HEAT PUMP AIR CONDITIONING SYSTEM FOR PURE ELECTRIC VEHICLE AT ULTRA-LOW TEMPERATURE

by

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When the ordinary heat pump air conditioning system of a pure electric vehicle runs at ultra-low temperature, the discharge temperature of compressor will be too high and the heating capacity of the system will decay seriously, it will lead to inactivity of the heating system. In order to solve this problem, a modification is put forward, and an experiment is also designed. The experimental results show that in the same conditions, this new heating system increases more than 20% of the heating capacity; when the outside environment temperature is negative 20 degrees, the discharge temperature of compressor is below 60 degrees.

Key words: *electric vehicle, ultra-low temperature, heat pump, air conditioning*

Introduction

With environment-friendly, low-carbon, energy-efficient advantages, pure electric vehicles (PEV) have aroused the extensive interest of most automobile enterprise in various countries, and many patterns have been developed [1]. Compared with air conditioning system of traditional fuel vehicle, air conditioning system of PEV requires higher requirements for the capacity of electric car batteries [2-4]. The air conditioning system of a traditional fuel vehicle makes use of the afterheat of the engine in winter. However, the air conditioning system of PEV can only depend on the positive temperature coefficient (PTC), semiconductor heating, and other electric heating ways. This will increases the consumption of batteries and reduces the endurance of batteries when the air conditioning is on. To solve this problem, relative scholars proposed various solutions, such as heat pump air conditioning system (HPACS), assistance of solar energy, *etc*. The efficiency of HPACS is much higher than other heating ways. However, as for the R134a, a generally applied medium warm refrigerant, the compressor discharges temperature can be as high as 120 °C when the ambient temperature outside the vehicle is lower than 10 °C. As a result, the air conditioning system attenuates the heat quantity dramatically, and even breaks down. Thus, this type of system still needs auxiliary heating equipment. Some scholar proposed the type of heat pump system with CO_2 as refrigerant, because its performance is better than that of R134a system, especially under low temperatures, and it is more environment-friendly than the R134a system [5]. However, the CO_2 heat pump system is not applicable for general utilization. On one hand, the pressure of this system is too high, which reduc-

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ing its reliability and security. On another hand, the substitution of R134a for R12 has just been completed in the industry of automotive air conditioning, and the substitution of other refrigerants calls for redesign of each part in the air conditioning system. In review these issues, with the combination of low temperature heat pump technology, a type of gas-mixing HPACS, which utilizes R134a as circulating refrigerant, is designed for the PEV. This research aims to study the performance and property of the R134a gas-mixing HPACS, and also to comparatively analyze the results with the ordinary HPACS in a PEV.

HPACS for PEV at ultra-low temperature

From the structural characteristics of the two-stage compression cycle heat pump technology and automobile air conditioning currently in use, a gas-mixing HPACS for PEV is developed, the flow diagram as shown in fig. 1. The system consists of a compressor, four-way valve, air-cooled heat exchanger outside the vehicle, one-way valve, liquid storage drier, main expansion valve, air-cooled heat exchanger inside the vehicle, gas-mixing expansion valve, and gas-mixing heat exchanger. When running the refrigeration mode, four-way valve switches to the refrigeration, and gas-mixing expansion valve is closed. The cooling process of the system is same as ordinary automotive air conditioning process. The circulating working fluid is discharged by the compressor, condensates in the air-cooled heat exchanger outside the vehicle through the four-way valve, enters the liquid storage drier through the one-way valve, enters the main expansion valve after the gas-mixing heat exchanger, then evaporates by the air-cooled heat exchanger inside the vehicle after the one-way valve, suctions by the compressor through the four-way valve. When running heating mode, four-way valve switches to heating, gas-mixing expansion valve is opened. The circulating working fluid is discharged by the compressor, condensates in the air-cooled heat exchanger inside the vehicle through the four-way valve. Then it divided into two paths after entering the liquid storage drier through the one-way

