EFFECTS OF ELECTRONIC EXPANSION VALVE SUPERHEAT ON REFRIGERATION PERFORMANCE OF NEW VEHICLE HEAT PUMP AIR CONDITIONING SYSTEM AT HIGH TEMPERATURES

by

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In response to the problem of serious deterioration in the refrigeration performance of the heat pump air conditioning system at high temperatures, the impact of the electronic expansion valve of the new refrigerant R1234yf on the vehicle low-voltage air conditioning heat pump system was investigated with regard to its refrigeration performance. In order to ascertain the effect of refrigeration performance parameters at a high temperature of 50 °C, the superheat of the main valve and the supplement valve was analyzed. To illustrate, when the primary valve was subjected to superheating by 3 °C at a temperature of 9 °C, the exhaust temperature exhibited an increase of 9.82 °C, while the opening degree exhibited a decrease of 7.8%. In addition, both the evaporation temperature and condensing temperature decreased by 3.97 °C and 11.25 °C, respectively. When the primary valve was subjected to superheating by 5 °C, the maximum refrigeration and COP were 3.201 kW and 1.769, respectively. This represents an increase of 13.96% and 10.91%, respectively. Upon the increase of the supplement excess heat by 15 °C, the exhaust temperature exhibited an increase of 7.23 °C, while the opening degree demonstrated a decrease of 20.7%. The evaporation temperature and condensing temperature have decreased by 1.8 °C and 6.15 °C, respectively. When the auxiliary valve was superheated at 10 °C, the cooling capacity and COP were 3.315 kW and 1.889, respectively. The values in question exhibited an increase of 3.01% and 7.51%, respectively, in comparison to the baseline conditions. The optimal temperature for the main valve is 5 °C, while the optimal temperature for the auxiliary valve is 10 °C.

Key words: *heat pump air conditioner, quasi-secondary compression, superheat, low-pressure tonic*

Introduction

In recent years, there has been a rapid development of new energy vehicles, with pure electric vehicles representing a significant advance in the field. These vehicles offer a number of advantages, including energy saving, low-carbon emissions, and environmentally friendly features. These developments are in line with the principles of sustainable development as outlined in [1, 2]. The Montreal Protocol Kigali Amendment essentially prohibits the utilization of R134a. Nevertheless, the recently developed refrigerant R1234yf exhibits com-

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parable physical properties to the existing R134a refrigerant [3], which is currently regarded as the optimal alternative, as evidenced by reference [4]. The car heat pump air conditioning system represents the second largest consumer of energy equipment [5], exerting a significant impact on the battery life of pure electric vehicles [6]. In the contemporary era, electronic expansion valves are extensively utilized in the thermal management systems of pure electric vehicles due to their advantageous attributes, including rapid response, precise control, and a broad operational range [7]. During the summer months, if the electronic expansion valves are not set at an appropriate level, this can lead to issues such as a reduction in refrigeration performance and an increased energy consumption in new vehicle heat pump air conditioning systems when the temperature reaches 50 °C. An investigation into the electronic expansion valve is of great importance in order to enhance the quality of the refrigerant flow and the stability of heat pump systems [8].

Beghi and Cecchinato [9] identified the control knowledge base and control rules of the heat pump system by regulating the electronic expansion valve to control heat. Zhang *et al.* [10] conducted a study on the electronic expansion valve control strategy in stages, with the objective of improving the energy efficiency ratio of a system by analyzing the minimum stable over-heat curve. The study examined the performance of an economic instrument in conjunction with a vortex compressor. It was determined that the refrigeration performance was enhanced, and the system exhibited greater reliability in high temperature environments [11, 12]. Gu *et al.* [13] investigated the impact of adjusting electronic expansion valves on the refrigeration performance of a heat pump air conditioning system. The study revealed that the valve opening size significantly affects the cooling capacity and the temperature of the air outlet. In the compressor absorbent port, the excessive heat of the refrigerant is controlled before aspiration, preventing liquid production of the compressor, and improving the efficiency of the system [14]. Through the adjustment of the electronic expansion valve, Su *et al.* [15] found that the optimal export of a refrigerator evaporator was the export of the best superheat, which was 6 °C. Zou *et al.* [16] demonstrated that alterations in the opening degree can influence the performance of heat pump systems, including superheat, COP, condensing temperature, and other crucial parameters. Hua *et al.* [17] established a test table to evaluate the heat pump system. Their findings indicated that the EXV opening can effectively adjust the outlet air temperature of the heat pump and that the system COP maximizes when the EXV opening is at its optimal setting. Li *et al.* [18] conducted an experiment on the heat pump electronic expansion valve with an economic instrument, which revealed that the opening of the main valve increased and the water inlet temperature decreased. The auxiliary valve differed from the main valve.

