is 1.08(mm). This is in consideration of the performance degradation by the increase in pressure drop of evaporation conditions. As a result, it reduces condensation performance. Therefore, the number of the holes is increased to 25 (EA) from 16 (EA) for improving condensation performance (The hydraulic diameter becomes 0.78(mm)). The improvement of the performance is predicted by CoilDesigner4.0 (Fig.7). The heat transfer ratio of the air side calculated it using STAR-CCM+11.02.009, the heat transfer ratio of the refrigerant side is calculated by Shah (2016) equation, and the pressure drop of the refrigerant side is calculated by Homogeneous equation on the evaporation and Mishima equation on the condensation. Performance of 25 holes is 7% higher than 16 holes on the condensation condition, which is less than 4,000 (mm) in tube-pass length that is usually applied with our residential air-conditioner. And the performance of the evaporation condition decreases to 16 holes when the tube-pass length becomes longer.

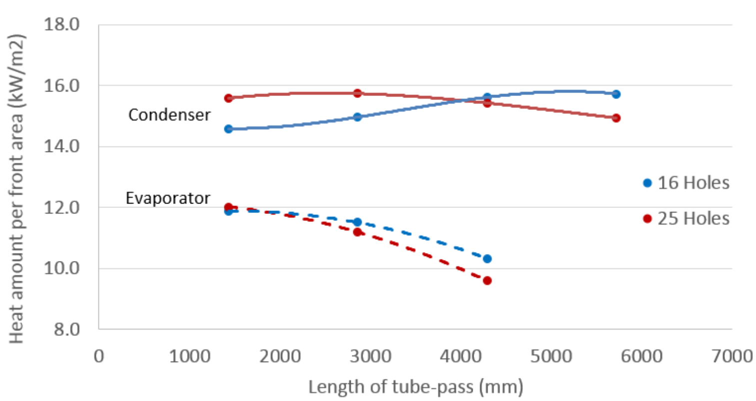
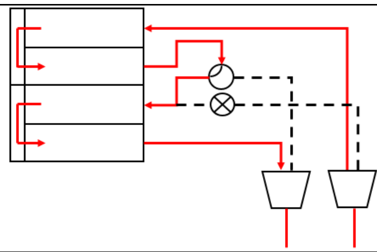
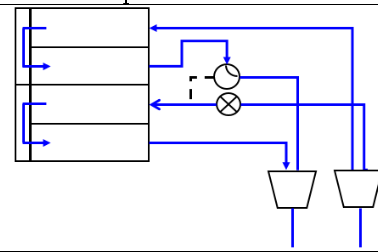


Figure 7: Influence on performance of hole size and tube-pass length

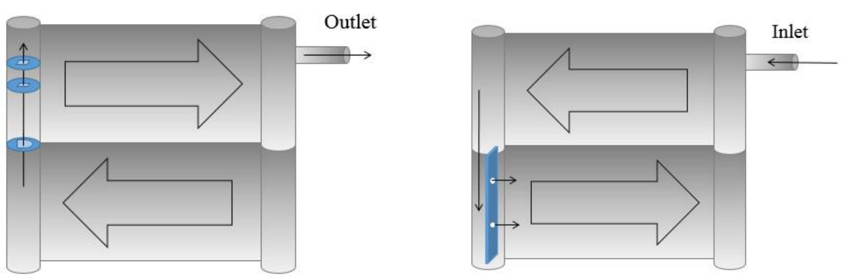
The variable tube-pass circuit which is different from the tube-pass length between condensation condition and evaporation condition is applied. It is for minimizing reduction of the performance of the evaporation condition (Table 3). In the case of the automotive heat pump system, the flow direction of the refrigerant is fixed, because a reverse cycle is not applied. The refrigerant always flows down from the upper section of MC-HEX. The variable tube-pass circuit is made by two Y-joints, 3-way valves, a valve and pipes. There is one inlet/outlet in the condensation condition, and the tube-pass consists of 4 sections. On the other hand, inlet/outlet becomes two in the evaporation condition, and the tube-pass consists of 2 sections. Therefore, the tube-pass length of the evaporation condition can make half of the tube-pass length of the condensation condition in the same MC-HEX.