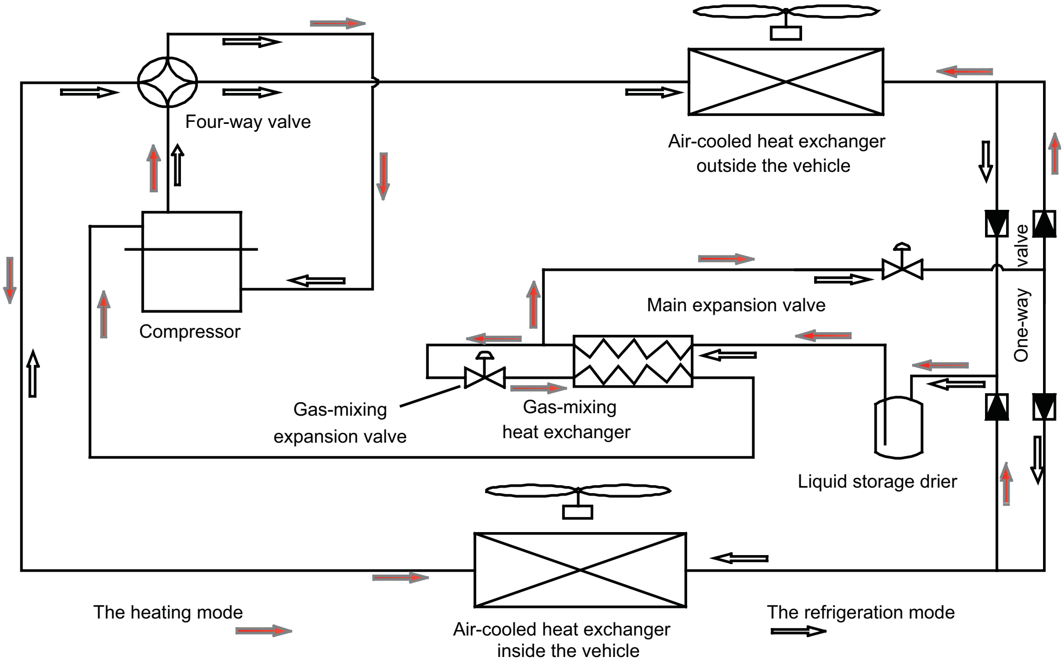

Figure 1. The flow diagram of the gas-mixing HPACS for PEV

valve. In one path, it is directly into the gas-mixing heat exchanger, enters the main expansion valve after heat transfer under heating with gas-mixing loop cycle, it evaporates by the air-cooled heat exchanger outside the vehicle after the one-way valve, and suctions by the compressor through the four-way valve. The other path, it is throttled to a pressure via the gas-mixing expansion valve. After that, it evaporates and absorbs heat after entering the gas-mixing heat exchanger. Then, it enters the compressor from the gas-mixing port of compressor.

Test condition and experimental scheme

Figure 2. The experimental platform of gas-mixing HPACS for PEV

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According to the principles, the experimental platform is set-up, and the systematic performance testing is carried out in the enthalpy difference laboratory. Figure 2 is the photo of the experimental platform of gas-mixing HPACS for PEV. Enthalpy difference lab is divided into indoor side and outdoor side. Dry bulb temperature control range of the environment in the indoor side is from 10 °C to 40 °C, that in the outdoor side is –26～45 °C, and the control precision is ±0.2 °C. The main body of the laboratory bench is placed in the test room of the outdoor side. The air-cooled heat exchanger inside the vehicle and its corresponding assembly is placed in the test room of the indoor side.

The formulation of the test plan of the test bench references the automotive air conditioning industry and national standards such as GB/T21361-2008 motor vehicle air-conditioning, QC/T657-2000 automotive air conditioning refrigerating unit test method, JB/T 6914-93 automotive air conditioner performance experiment method, QCT656-2000 automotive air conditioning refrigerating performance requirements. Due to the lack of the test condition and standard of the automotive HPACS, it should reference the correlative test condition and standard of the heat pump system of air conditioning industry in GB7725-2004 room air conditioner and GB 7941-87 Testing of refrigerating unit. The instrument in the test is in conformity with the relevant provisions of the national standard QC/T72.2 – 93, experiment test conditions as shown in tab. 1.

