EXPERIMENTAL RESEARCH ON REFRIGERATION PERFORMANCE OF AIR CONDITIONING SYSTEM OF PURE ELECTRIC PASSENGER CARS WITH ECONOMIZER

by

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Original scientific paper
https://doi.org/10.2298/TSCI2203599Y

Aiming at solving the problems of the high compressor discharge temperature, the high discharge pressure, the insufficient cooling capacity, and the reduced system efficiency in the air-conditioning system of pure electric passenger cars in the summer high temperature environment, this paper develops a low pressure economizer using the principle of the quasi-two-stage compression cycle. The heat pump air conditioning system of the air-supplemented pure electric passenger car is set up to study its refrigeration performance. The results show that in a high environment temperature of 50 °C, compared with the non-supplemented system, the discharge temperature in the low pressure supplemental gas system drops by 13.54 °C, the refrigeration capacity reduces by 2.0%, the compressor power drops by 3.4%, and the refrigeration coefficient increases by 1.4%.

Key words: *pure electric passenger car, air conditioning system, low pressure air supplement, refrigeration performance*

Introduction

Under the current worldwide wave of the urgent development of new energy vehicles, the best candidate to solve the problems of the energy shortage and the environmental pollution in the world is to thrive pure electric buses, especially in China under her current fast economic development [1].

As an auxiliary system for electric buses with the largest power consumption, the heat pump air conditioning system directly affects the cruising range of pure electric buses. Therefore, it is of great significance to develop an efficient, environmentally friendly, and widely applicable heat pump air conditioning system [2]. When a pure electric passenger car runs in a high temperature environment in summer, the heat pump air conditioning system will have problems such as excessive compressor discharge temperature and discharge pressure, insufficient cooling capacity, and reduced system efficiency.

In view of the outstanding problems of heat pump air conditioning systems in high temperature environments, many experts and scholars have proposed solutions using quasi-

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two-stage compression cycle technology, which adds a supplementary air circuit to the heat pump cycle. Through the technology of supplemental air enthalpy, the compressor discharge temperature is reduced, and the system performance is improved [3]. Dutta *et al.* [4] conducted an experimental study on the characteristics of the quasi-two-stage compression cycle of scroll compressors, Xu *et al.* [5] studied the influence of air supplement technology on the performance of the heat pump system, and Tang *et al.* [6] experimentally studied the quasi-two-stage scroll compressor and single-stage scroll compressor heat pump performance. Yang *et al.* [7] experimentally studied the effect of air supplement technology on the performance of screw compressor heat pump system. Autors [8-10] also conducted a lot of research on the applications of air supplement technology in the heat pump air conditioning system of pure electric vehicles. He and Li [11] suggested a novel and effective numerical method for heat equation.

In this paper, R407C is used as the refrigerant, and the low pressure gas supplement enthalpy technology with economizer is used to conduct an experimental study on the refrigeration performance of the heat pump air conditioning system of a pure electric passenger car.

The circulation principle of the heat pump air conditioning system of low pressure air supplement type pure electric passenger car

The system components include electric scroll compressors, tube-fin heat exchangers inside and outside the car, economizers, filter driers, accumulators, gas-liquid separators, main circuit electronic expansion valves, supplementary circuit electronic expansion valves, and one-way valves and other necessary auxiliary devices. The system flow chart is shown in fig. 1, and the low pressure supplemental gas theoretical cycle pressure enthalpy diagram is shown in fig. 2. The refrigerant is discharged from the compressor discharge port (state 2), cooled by the condenser (states 2-state 5), and divided into main and supplementary circuits. The main circuit refrigerant is sub-cooled by the supplementary refrigerant in the economizer to state 3, and then is throttled to state 4 by the main expansion valve, and evaporates in the evaporator (state 4-state 1). The supplementary refrigerant is throttled by the supplementary expansion valve (state 5-state 6), and then enters the economizer to absorb heat and evaporate