Table 3: Constitution method of the variable tube-pass circuit

	Condensation condition	Evaporation condition
Constitution of the tube-pass		
Circuit	1 by 1 pass (4 sections)	2 by 2 pass (2 sections)

2.3 Modify the structure of the refrigerant distribution

The characteristics of the refrigerant distribution in the evaporation condition have a big influence on the performance of MC-HEX. Our MC-HEX (FMC) has a structure that improves refrigerant distribution which solves the state when a liquid refrigerant is hard to arrive at the upper part in header for gravity (Fig.8a). The direction of the refrigerant flow of MC-HEX in the evaporation condition is reversed for the automotive heat pump system. Therefore, a new structure which is suitable for a down flow of refrigerant is applied (Fig.8b). Furthermore, the position of inlet, outlet and cross section of the header suitable for a down flow in evaporation condition is considered using a jig (Fig.9).



(a) Original header structure (Evaporation) (b) Modified header structure (Evaporation)

Figure 8: Structure to improve refrigerant distribution

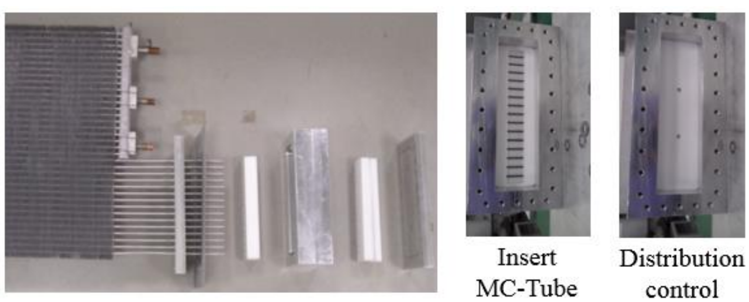
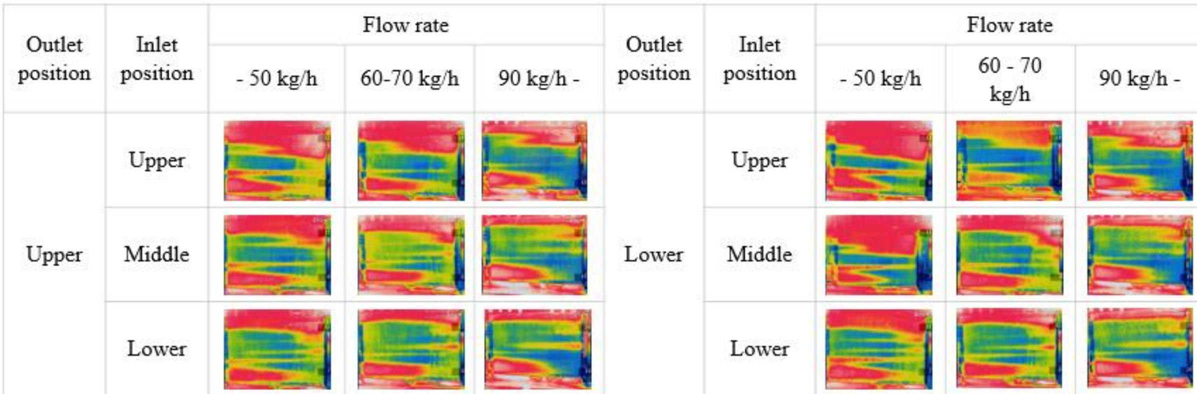