The existing literature primarily examines the performance of heat pump systems from the perspective of a single expansion valve and the refrigeration side of the heat pump. However, there is a paucity of research on the refrigeration performance of the entire heat pump system under high temperatures of 50 °C. This is despite the fact that dual-electron expansion valves with R1234yf as the working fluid have been studied in detail. At temperatures of 50 °C, the primary and auxiliary valves are adjusted to analyze the effects of exhaust temperature, opening, refrigeration, compressor power, COP, evaporation temperature, condensing temperature, exhaust pressure, and pressure ratio.

Experimental device

Figure 1 illustrates the fundamental principle of circulation for the heat pump air conditioning system. The refrigeration cycle of the system is divided into two distinct categories: the main roads and the auxiliary roads. The main road is, subsequently, the high temperature and high pressure gaseous working quality enters the four-way valve, which then directs it to the outside heat exchanger of the vehicle. This is followed by a unidirectional valve, a storage device, a filtering dryer, and finally, the low temperature and high pressure liquid working quality. A portion of the heat is released to the middle heat exchanger, where a low temperature and low pressure construction of low temperature and low pressure working quality is formed after the main valve is thrown. This construction is then absorbed by the heat exchanger on the inner side of the car and returned to the compressor. Make-up for the way. The auxiliary and main road cycle are consistent before passing through the intermediate heat exchanger. Following the opening of the supplementary valve, which reduces the blood pressure, the middle heat exchanger absorbs the work quality of the outer condenser from the outside of the car, thereby reducing the excessive heat that enters the compressor. This heat is replenished by low pressure gas, and the main road increases the quality of the work flow. The next cycle commences.

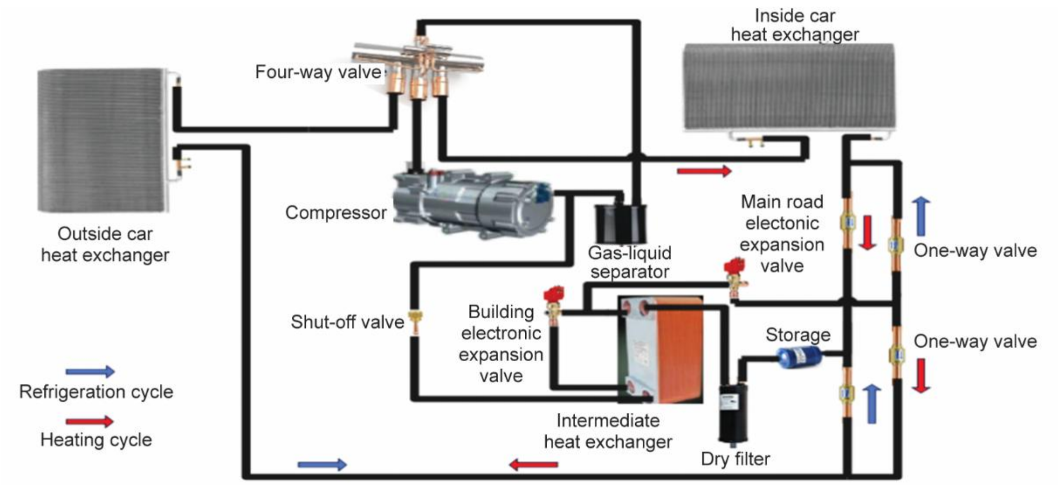

Figure 1. System cycle principle

The heat exchanger outside the car exchanges heat:

$$Q_{\mathrm{h}} = \dot{m}_{\mathrm{r}}(h_2 - h_3)$$

where Q_{h} is the heat exchanger for the outside car, $\dot{m}_{\mathrm{r}}$ – the quality flow of the refrigerant export refrigerant from the outside of car, h_2 – the refrigerant of heat exchanger in the car, and h_3 – the enthalpy value of refrigerant at the outlet of external heat exchanger.

