Experimental Study on Influence of Inlet and Outlet Layout of External Heat Exchanger on Performance of Heat Pump System for Electric Cars

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Abstract

External heat exchanger of the heat pump air-conditioning system is a core component for electric cars. It functions not only as an evaporator but also as a condenser and has a great impact on the overall performance of the heat pump system. In this paper, a reversible flow chart of a heat pump air conditioning system is presented and an experimental bench is set up to study the influence of inlet and outlet layout of external heat exchanger on performance of the heat pump system. The results show: under heating conditions, heating performance of the system is optimal when the inlet is at the bottom; while under cooling conditions, the inlet set at the top is better for the heat pump performance. This verifies that the reversible flow chart of a heat pump air conditioning system is practical for improving the heat pump comprehensive performance in both cooling and heating mode.

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Kewords: Electric cars, external heat exchanger, structural design, heat pump;

1. Introduction

Compared with the PTC (positive temperature coefficient) electric heating method, heat pump air conditioning system, greatly reducing heating energy consumption and improving the driving distance of EVs after one charge, has become an important development direction of air conditioning system for EVs. External micro-channel heat exchanger is a crucial component which needs to function as the evaporator and condenser. As the evaporator, the refrigerant is in the two-phase evaporating process. As the condenser, the ref. is in the two-phase condensing process. And the heat transfer mechanism of the two working conditions is very different. Therefore, the design of external heat exchanger has a great impact on performance of heat pump air conditioning system, which is an important research content.

The micro-channel parallel flow heat exchanger has been widely used in the field of automobile air-conditioning due to its high heat transfer efficiency and small charge capacity. Yan et al. [1] experimentally studied the influence of uneven distribution of temperature on the micro-channel heat exchanger used as the condenser and evaporator. The results show: the influence of uneven distribution of temperature on the heat pump performance accounts for 3.5% and 7.3% respectively and numbers of passes have different effects on the

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condenser and evaporator. Nae-Hyun et al. [2] experimentally studied the effect of three different inlet configurations (parallel, normal, vertical) on the refrigerant distribution in a parallel flow mini-channel heat exchanger. The investigation results show: The flow distribution is better for normal or vertical inlet configuration than for the parallel inlet configuration. Normal or vertical inlet yields approximately similar flow distribution, although slightly better results were obtained for normal inlet at high mass fluxes or high qualities. Shi et al. [3] studied the influence of internal structure of the parallel evaporator on performance of the evaporator, the results show: reasonable manifold structure can improve heat transfer performance of the evaporator, and the uniformity of flow distribution within the evaporator becomes better. Zhao et al. [4] analyzed performance of two sets of evaporators with different flow structures through combination of experiment and simulation methods and the error is within 10%. The results show that the 2-process design has better heat transfer and pressure drop characteristics than the 4-process design. Fang et al. [5] established the steady-state distribution parameter model of the multi-microchannel parallel flow condenser, and used the model to study influence of the parameters such as the number of flat tube hole, the ratio of height and width of holes and process layout on heat transfer and flow properties of the condenser. Peng et al. [6] experimentally studied performance of parallel flow condensers with different flow arrangements, obtaining the optimal flow arrangement ratio under certain conditions.加一句总结。

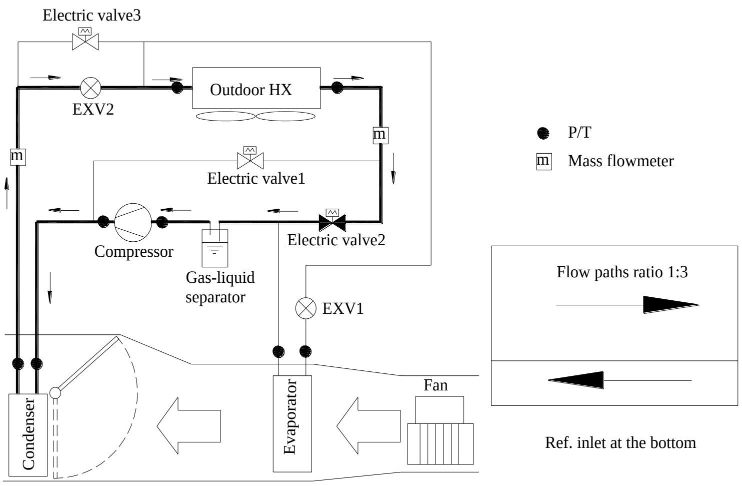
In this paper, a reversible flow chart of a heat pump air conditioning system is presented and the effect of inlet and outlet layout of double-process parallel flow heat exchanger with horizontal flat tubes on overall performance of heat pump system is studied to verify the optimized system.