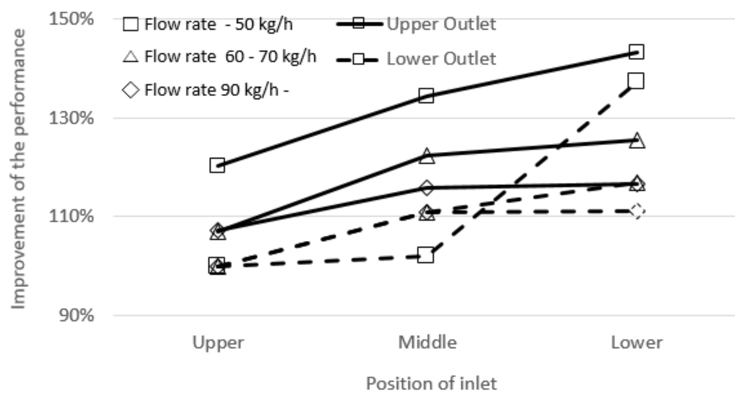
Figure 9: Jig for refrigerant distribution examination

The characteristics of the refrigerant distribution and the effects of performance improvement for inlet/outlet positions are shown in Figure 10. The position of the outlet is considered in upper and lower, and the position of inlet is considered in upper, middle and lower. It is evaluated with various refrigerant flow rates which are controlled by air side temperature, saturation temperature and the super heat of refrigerant outlet. The upper outlet has a good distribution characteristic and the performance is higher than the lower outlet in evaporation condition. Also the lower inlet has a good distribution characteristic and the performance is higher than the upper and middle inlets in the evaporation condition. The effect of performance improvement is large with low refrigerant flow rates. Its effect is 43%. The same evaluation is considered for the condensation condition, but the characteristics of the refrigerant distribution do not show a big difference. The effect of performance improvement is less than 2%.

The cross section of the header for characteristic of refrigerant distribution is also examined. It is evaluated with various refrigerant flow rates with 60% and 70% of cross sections for an original header (Fig.11). Distribution characteristics of the low flow rate condition are improved by reducing the cross section of the header, and performance is improved about 10%. However, the performance decreases about 5% with the high flow rate. In addition, refrigerant pressure drop is increased to approximately 5 times by reducing a cross section.
Finally, the header of the original cross section which has a new distribution control plate with lower inlet and upper outlet is selected.



(a) Image of refrigerant distribution by IR camera (Evaporation)



(b) Ratio of the performance improvement (Evaporation)