Table 1. The experimental test conditions

Test conditions	Rotational speed of the compressor [rpm]	The wind speed on the surface of the air-cooled heat exchanger outside the vehicle [ms^{-1}]	The ambient temperature outside the vehicle [°C]	The ambient temperature inside the vehicle [°C]
Ordinary heat pump heating	6000	4.5	15	20
			12	
			10	
Gas-mixing heat pump heating	6000	4.5	10	20
			5	
			0	
			–5	
			–10	
			–15	
			–20	

Analysis of the experimental results

Performance analysis of the ordinary HPACS in PEV

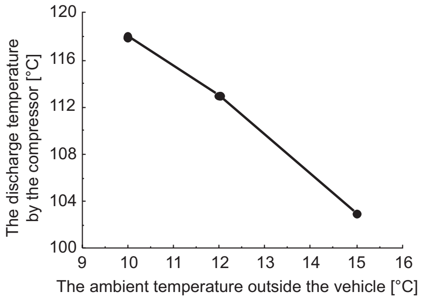

Figure 3. The impact of the ambient temperature outside the vehicle on the discharge temperature by the compressor

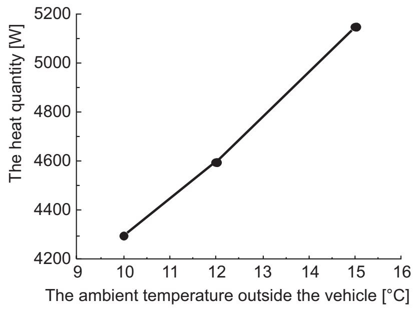

Figure 4. The impact of the ambient temperature outside the vehicle on the heat quantity

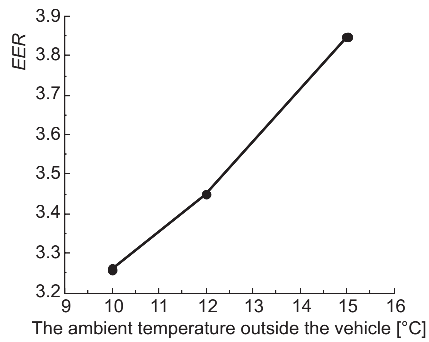

Figure 5. The impact of the ambient temperature outside the vehicle on the *EER*

The performance of ordinary HPACS under the condition of low temperature is shown as in figs. 3, 4, and 5. It can be seen from fig. 3 that, when the rotational speed of the compressor is 6000 rpm and the ambient temperature inside the vehicle is 20 °C, the discharge temperature by the compressor increases from 103 °C to 118 °C with the decrease of the temperature outside the vehicle from 15 °C to 10 °C. If the ambient temperature outside the vehicle continues to decrease, the discharge temperature by the compressor will exceed the maximum, 120 °C, and the system will not be able to run normally. As is shown in figs. 4 and 5, with the decrease of the temperature outside the vehicle, the heat quantity drops from 5150 W to 4200 W, and the energy efficiency ratio (*EER*) drops from 3.85 to 3.24. It is because, with the reducing temperature outside the vehicle, the suction pressure decreases and the specific volume of the refrigerant R134a increases gradually while the suction quantity of compressor remains unchanged, which reduces the quality of the mass flow of circulation system. From the above it can be observed that, when the ambient temperature outside the vehicle is below 10 °C, the ordinary HPACS cannot run normally because the discharge temperature by the compressor exceeds the maximum, 120 °C.

Performance analysis of the gas-mixing HPACS in PEV

Systematic experiments are implemented to study the performance of the ordinary HPACS and the gas-mixing HPACS under the research conditions as shown in tab. 1. The research results are shown in figs. 6-8. It can be seen from fig. 6 that, the circling refrigerant in the gas-mixing loop road enters gas-mixing port of the compressor, as for the gas-mixing HPACS, to mix up with the refrigerant from the main road at the compressor, which reduces the degree of superheat of the suction working medium, so that the discharge temperature by the compressor decreases from 118 °C to 75 °C when the ambient temperature outside the vehicle is 10 °C.