Nomenclature

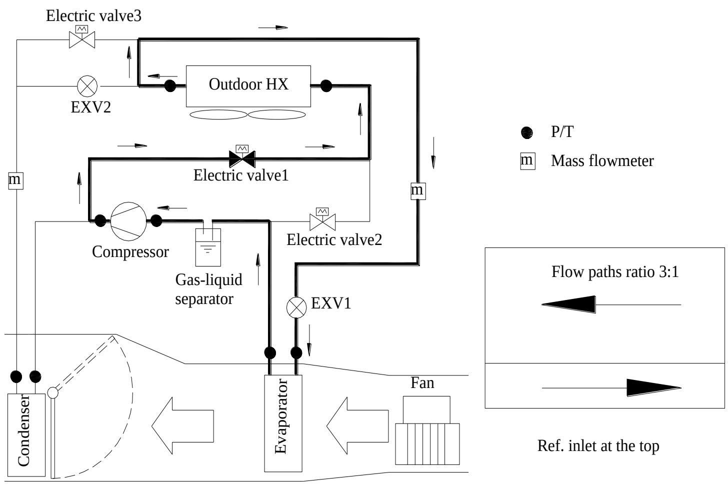
Ref.	Refrigerant	P	Pressure (bar)
HX	Heat exchanger	T	Temperature (℃)
Δh	Enthalpy difference between inlet and outlet of the condenser under heating conditions		
Δh’	Enthalpy difference between inlet and outlet of the compressor under heating conditions		
Δh”	Enthalpy difference between inlet and outlet of the evaporator under cooling conditions		

2. Experimental setup

Fig.1 displays schematic diagram of the experimental bench system and structures of test samples, including some main components and measurement devices. Table 1 and 2 respectively shows the basic parameters of measurement devices and test samples. On heating conditions, the ref. flows into the external HX at the bottom, as shown in fig.1 (a). On cooling conditions, the ref. flows into the external HX at the top, as shown in fig. 1(b).



(a) Heating cycle



(b) Cooling cycle

Fig.1 Schematic diagram of the heat pump system of test bench

Table 1 Parameters of measurement devices

Parameter	Type	Range	Error
Temperature	Thermocouple	-30 to 130℃	±0.5℃
Pressure	Diaphragm	0 to 30bar	±0.5%
Air speed	Hot bulb	0 to 30m/s	±2%
Mass flow rate of Ref	Coriolis	<200kg/h	±0.1%

Table 2 Parameters of test samples

Types	Ref. inlet at the bottom	Ref. inlet at the top
Size/mm	580x430x16	580x430x16
Distribution of flow channel	Double(1:3)	Double(3:1)
Number of flat tubes	48	48