Figure 10: Improvement of refrigerant distribution by position of inlet/outlet

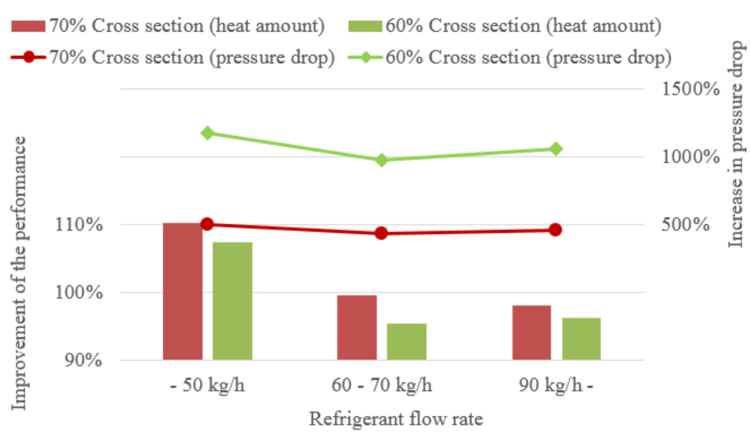


Figure 11: Improvement of refrigerant distribution by cross section of header

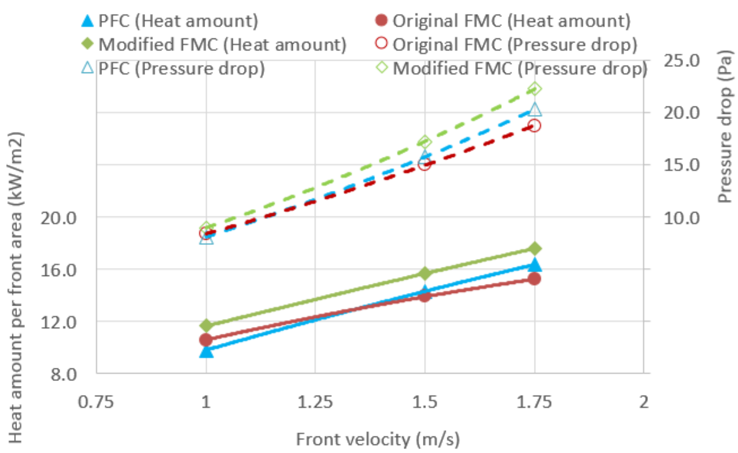
3. EXPERIMENTAL RESULTS OF MODIFIED MC-HEX (FMC)

In this section, modified MC-HEX (FMC) which has a modified fin shape, 25 holes MC-Tube with a variable tube-pass circuit, and a new distribution control plate is evaluated experimentally. Table 4 shows the test conditions and the specifications of MC-HEX (PFC, FMC). Test results are shown in Fig.12.

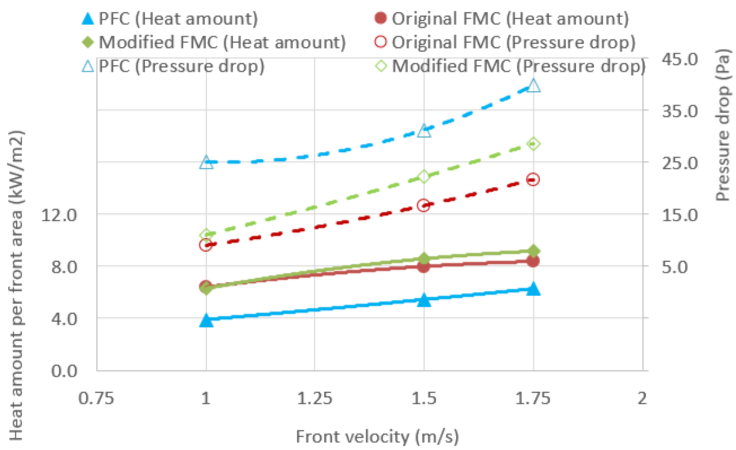
Table 4: Testing condition and specification of MC-HEX

Item	Unit	Condensation	Evaporation
Inlet air temp. (DB)	[℃]	35	7
Inlet air temp. (WB)	[℃]	24	6
Air velocity	[m/s]	1.0 – 1.75	1.0 – 1.75
Inlet ref. pressure	[MPa]	2.915	-
Outlet ref. pressure	[MPa]	-	0.797
Inlet ref. quality	[-]	-	0.26
Inlet ref. temp.	[℃]	78.0	-
Outlet ref. SC	[K]	7.0	-
Outlet ref. SH	[K]	-	1.5
		PFC	FMC
Size	[mm]	W690 H372 D16	W690 H378 D28
Number of MC-Tube	[EA]	37	35
Tube pitch	[mm]	1.2	1.4
Fin pitch	[mm]	9.8	10.5
Tube-pass	-	22-15	9-9-9-8 (9-9 / 9-8)

In the condensation condition, the tube-pass design of modified MC-HEX (FMC) is consisted of 1 pass and 4 sections (9-9-9-8). The heat amount of modified MC-HEX (FMC) improves about 15% more than the original MC-HEX (FMC), and it is 7% higher than MC-HEX (PFC). Pressure drop is increased about 19%, and it is 10% higher than MC-HEX (PFC). In the evaporation condition, the tube-pass design of the modified MC-HEX (FMC) is consisted of 2 passes, which has 2 sections (9-9, 9-8) each. MC-HEX (PFC) is specified only as a condenser originally, but it is compared by reference. The heat amount of modified MC-HEX (FMC) improves about 9% more than the original MC-HEX (FMC), and it is 46% higher than MC-HEX (PFC). Pressure drop is increased about 32%, and it is 28% lower than MC-HEX (PFC). As a results, the condensation performance of the modified MC-HEX (FMC) is higher than MC-HEX (PFC), and the evaporation performance of the modified MC-HEX (FMC) is higher than the original MC-HEX (FMC), while the pressure drop is almost the same with MC-HEX (PFC).