Figure 7 shows that, when the ambient temperature outside the vehicle is 10 °C, the heat quantity of gas-mixing HPACS is about 5020 W while the heat quantity of the ordinary

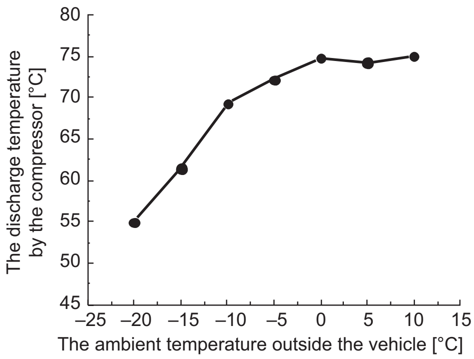

Figure 6. The impact of the ambient temperature outside the vehicle on the discharge temperature by the compressor

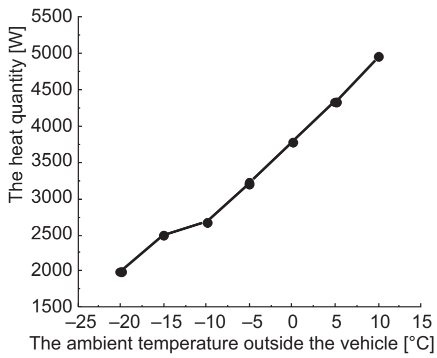

Figure 7. The impact of the ambient temperature outside the vehicle on the heat quantity

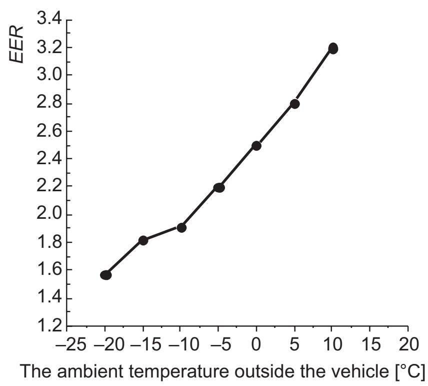

Figure 8. The impact of the ambient temperature outside The vehicle on the *EER*

HPACS is 4200 W or so, that is to say, the heat quantity is enhanced by about 20%. For gas-mixing HPACS, the suction gas superheat drops at the compressor and reduces the refrigerant specific volume with the mixing between the circling refrigerant in the gas-mixing loop road and the refrigerant in the main road at the suction cavity of compressor. Thus, the quality of the mass flow increases, which means a great increase of heat quantity created by the gas-mixing heat pump air conditioning heating system, compared with the ordinary heat pump air conditioning heating system. When the ambient temperature outside the vehicle decreases from 10 °C to –20 °C, the heat quantity of the gas-mixing heat pump air conditioning heating system drops from 5300 W to 2000 W. It is because the pressure of evaporation for the heat exchanger outside the vehicle decreases gradually with the drop of the ambient temperature outside the vehicle, which reduces the suction pressure of the compressor but increases the specific volume of the work substance. In one word, the heat quantity of the gas-mixing heat pump air conditioning heating system decreases with the drop of the ambient temperature outside the vehicle.

Figure 8 shows that, when the ambient temperature outside the vehicle drops to –20 °C, the heat quantity of gas-mixing heat pump air conditioning heating system decreases greatly, and the *EER* at about 1.5. Therefore, under low temperature conditions, the efficiency of the gas-mixing heat pump air conditioning heating system is higher than that of the ordinary heat pump air conditioning heating system, like PTC, *etc*.

Conclusions

On the basis of the quasi two-stage compression cycle heat pump technology and the structural characteristics of the automotive air conditioning, this gas-mixing HPACS is well designed to realize the application of low temperature heat pump technology in air conditioning system for PEV. The experimental results show that, under the same operating conditions, the gas-mixing HPACS enhances the heat quantity by over 20% than the ordinary HPACS in electric vehicles, and that when the ambient temperature is –20 °C, the discharge temperature by the compressor can be controlled under 60 °C, and increases the energy efficiency over 50% than other electric heating systems, like PTC, semiconductor, *etc*. Therefore, this system is a better solution to settle the high discharge temperature of compressor and the heating capacity of the system attenuation of the ordinary heat pump systems in electric vehicles under low temperature conditions. In a word, gas-mixing HPACS paves the road for the development of heat pump system in PEV.

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