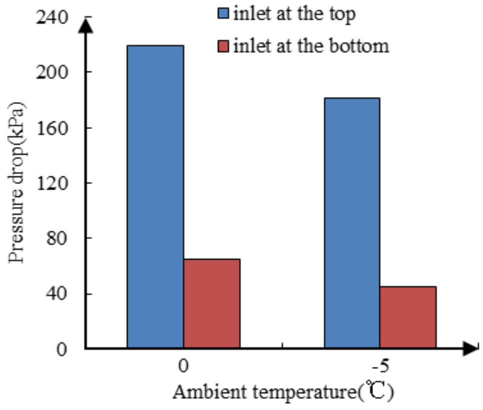
3. Results and discussions

3.1 Heating condition

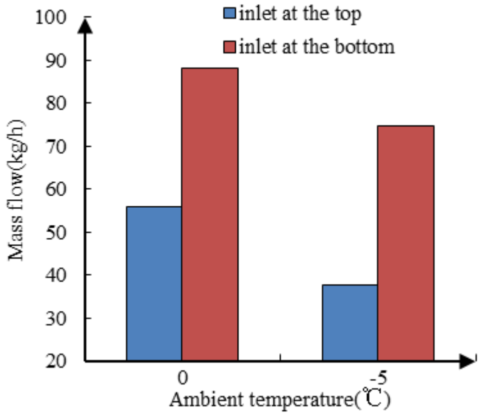
Fig. 2 shows performance comparison of the heat pump system under heating conditions. For external HX with ref. inlet at the bottom, the pressure drop is respectively lower 70% and 75% than that of external HX with ref. inlet at the top under the same condition, as shown in fig. 1(a). This mainly results from the fact: during the evaporating process, the ref. changes from the gas-liquid phase to the gas phase and its specific volume increases. Meanwhile, with inlet at the bottom, the flow area of ref. gradually increases, which is consistent with phase change of the refrigerant. Due to the lower pressure drop, the specific volume of the ref. flowing into the compressor becomes smaller and then along with a much larger mass flow rate, as shown in fig. 1(b). The mass flow rate respectively increases by about 36% and 49% at 0 ℃ and -5℃. Compared with the mass flow rate difference, enthalpy difference between the inlet and outlet of the condenser and the compressor is not so large, as shown in fig. 1(c) and (e). Thus, heating capacity of the heat pump system is larger and compressor power consumption is higher for external HX with ref. inlet at the bottom. They respectively increase by 33% and 40%. Based on the results shown in fig. 1(d) and (f), COP of the system is slightly better for external HX with ref. inlet at the top, as shown in fig. 1 (g). However, with inlet at the top, heating capacity of the system is insufficient.

When using PTC auxiliary heating to make up the heating capacity, the converted COP is worse than that of the heat pump system for external HX with ref. inlet at the bottom, as shown in fig. 1(h).

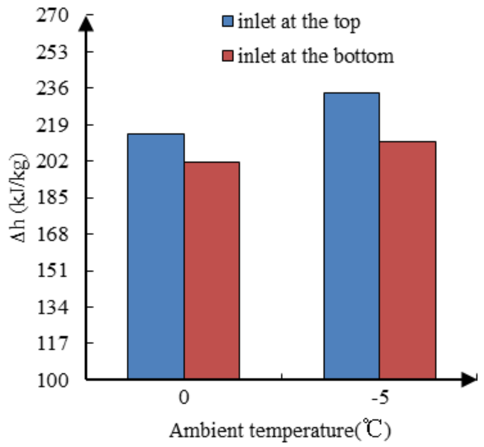
In summary, on heating conditions, with the external HX with ref. inlet at the bottom selected for the heat pump system, the heating performance is optimal.



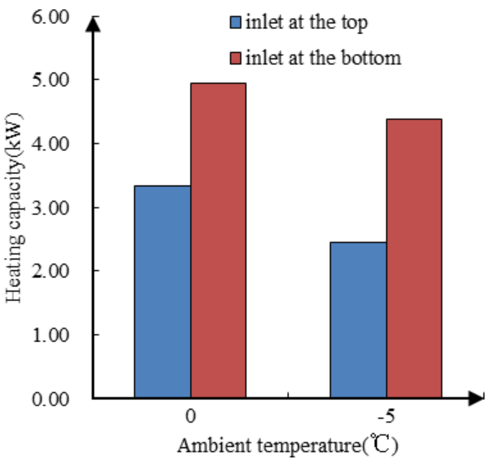
(a) Pressure drop of HX



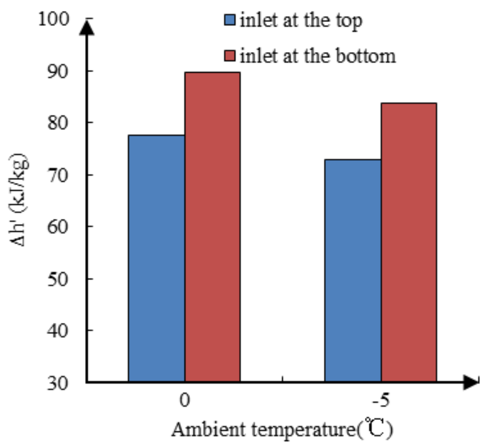
(b) Mass flow rate



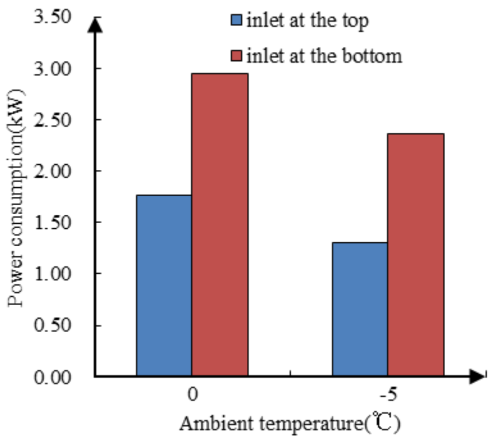
(c) Enthalpy difference of the condenser