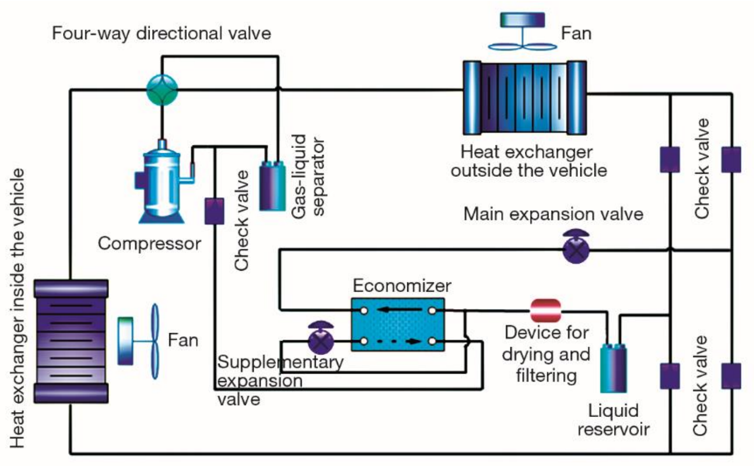

Figure 1. System flow chart

(state 6-state 7). Before the make-up refrigerant enters the low-pressure supply port, there is a short pipe section that throttles (state 7-state 8). After throttling, the make-up refrigerant enters the low-pressure supply port and mixes with the main refrigerant (state 8-state 9). The mixed refrigerant is compressed to form exhaust state 2, and the cycle is repeated to realize the quasi-two-stage compression of a single compressor; if the subcooling of the supplementary refrigerant is too large, state 9 will shift to state 9', the corresponding state 2 will shift to 2'.

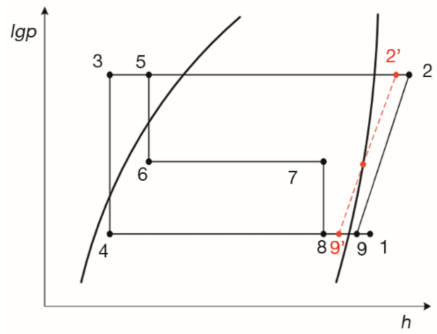

Figure 2. Low pressure supplemental gas theoretical cycle pressure enthalpy diagram

The theoretical cycle is calculated:

– Condenser side heating capacity of a heat pump system:

$$Q_h = m_r(h_2 - h_5) \tag{1}$$

– Compressor power:

$$W = m_r(h_9 - h_2) \tag{2}$$

– Cooling capacity on the evaporator side of the heat pump system:

$$Q_c = m_o(h_1 - h_4) \tag{3}$$

– Refrigeration coefficient of a heat pump system:

$$COP_c = \frac{Q_c}{W} \tag{4}$$

Mass flow of supplemental gas refrigerant:

$$m' = m_r - m_o \tag{5}$$

– Economizer heat exchange:

$$Q' = m_o(h_5 - h_3) \tag{6}$$

Experimental processes

Experimental set-up

According to the quasi-two-stage compression cycle technology and the structural characteristics of the automobile air conditioning system, the experimental platform was built. This experiment was carried out in the standard enthalpy difference laboratory. Table 1 shows the details of the main experimental equipment and measuring devices, and fig. 3 shows the low pressure air-supplemented pure electric passenger car heat pump air conditioning system under test.

Table 1. Details of main experimental equipment and measuring devices

Equipment name	Specification model	Manufacturer
Compressor	Scroll inverter compressor: EVS34C, DC400~700V, Applicable working fluid: R407C, speed: 2000~6000 rpm, maximum cooling capacity: 10 kW	Shanghai Highly
External heat exchanger	Tube-fin heat exchanger, overall dimensions:1940 mm long, 10 rows and 5 columns; Adapted to 5 sets of axial fans: Fanstar-AR300D3-DD0-05 Rated total air volume 8000 m^3 per hour	Zhengzhou Kelin
In-car heat exchanger	Tube-fin heat exchanger, dimensions: length 1600 mm, 4 rows and 6 columns; Adapt to 6 centrifugal fans: Ebmpapst-K3G097-AK34-65, Rated total air volume 6000 m^3 per hour	Zhengzhou Kelin
Main circuit expansion valve	Electronic expansion valve, E^2V-18, adapted refrigerant: R407C, capacity: 12.6 kW	Carle
Complementary circuit expansion	Electronic expansion valve, valve E^2V-11, adapted working fluid: R407C, capacity: 5 kW	Carle
Economizer	Plate heat exchanger: B3-014-10D-3.0	Jiangsu Weiyi
Four-way reversing valve	DSF-20, applicable capacity: 7.1~25 kW	Zhejiang Dunan
Pressure transmitter	PT5-30M/T and PT5-07M/T, measurement accuracy: ≤ ±1%FS	Emerson, USA
Temperature sensor	*T* type, measurement accuracy: ≤ ±0.5 ℃	Self-made
Electronic breeze meter	EY3-2A electronic breeze meter, test range: 0~30 m/s	Tianjin ZhonghuanTianyi
Data collector	Agilent 34972A	Agilent, USA

