Development and Application of Micro Channel Heat Exchanger for Heat Pump

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Abstract

In the paper, micro channel heat exchangers are applied to residential and commercial heat pump air-conditioning systems. The performance of heat pump system using micro channel heat exchangers is compared with that of baseline heat pump system using tube & fin heat exchangers. Experimental results show that the capacity of heat pump system can increase by 4% at most by using micro channel heat exchangers, and energy efficiency can increase by 4% at most. The weight of heat exchangers can be reduced by 45% at most, and the refrigerant charge can be reduced by 51% at most. In addition, the distribution of refrigerant becomes more uniform by distribution optimization.

Keywords: Micro channel heat exchanger; air-conditioning; heat pump; SEER; HSPF; refrigerant charge; defrosting; frosting;

1. Introduction

With the improvement of the air-conditioning energy efficiency, as well as cost increase, the air conditioner manufacturers are looking for the solutions of efficiency improving and cost saving. Micro channel heat exchanger (MCHE), gets the attention from air-conditioning refrigeration industry because it has many advantages such as the high heat transfer efficiency, less refrigerant charge, compact structure and light weight. So MCHE is applied to the air conditioner system gradually. But till now, the MCHE has not been used for mass productive heat pump system widely because the refrigerant maldistribution and defrosting issue are not easy to deal with.

In Satish G. Kandlikar's (2007) study, he provided a roadmap for their implementation, with a critical review of the status of his understanding in this field, recommendations for obtaining fundamental performance data and correlations, and an emphasis on innovative designs of minichannel heat exchangers. According to the study of Zhaogang Qi etc. (2009), the new mini-channel evaporator had advantages on volume (17.2% smaller), weight (2.8% lighter) and heat transfer (4.3% higher), but a little penalty on air and refrigerant side pressure drop. In the paper of Liang-Liang Shao etc. (2010), the refrigerant-side maldistribution was found remarkable impact on the microchannel heat pump system performance under the frost conditions. And they figured out the best trade-off in the design of frost tolerant evaporators. Jianghong Wu etc. (2011) studied the frosting process of a folded－louvered-fin. The non-uniform surface temperature distribution caused by the unequal distribution of the refrigerant flux in the flat tubes' micro channels resulted in uneven distribution of frost. Ehsan Moallem etc. (2012) found out that at a given air dry bulb temperature, the fin surface temperature and air humidity were the primary parameters that influence the frost growth rates. Water retention and air velocity had a secondary impact on the frosting performance. There were some studies about applying the MCHE to heat pump system. In the

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study of Bo Xu etc. (2013), ice blockage formed in the fin root gaps of the horizontal-tube sample was because of water retention. The vertical-tube sample exhibited no obvious water retention on the surface.

In this study, the MCHEs are applied to residential and commercial heat pump systems. The performance, weight and refrigerant charge of the heat pump system using MCHEs are compared with that using copper tube & fin heat exchangers (TFHEs). And the refrigerant maldistribution and defrosting issue are solved.

2. Micro channel heat exchanger for the residential heat pump system

2.1. Micro channel heat exchanger design

The MCHEs are applied to a residential heat pump system, which is a common residential 3Ton unitary split unit in North America. The refrigerant is R410a. The indoor and outdoor units are shown in Fig. 1. And Fig. 2 shows the pictures of indoor and outdoor heat exchangers. The indoor TFHE is "A" shape, and has 3 rows φ9.52 mm copper tubes, which is replaced by a 1 row 25.4 mm width MCHE. And the outdoor TFHE is "C" shape, and has 1 row φ9.52 mm copper tubes, which is replaced by a 16 mm width MCHE. Both of the indoor and outdoor MCHEs have horizontal headers, vertical micro channel tubes and louver fins. The details of TFHEs and MCHEs could be found in Table 1. The heat pump system with TFHEs is named case 1, and the heat pump system with MCHEs is case 2.

The experiments are performed on the psychrometric calorimeter test bench of Sanhua company. The test conditions are shown in Table 2.

This paper compares the performance of the heat pump system with TFHEs (case 1) and the heat pump system with MCHEs (case 2). As shown in Fig. 3, when compared with case 1, the cooling capacity and SEER of case 2 increase by 4% and 2% separately. Meanwhile, case 2 has equal heating capacity with baseline case 1, and HSPF can increase by 1%. Fig. 3 also shows that the weight of heat exchangers in case 2 is only 56% of case 1. And the refrigerant charge of case 2 is only 49% of case 1.

Two phase refrigerant mal-distribution is one of the main problem for MCHE when it is used as evaporator. The outdoor MCHE is taken as an example to show the distribution optimization. The thermal images of outdoor MCHE before and after refrigerant distribution optimization could be seen in Fig. 4.