Compressor power:

$$W = \dot{m}_{\mathrm{r}}(h_2 - h_9)$$

where W is the compressor power and h_8 – the enthalpy value of refrigerant when mixing the main route and the replacement route.

The heat exchanger in the car changes heat:

$$Q_{\mathrm{C}} = \dot{m}_o(h_9 - h_8)$$

where Q_{C} is the heat exchange of heat exchanger in the car, $\dot{m}_o$ – the mass-flow of refrigerant into the heat exchanger, h_9 – the enthalpy value of refrigerant at the outlet of heat exchanger in the car, and h_8 – the enthalpy value of inlet refrigerant of heat exchanger in the car.

Air mixing cycle mass-flow of circulating working medium:

$$\dot{m}' = \dot{m}_\mathrm{r} - \dot{m}_0$$

The COP refrigeration coefficient:

$$COP = \frac{Q_\mathrm{C}}{W} = \frac{\dot{m}_o (h_9 - h_4)}{\dot{m}_\mathrm{r} (h_2 - h_9)}$$

Experimental equipment

Set up the experimental bench, the selection of Hailey inverter scroll EVS34 compressor, its operating range of 1000~7000 rpm and the maximum refrigeration capacity of 7 kW. Inside and outside the car heat exchanger are used in Zhengzhou Kelin, the heat transfer area of 2.07 m^2 and 1.40 m^2, respectively. A Shanghai Dedong FAD60-4 axial fan and an Ebm-K3G097 inverter centrifugal fan are used inside and outside the vehicle, respectively. Table 1 shows the main parameters of the experimental prototype and test instrument.

Table 1. Main parameters of the experimental prototype and test instrument

Equipment name	Specifications
Main expansion valve	CAREL E^2V-24, capacity: 16.3 kW, adjustment range: 10%~100%
Auxiliary expansion valve	CAREL E^2V-14, capacity: 5.7 kW, adjustment range: 10%~100%
Intermediate heat exchanger	Weal Yield (Jiangsu) plate heat exchanger model B3-014-20D-3.0; design capacity: 6.06 kW; design temperature: –160~200 °C
Four-way valve	Dunan DSF-20, applicable capacity: 7.1~25 kW

Table 2. Experimental test conditions

Testing conditions	Outside temperature [°C]	In-car temperature [°C]		Main valve outlet superheat	Auxiliary valve outlet volume	Replenishment technology
	Dry-bulb	Dry-bulb	Wet-bulb	°C	°C	
Testing condition 1	50	27	19	3		No replenishing technology
				5		
				7		
				9		
Testing condition 2	50	27	19	5	8	Low-pressure gas replenishment technology
					10	
					12	
					15	

Experimentation in the standard enthalpy difference laboratory, which the experimental conditions show in tab. 2. The refrigerant charge of R1234yf is 1632 kg, the outside-car heat exchanger and inside-car heat exchanger fans air volume are set at 1200 m^3/h and 7830 m^3/h, respectively, and the compressor speed is set at 3600 rpm.

Effect of the main valve superheat on cooling performance

Figure 2 illustrates that as the main valve outlet superheat setting value increases, the compressor exhaust temperature tends to rise, while the compressor power generally declines. The superheat setting value of the main valve was increased from 3 °C to 9 °C, and the exhaust temperature of the compressor was increased from 77.9 °C to 87.72 °C, representing an increase of 12.61%. The compressor power is 1.82 kW, 1.809 kW, 1.805 kW, and 1.798 kW.

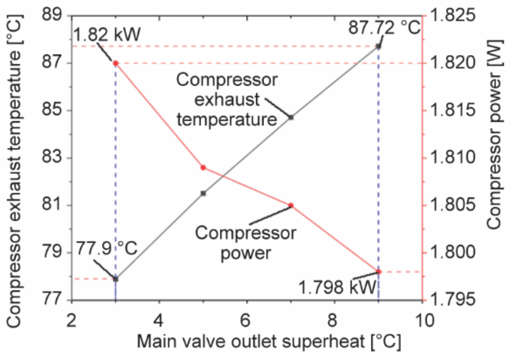

Figure 2. Influence of main valve outlet superheat setting value on compressor exhaust temperature and compressor power