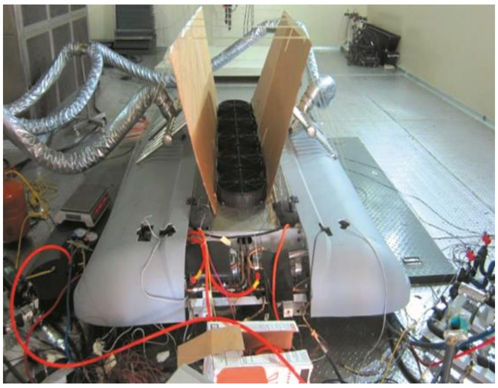

Figure 3. The heat pump air conditioning system of a pure electric passenger car with low pressure supplemental air under test

Experimental test conditions

According to QC/T656-2000 *Performance Requirements for Automotive Air Conditioning and Refrigeration Equipment*, QC/T657-2000 *Test Method for Automobile Air Conditioning Refrigeration Equipment*, GBT12782-2007 *Automobile Heating Performance Requirements and Test Methods*, GBT21361-2008 *Car Air Conditioner*, and GB7725-2004 *Room Air Conditioner* and other national and industry standards formulate experimental test conditions shown in tab. 2. During the experiment, the compressor speed is 5000 rpm.

Table 2. Experimental test conditions

Test conditions		Ambient temperature inside the car		Ambient temperature outside the car	
		Dry bulb temperature	Wet bulb temperature	Dry bulb temperature	Wet bulb temperature
Refrigeration	Low temperature refrigeration	21	15.5	21	16
	Rated cooling	27	19.5	35	27
	Maximum operation	32.5	26	50	36

Analysis of experimental results

Figure 4 shows the change curve of the compressor discharge temperature with the ambient temperature outside the vehicle. It can be seen from fig. 4 that under cooling conditions, the compressor discharge temperature gradually increases with the increase of the ambient temperature outside the car, and at the same parameter points, the discharge temperature of the non-supplemented system is greater than that of the low pressure supplementary system temperature. Through the low pressure supplemental gas technology, the system exhaust temperature is within 90 ℃, especially in the high temperature 50 ℃ environment, the exhaust temperature of the non-supplemented system is as high as 97.59 ℃, and the low pressure supplementary system exhaust temperature is 84.05 ℃, which is 13.54 lower than that. This is because the supplementary refrigerant and the main refrigerant at the outlet of the evaporator become low pressure saturated gaseous refrigerant after being mixed at the low pressure supplementary port. Under the same compression ratio, the exhaust temperature is significantly reduced.

Figure 5 shows the change curve of the system cooling capacity with the ambient temperature outside the car. It can be seen from fig. 5 that under cooling conditions, as the ambient temperature rises, the system cooling capacity first increases and then decreases. At the same parameter points, the cooling capacity of the system without supplemental air is greater than that of the low pressure supplemental system. When the ambient temperature outside the vehicle rises from 21 °C to 50 °C, the refrigeration capacity of the low pressure supplemental air system is reduced by 1.2%, 1.8%, and 2.0%, respectively. This is because after the low pressure supplemental gas technology is adopted, the supplemental gas circuit divides a part of the main refrigerant mass-flow entering the evaporator, resulting in a decrease in the refrigerant flow rate of the evaporator and the system cooling capacity.

The changes in system compressor power and COPc with the ambient temperature outside the vehicle are shown in figs. 6 and 7. It can be seen from figs. 6 and 7 that under refrigeration conditions, as the ambient temperature increases, the system compressor power gradually increases, and the system COPc gradually decreases. At the same parameter points, the compressor power of the non-supplemented system is greater than that of the low pressure supplemental system, and the COPc of the non-supplemented system is less than that of the low pressure supplementary system. When the ambient temperature outside the car rises from 21 °C to 50 °C, the compressor power of the non-supplemented system increases by 7.6%, 5.6%, and 3.4%, for the lower pressure supplemental system decreases by 6.1%, 3.7%, and 1.4%. This is because after using low pressure air supplement technology, the condensing pressure decreases, the evaporation pressure increases, and the compressor pressure ratio de-