Defrosting is another problem for the outdoor MCHE when it runs as evaporator. Residual frost is not accepted, and the drainage water needs flow down quickly during the defrosting process. According to the tests, there is no frost remain and no drainage problem during the defrosting process for the outdoor MCHE.

Fig. 1. Pictures of the indoor unit and outdoor unit for the 3Ton unitary split heat pump system.

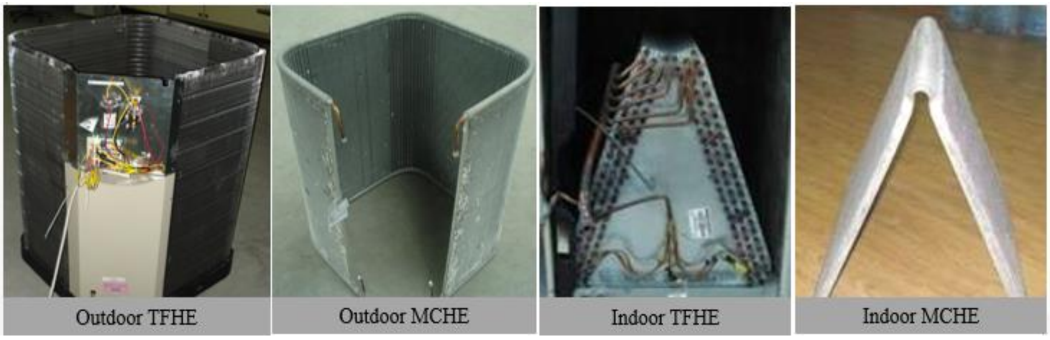

Fig. 2. Pictures of the indoor and outdoor heat exchangers.

Table 1. Information of tube & fin heat exchangers (TFHEs) and microchannel heat exchangers (MCHEs) for the 3Ton unitary split heat pump system.

Case	Indoor/Outdoor	Coil Type	Size (mm×mm)	Tube Parameter (mm)	Fin Height (mm)	FPI	Row
1	Indoor Coil	TFHE	420×610	φ9.52	/	14	3
	Outdoor Coil	TFHE	2320×1020	φ9.52	/	16	1
2	Indoor Coil	MCHE	420×610	25.4*1.3	8.1	16	1
	Outdoor Coil	MCHE	2170×880	16*1.3	8.1	14	1

Table 2 Test conditions

	Indoor Dry-Bulb (℉)	Indoor Wet-Bulb (℉)	Outdoor Dry-Bulb (℉)	Outdoor Wet-Bulb (℉)
ARI-A	80	67	95	75
ARI-B	80	67	82	65
ARI-C	80	≤57	82	—
ARI-D	80	≤57	82	—
ARI-H1	70	60	47	43
ARI-H2	70	60	35	33
ARI-H3	70	60	17	15

2.2. Experiment results and analysis

This paper compares the performance of the heat pump system with TFHEs (case 1) and the heat pump system with MCHEs (case 2). As shown in Fig. 3, when compared with case 1, the cooling capacity and SEER of case 2 increases by 4% and 2% separately. Meanwhile, case 2 has equal heating capacity with baseline case 1, and HSPF can increase by 1%. Fig. 3 also shows that the weight of heat exchangers in case 2 is only 56% of case 1. And the refrigerant charge of case 2 is only 49% of case 1.

Two phase refrigerant mal-distribution is one of the main problem for MCHE when it is used as evaporator. The outdoor MCHE is taken as an example to show the distribution optimization. The thermal images of outdoor MCHE before and after refrigerant distribution optimization could be seen in Fig. 4. Fig. 5 shows that the heating capacity of heat pump system increases by 5% after distribution optimization of outdoor MCHE. Also, the HSPF has 4% increase according to the optimization.

Defrosting is another problem for the outdoor MCHE when it runs as evaporator. Residual frost is not accepted, and the drainage water needs flow down quickly during the defrosting process. According to the tests, there is no frost remain and no drainage problem during the defrosting process for the outdoor MCHE.

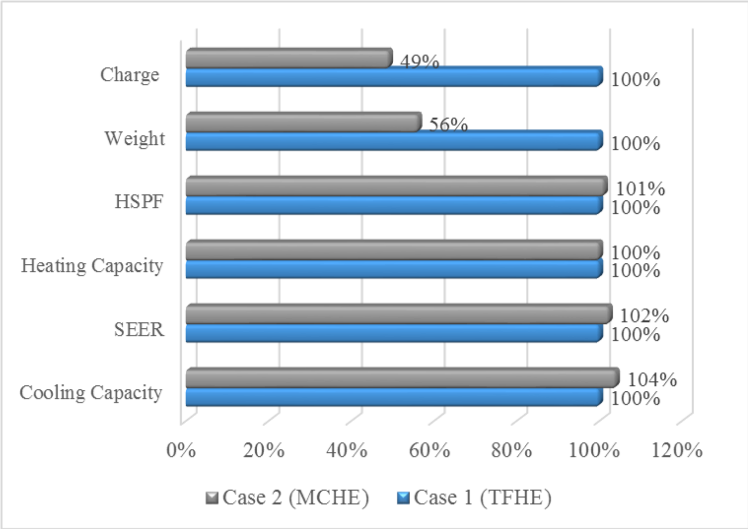

Fig. 3. Comparison of 3 Ton unitary split heat pump systems using TFHEs (Case 1) and MCHEs (Case 2).