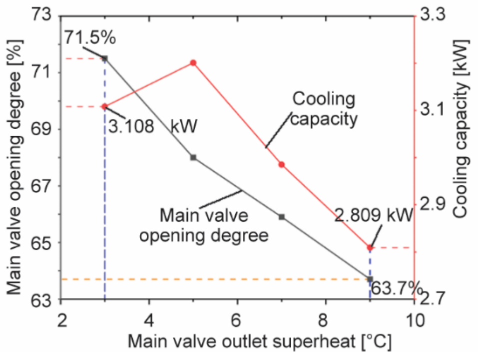

Figure 3. Influence of main valve outlet superheat setting value on main valve opening degree and cooling capacity

Figure 3 illustrates that as the setting value of the main valve is increased, the degree of valve opening decreases, and cooling capacity generally declines. However, the maximum cooling capacity is observed when the main valve is set to 5 °C. When the main valve outlet superheat setting value is adjusted from 3 °C to 9 °C, the degree of valve opening decreases from 71.5% to 63.7%, resulting in a 7.8% reduction in relative opening. Concurrently, the cooling capacity is observed to decrease from 3.108 kW to 2.809 kW, representing a 12.6% reduction. The maximum cooling capacity is observed at a temperature of 5 °C. An increase in the main valve outlet superheat results in a reduction in the opening, which in turn leads to a decline in refrigerant quality flow. Prior to the main valve outlet superheat reaching 5 °C, the refrigerant mass-flow in the evaporator is excessive, resulting in a lack of heat exchange. Consequently, the cooling capacity is enhanced. However, as the main valve outlet superheat continues to increase, the quality flow of refrigerant declines, and the effective heat exchange area of the evaporator is reduced. Both of these circumstances can lead to a decline in cooling capacity.

Figure 4 illustrates that as the main valve outlet superheat increases, the evaporation temperature and condensing temperature decrease. The main valve outlet superheat increased from 3 °C to 9 °C, while the evaporation temperature decreased from 19.19 °C to 15.22 °C, representing a 3.97 °C reduction. In contrast, the condensing temperature declined from 55.57 °C to 44.32 °C, resulting in a 11.25 °C drop. As a consequence of the reduction in the opening of the main valve, which is accompanied by a decline in the quality of the flow of evaporator refrigerant, the evaporator export temperature and the specific volume increase. This results in the appearance of superheated gas at the evaporator outlet, which in turn leads to a reduction in the evaporation temperature. The reduction in the cycle working medium of the system is accompanied by a consistent change in condensing temperature, in accordance with the change in evaporation temperature.

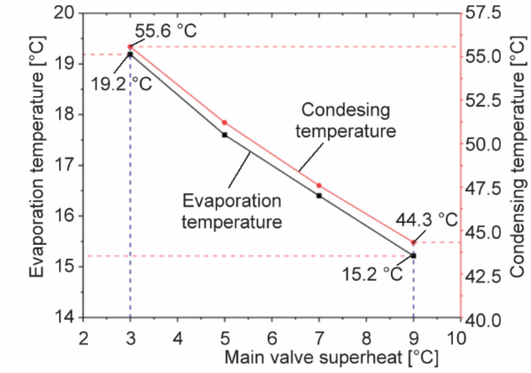

Figure 4. Influence of main valve outlet superheat setting value on evaporation temperature and condensing temperature