(a) Comparison of performance and pressure drop (Condensation)



(b) Comparison of performance and pressure drop (Evaporation)

Figure 12: Result of performance improvement (PFC vs. FMC vs. Modified FMC)

On the other hand, the frost characteristics of the modified MC-HEX (FMC) is evaluated (Fig.13). The time of the peak performance is different between the original MC-HEX (FMC) and modified MC-HEX (FMC), but as for the performance in the same time, the modified MC-HEX (FMC) is decreased up to 18% more than the original MC-HEX (FMC). The total heat amount of the modified MC-HEX (FMC) is decreased by 4% compared to the original MC-HEX (FMC). It is supposed that the gap of the louver part delays air flow blocked by frost.

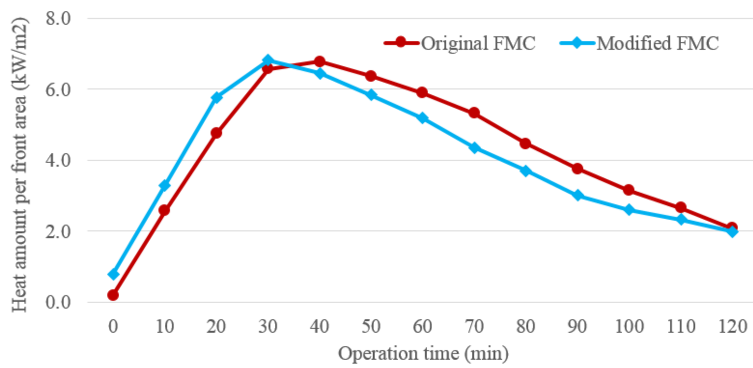


Figure 13: Comparison of frost performance (FMC vs. Modified FMC)

4. CONCLUSIONS

Our MC-HEX (FMC) for an outdoor unit of a residential air-conditioner is modified to apply to the automotive heat pump cycle. The tube-pass design of our MC-HEX (FMC) for the outdoor unit of a residential air-conditioner gives priority to the performance in the evaporation condition (heating mode) because of improving annual efficiency. As a result, the condensation performance should decrease, because the most suitable tube-pass design for the condensation is different from the evaporation in MC-HEX. But a large cooling capacity is necessary for the heat load by the sun, and a large heating capacity is necessary to heat low temperature fresh air directly for the automotive heat pump system. And generally, frost performance decreases if heat transfer performance increases.

This trade-off is solved by developing a variable circuit which applied the tube-pass design that is different from a condensation condition and an evaporation condition. It makes it possible to reduce the hole size of MC-Tube and increase the condensation performance. Also, the new fin shape, which has a gap in the louver part to bypass the air flow, is developed. The inside structure of the header for controlling distribution, which can correspond to the down flow of the refrigerant in the evaporation condition, is also developed.

As a result, the condensation performance of the modified MC-HEX (FMC) is higher than MC-HEX (PFC), and the evaporation performance of the modified MC-HEX (FMC) is higher than the original MC-HEX (FMC), while the

pressure drop is almost the same with MC-HEX (PFC). In other words, our modified MC-HEX (FMC) has the same condensation performance as the automotive HVAC system with good frosting and de-frosting performance.
This paper showed the possibility of the application of MC-HEX, and a further application is expected for the small size and high efficiency of the heat exchanger and reduction of the refrigerant quantity in the future. In order to do that, the sustained study about a tube-pass design, refrigerant distribution and frost characteristic will be necessary.

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