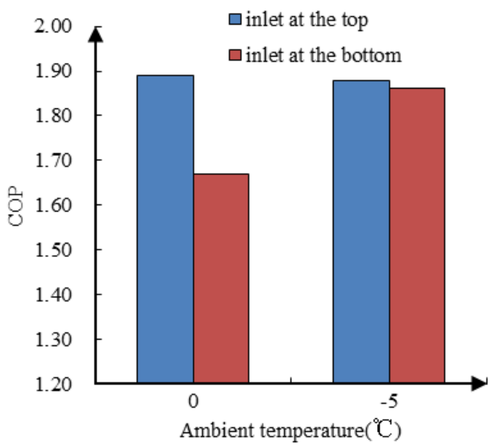
(d) Heating capacity



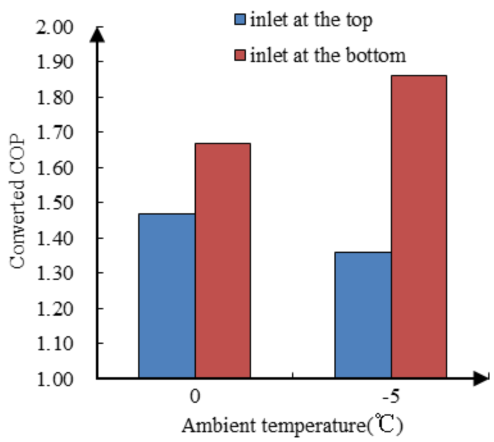
(e) Enthalpy difference of the compressor



(f) Power consumption



(g) COP



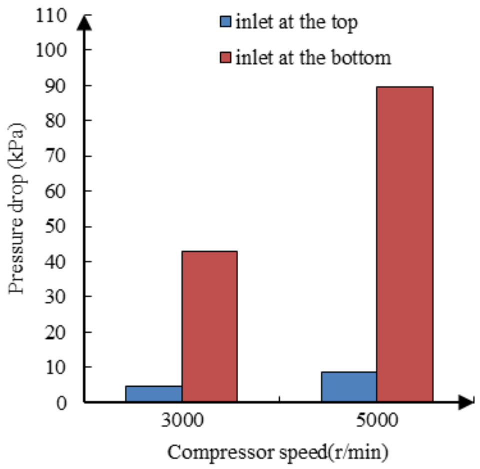
(h) Converted COP

Fig. 2 performance comparison of the heat pump system

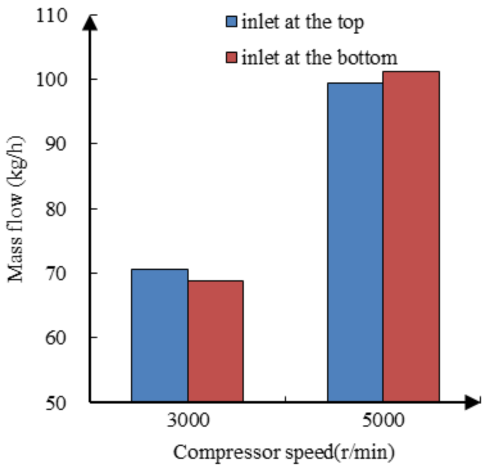
3.2. Cooling condition

Fig. 3 shows performance comparison of the heat pump system under cooping conditions. For external HX with ref. inlet at the top, the pressure drop is respectively lower 85% and 90% than that of external HX with ref. inlet at the bottom under the same condition, as shown in fig. 1(a). This mainly results from the fact: during the condensing process, the ref. changes from the gas phase to the liquid phase and its specific volume decreases. Meanwhile, with inlet at the top, the flow area of ref. gradually decreases, which is consistent with phase change of the refrigerant. Because pressure drop of the external HX functioning as the condenser has little impact on the status of the ref. flowing into the compressor, the mass flow rate almost remains equal under the same cooling condition, as shown in fig. 2(b). In addition, the lower pressure drop results in a lower discharge pressure. Therefore, the compressor power consumption is lower for the external HX with ref. inlet at the top, as shown in fig. 2(e). Fig. 2(c) displays that enthalpy difference between the inlet and outlet of the evaporator nearly remains identical. Based on the results shown in fig. 2(b) and (c), differences between cooling capacities are very small. And a little better COP is obtained for external HX with ref. inlet at the top, as shown in fig. 2(f).