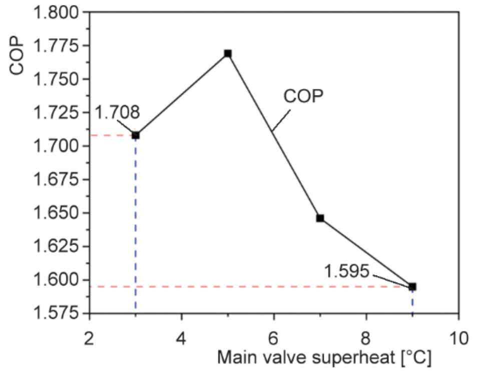

Figure 5. Influence of main valve outlet superheat setting value on COP

Figure 5 illustrates that as the main valve outlet superheat increases, the COP initially increases, reaches a maximum value, and then decreases. When the main valve outlet superheat increases from 3 °C to 9 °C, and the cooling performance coefficients of COP are 1.708, 1.769, 1.646, and 1.595, respectively, the following observations can be made. At 5 °C, the COP reaches a peak of 1.769. This is primarily due to the compressor power remaining relatively constant, while the cooling capacity assumes a dominant role. With an increase in the main valve outlet superheat, the opening degree is reduced. Initially, the refrigerant did not fully transfer heat, and the enhanced cooling capacity led to an increase in the COP. When the main valve was superheated by 5 °C, the cooling performance was optimal. However, as the opening degree continued to decrease, the effective heat exchange area in the evaporator decreased, and the cooling capacity decreased. At this juncture, the change in cooling capacity continues to exert a significant influence, thereby reducing the COP. When the main valve outlet superheat is set at 5 °C, the peak value is reached, and the COP reaches its optimal value.

Effect of auxiliary valve overheat superheat on cooling performance

Figure 6 illustrates that as the auxiliary valve outlet superheat setting value is increased, the compressor exhaust temperature rises, while the compressor power decreases. When the auxiliary valve outlet superheat is set to 8 °C, 10 °C, 12 °C, and 15 °C, the compressor exhaust temperature increases from 70.41 °C to 77.64 °C, representing an increase of 7.23 °C. Concurrently, the compressor power is reduced from 1.832 kW to 1.81 kW, resulting in a change of 0.022 kW. The primary reason for this phenomenon is that as the auxiliary valve outlet superheat increases, the mass-flow of auxiliary refrigerant through the intermediate heat exchanger declines, accompanied by a reduction in supplementary gas volume. Consequently, the temperature of the auxiliary refrigerant rises, resulting in an elevated compressor exhaust temperature. The suction capacity of the compressor is reduced at the mixed mouth, which in turn reduces the compressor power.

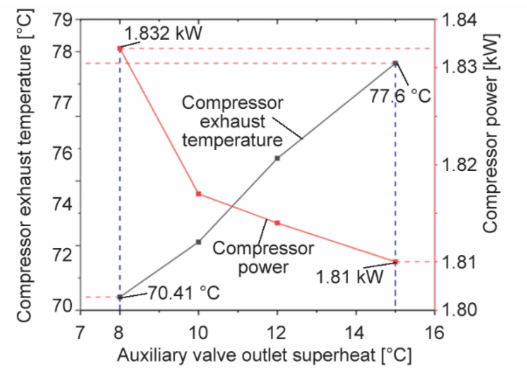

Figure 6. Influence of auxiliary valve outlet superheat setting value on compressor exhaust temperature and compressor power

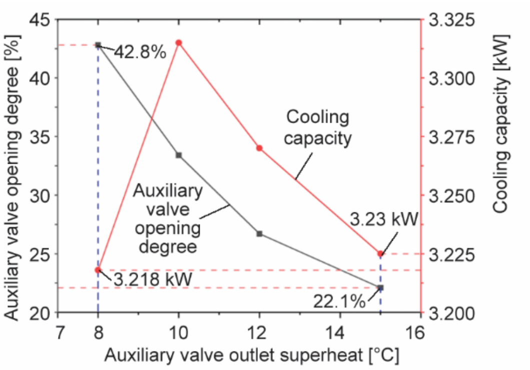

Figure 7. Influence of auxiliary valve outlet superheat setting value on auxiliary valve opening degree and cooling capacity

Figure 7 illustrates that as auxiliary valve superheat increases, the degree of auxiliary valve opening decreases, while cooling capacity initially rises and then declines. An increase in the superheat setting value of the auxiliary valve from 8 °C to 15 °C resulted in a reduction in the auxiliary valve opening degree from 42.8% to 22.1%, which represents a 20.7% decrease in the relative opening degree. The cooling capacity exhibited a corresponding decline, reaching 3.218 kW, 3.315 kW, 3.27 kW, and 3.225 kW, respectively. The maximum cooling capacity is achieved when the auxiliary valve outlet superheat setting value is 10 °C. Due to the auxiliary valve outlet superheat being relatively small, the auxiliary refrigerant is not fully utilized. As the auxiliary valve opening degree continues to decrease, the filling volume also decreases. Prior to 10 °C, the cooling capacity displays a rising trend. However, after 10 °C, the replenishment gas continues to decrease, which results in the auxiliary refrigerant absorbing less heat from the main refrigerant. Consequently, the enthalpy difference between the import and export of the evaporator decreases, and the cooling capacity is reduced.