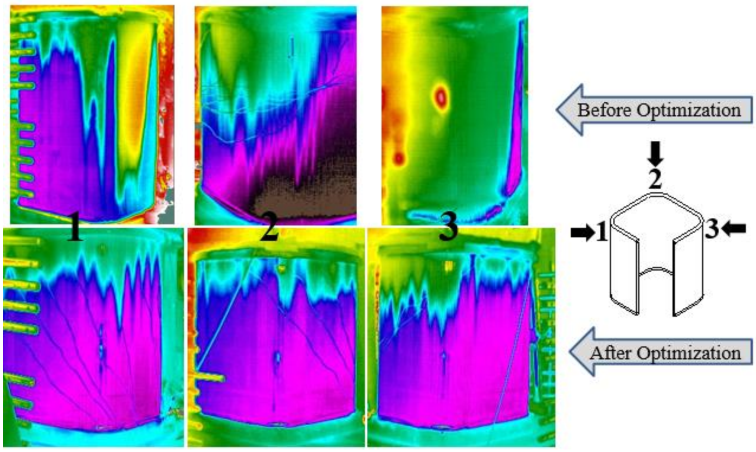

Fig. 4. Thermal images of outdoor MCHE before and after refrigerant distribution optimization.

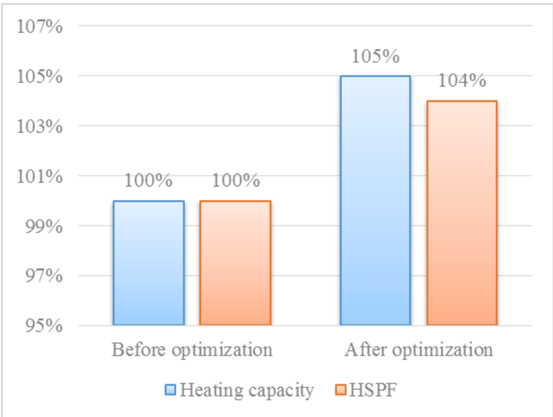

Fig. 5. Comparison of heating capacity and HSPF before and after distribution optimization of outdoor MCHE.

3. Micro channel heat exchanger for the commercial heat pump system

3.1. Micro channel heat exchanger design

The MCHEs are applied to a 65 kW commercial heat pump system, which is a modular air cooled type in China. The refrigerant is R410a. Fig. 6 shows the pictures of the unit. There are four TFHEs in the unit, each of which has 3 rows φ9.52 mm copper tubes. All of the TFHEs are replaced by the MCHEs, and MCHEs have horizontal headers, louver fins and 2 rows vertical 20.6 mm width microchannel tubes. Fig. 7 shows the 3D model picture of two MCHEs. The 2 rows MCHEs are designed to be counter-flow when used as condensers, and they are parallel-flow when used as evaporators. And there are different FPI for each row. The row which transfer heat with the air flow first is 8.5FPI, and the second row is 16FPI. The heat pump system with TFHEs is named case 3, and the heat pump system with MCHEs is case 4. The details of the TFHEs and MCHEs could be found in Table 3.

The experiments are performed on the psychrometric calorimeter test bench of Sanhua’s customer. The test conditions are shown in Table 4.

Fig. 6. Pictures of the 65kW commercial heat pump unit.

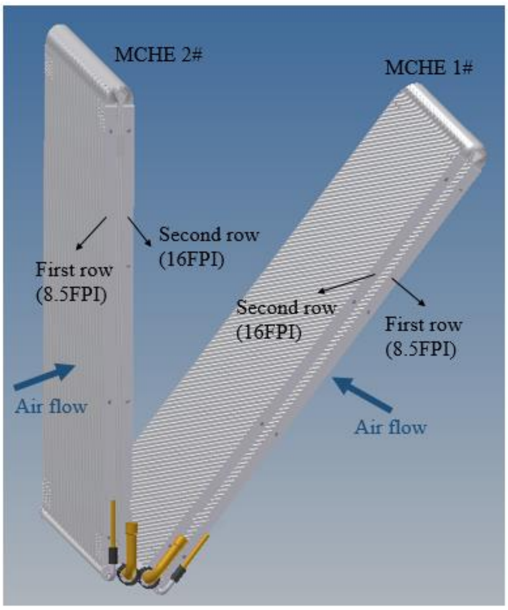

Fig. 7. 3D pictures of the MCHEs for the 65kW commercial heat pump unit.