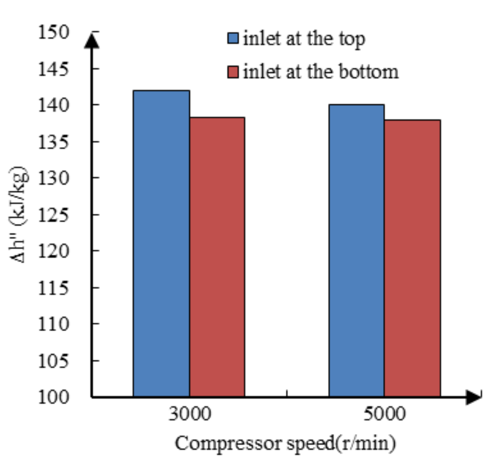
In summary, on cooling conditions, adopting the external HX with ref. inlet at the top, the overall cooling performance of the heat pump system will be better.



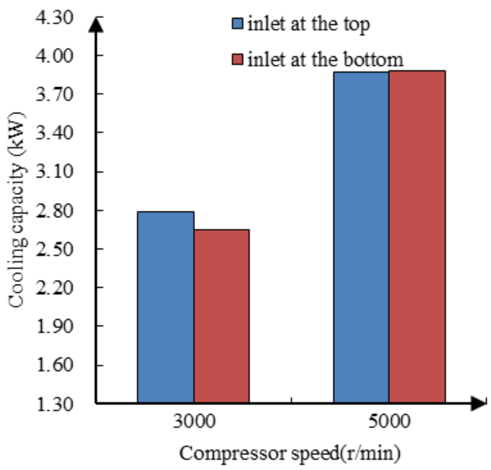
(a) Pressure drop of HX



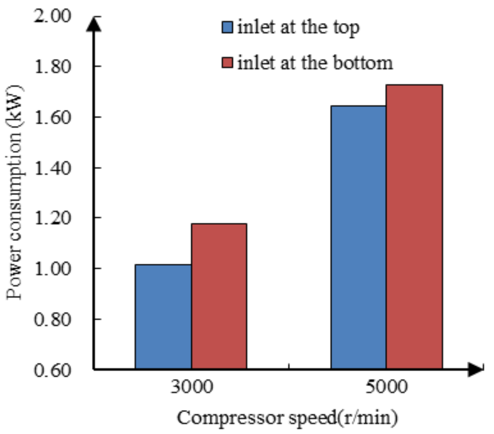
(b) Mass flow rate



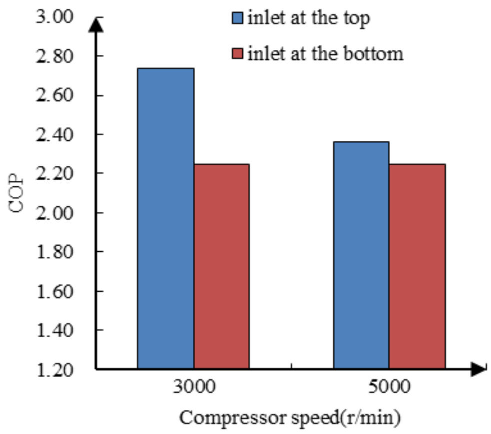
(c) Enthalpy difference of the evaporator



(d) Cooling capacity



(e) Power consumption



(f) COP

Fig. 3 performance comparison of the heat pump system

4. Conclusions

According to the above experimental research, influences of the ref. inlet and outlet layout of the external HX on the performance of the heat pump system are investigated. Listed below are major conclusions:

(1) On heating conditions, with ref. inlet at the bottom, phase change of the ref. in the outdoor HX can match well with the flow area of ref. and a lower pressure drop and optimal heating capacity can be obtained. In this case, even though the system COP is a little worse, heating capacity for external HX with inlet at the top is insufficient. While using PTC auxiliary heating to make up the heating capacity, the system COP becomes better. Considering the comprehensive heating performance of the heat pump system, ref. inlet at the bottom is a preferable choice for external HX.

(2) On cooling conditions, with ref. inlet at the top, phase change of the ref. in the outdoor HX can match well with the flow area of ref. and a lower pressure drop can be obtained and then along with a lower power consumption and a little better COP.

(3) According to (1), (2), the reversible flow chart of a heat pump air conditioning system is practical for improving the overall performance of the heat pump system to the fullest.

Acknowledgements

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