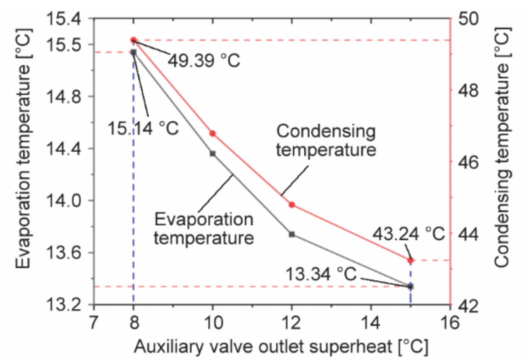

Figure 8. Influence of auxiliary valve outlet superheat setting value on evaporation temperature and condensing temperature

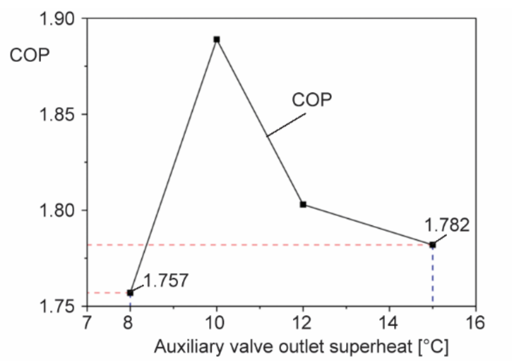

Figure 9. Influence of auxiliary valve outlet superheat setting value on COP

Figure 8 illustrates that an increase in the auxiliary valve outlet superheat is associated with a reduction in both the evaporation and condensing temperatures. When the auxiliary valve outlet superheat is between 8 °C and 15 °C, the evaporation temperature decreases from 15.14 °C to 13.34 °C, representing a reduction of 1.8 °C. Similarly, the condensing temperature decreases from 49.39 °C to 43.24 °C, representing a reduction of 6.15 °C.

Figure 9 illustrates that the cooling performance of COP exhibits an initial increase and subsequent decline as the auxiliary valve outlet superheat setting value is augmented. A peak COP is observed when the auxiliary valve outlet superheat reaches 10 °C. As the auxiliary valve outlet superheat setting value is increased from 8 °C to 15 °C, the cooling performance of COP is observed to be 1.757, 1.889, 1.803, and 1.782, respectively. Of particular interest is the observation that the maximum COP is achieved when the auxiliary valve is increased to 10 °C. As cooling capacity is the primary determinant of COP, and compressor power remains relatively constant, the optimal cooling capacity is achieved when the auxiliary valve is set to 10 °C. This, in turn, results in the highest COP, and the system's refrigeration performance is at its peak.

Conclusions

- The main valve outlet superheat setting value is increased from 3 °C to 9 °C, resulting in an increase of 9.82 °C in the exhaust temperature of the compressor. Concurrently, the main valve opening degree is reduced by 7.8%, while the evaporation temperature and condensing temperature are decreased by 3.97 °C and 11.25 °C, respectively. Notably, the compressor power, exhaust pressure, and pressure ratio exhibit a relatively stable trend, whereas the cooling capacity and COP demonstrate an initial increase followed by a subsequent decline. When the main valve outlet superheat is 5 °C, the peak of cooling capacity and COP are 3.201 kW and 1.769, respectively.
- An increase in the auxiliary valve outlet superheat setting value from 8 °C to 15 °C resulted in an increase in the exhaust temperature of the compressor by 7.23 °C, a decrease in the auxiliary valve opening degree by 20.7%, a reduction in the evaporation temperature and condensing temperature by 1.8 °C and 6.15 °C, a slight change in compressor power, and an increase in the exhaust pressure and pressure ratio by 1.8 bar and 0.8, respectively. However, the cooling capacity and COP initially increased and then decreased. When the auxiliary valve outlet superheat is 10 °C, the peak cooling capacity is 3.315 kW, and the peak COP is 1.889.
- The setting of the main valve and auxiliary valve outlet superheat can effectively enhance the refrigeration performance. The refrigeration performance is optimal when the main valve outlet superheat is at 5 °C, and when the auxiliary valve outlet superheat is 10 °C. This research provides a certain degree of guidance for subsequent studies of new vehicle heat pump systems utilizing the R1234yf refrigerant.

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