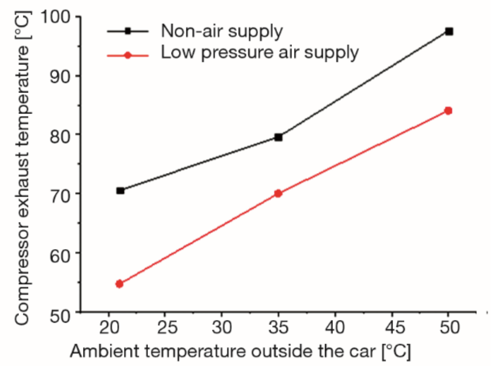

Figure 4. The compressor discharge temperature changes with the ambient temperature outside the car

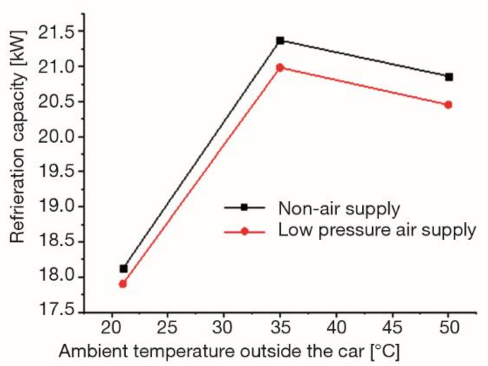

Figure 5. The cooling capacity of the system changes with the ambient temperature outside the car

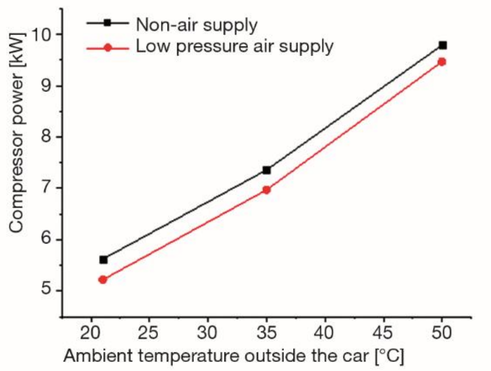

Figure 6. The change of system compressor power with the ambient temperature outside the car

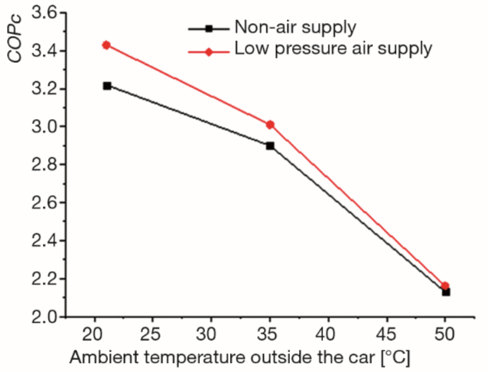

Figure 7. The change of system COPc with the ambient temperature outside the car

creases, resulting in a decrease in compressor power; and the system COPc is the ratio of the system refrigeration capacity to the compressor power. The effect ultimately results in the COPc of the non-supplemented air system being less than the COPc of the low-pressure air supplementing system.

Conclusions

The following conclusions are made.

- Under refrigerating conditions, the compressor discharge temperature gradually increases with the increase of the ambient temperature outside the car. In a high temperature 50 °C environment, the discharge temperature of the non-supplemented system is as high as 97.59 °C, while the low pressure supplementary system's discharges temperature is 84.05 °C. It shows that under high temperature conditions, the low-pressure air supplement technology can improve the operating reliability of the system compressor.
- Under cooling conditions, as the ambient temperature rises, the cooling capacity of the system first increases and then decreases. The compressor power of the system gradually increases, while the COPc of the system gradually decreases. In a high temperature 50 °C

environment, compared with the non-supplemented system, the refrigeration capacity of the low pressure supplementary system is reduced by 2.0%, the compressor power is reduced by 3.4%, and the COPc is increased by 1.4%.

Acknowledgment

The work is supported by the Research Funds of Key Laboratory of Heating and Air Conditioning, The Education Department of Henan Province (No. 2017HAC203) and Fundamental Research Funds Special Fund Project of Zhongyuan University of Technology (No. K2018QN006).

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Paper submitted: August 15, 2020
Paper revised: November 26, 2021
Paper accepted: November 27, 2021

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