Table 3. Information of tube & fin heat exchangers (TFHEs) and microchannel heat exchangers (MCHEs) for the commercial heat pump.

Case	Indoor/Outdoor	Coil Type	Size (mm×mm)	Tube Parameter (mm)	Fin Height (mm)	FPI	Row
3	Outdoor Coil 1#&3#	TFHE	890*1016	φ9.52	/	16	3
	Outdoor Coil 2#&4#	TFHE	890*914	φ9.52	/	16	3
4	Outdoor Coil 1#&3#	MCHE	889*1017	20.6*1.3	8.1	8.5 & 16	2
	Outdoor Coil 2#&4#	MCHE	889*919	20.6*1.3	8.1	8.5 & 16	2

Table 4. Test conditions.

	Water flow rate [m3/(h·kW)]	Water Temperature (℃)	Outdoor Dry-Bulb (℃)	Outdoor Wet-Bulb (℃)
Cooling	0.172	7	35	-
Heating	0.172	45	7	6
Defrosting	0.172	45	2	1

3.2. Experiment results and analysis

The performance of the heat pump system with TFHEs (case 3) is compared with the heat pump system with MCHEs (case 4) in this study. As shown in Fig. 8, the cooling capacity and EER of case 4 increases by 2% and 4% separately when compared with case 3. Meanwhile, the heating capacity and COP are same with baseline. Fig. 8 also shows that the weight of heat exchangers in case 4 is only 65% of case 3. And the refrigerant charge of case 4 is only 60% of case 3.

The MCHEs are 2 rows parallel-flow design which have different FPI for each row. The refrigerant flow velocity in the microchannel tubes is enhanced by using this 2 rows design, so the heat transfer coefficient in the tube is enhanced, and the oil return risk is reduced greatly. The first row which transfer heat with the air flow first is designed to be 8.5 FPI in order to avoid the blocks of air flow path by frost, and the second row is 16 FPI to increase the heat transfer area as much as possible. Though the refrigerant distribution optimization of 2 rows MCHE is much more difficult than 1 row MCHE when used as evaporator, a good distribution is gotten after optimization. There is no frost remain or drainage issue for the defrosting condition. The system heating capacity and HSPF can meet the target finally.

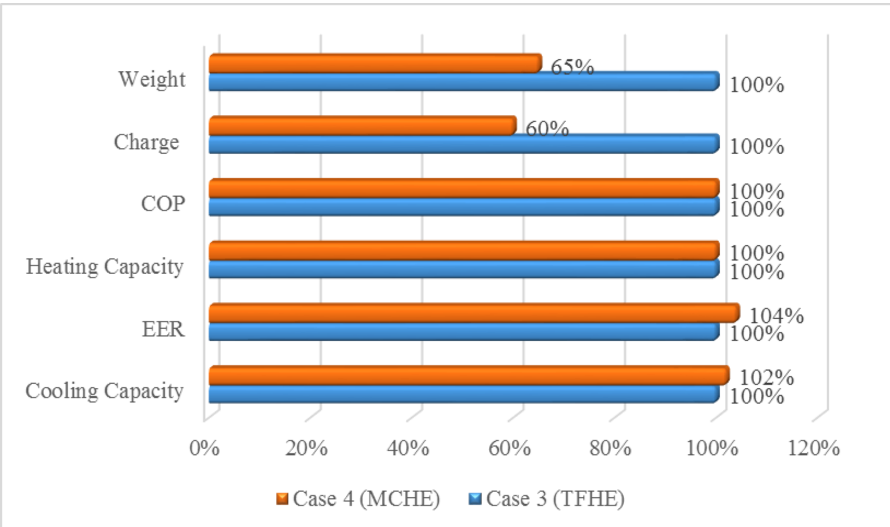

Fig. 8. Comparison of 65 kW commercial heat pump systems using TFHEs (case 3) and MCHEs (case 4).

4. Conclusion

For the 3Ton residential heat pump system, when compared to the system with TFHEs, the cooling capacity can increase by 4% by using MCHEs, and SEER and HSPF can increase by 2% and 1%. The weight of heat exchangers can be reduced by 44%. And the refrigerant charge can be reduced by 51%.

For the 65kW commercial heat pump system, the cooling capacity can increase by 2% by using MCHEs, and EER can increase by 4%. The weight of heat exchangers can be reduced by 35%. And the refrigerant charge can be reduced by 40%.

The refrigerant distribution of MCHE can become more uniform by optimizing. And the performance under frosting and defrosting condition can meet the target. And there is no frost remain and drainage issue.

It is verified that MCHEs has higher heat transfer performance, much lower weight and refrigerant charge, which is a good choice for improving the efficiency and saving cost.

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