ABSTRACT: The application of a mixed refrigerant HFO1234yf/HFC134a (89:11, by mass) of GWP 144 in a vehicle air-conditioner system with and without an internal heat exchanger was studied under refrigerating and heating conditions, and it was compared with an R134a original system. The results show that under refrigerating conditions, the refrigerating capacity of the HFO1234yf/HFC134a system with an internal heat exchanger is increased by 2–4%, which is slightly larger than that of R134a system. The refrigerating COP of the HFO1234yf/HFC134a system with an internal heat exchanger is increased not largely. However, it tends to decrease at high-temperature conditions. In heating conditions, the heat capacity of the HFO1234yf/HFC134a system with an internal heat exchanger is improved by 2–5%, basically equal to that of the R134a system. The heating COP of HFO1234yf/HFC134a with an internal heat exchanger is increased with a maximum of 6% at low-temperature conditions. HFO1234yf/HFC134a can be used as an environmental alternative to R134a as an introduction of an internal heat exchanger into an automobile air-conditioning systems.

1. INTRODUCTION

Global warming is a problem that cannot be ignored. There is an urgent need to replace refrigerants with high global warming potential (GWP). The use of high-GWP refrigerants should be gradually reduced on the basis of the Kyoto protocol. Europeans prohibited greenhouse gases with a GWP greater than 150 in newly manufactured vehicle air-conditioner systems from 2011 and all vehicle air-conditioner systems from 2017. In October 2016, the “Kigali Programme” continued the further promotion of the decrease of refrigerants with high GWP. In this agreement, a time table for the reduction of hydrofluorocarbon emission was established, which mainly stipulated that the target of 80–85% emission reduction should be achieved by 2040. Developed countries should take the lead. Most developing countries, like China, should phase out hydrofluorocarbons after 2024. Some developing countries, like India and Pakistan, should begin to phase out HFCs after 2028. HFC134a is highly applied in vehicle air-conditioner systems, water chillers, and refrigeration units. Since the GWP value of R134a is 1300, it will also be phased out in the near future.

In past research, the refrigerants that can replace R134a mainly contain hydrocarbons, HFC152a and CO₂. Hydrocarbons are used in refrigeration equipment because of their good oil solubility and absence of a chemical reaction with common materials. Moreover, the system performance of most hydrocarbons is better. However, due to the higher flammability, explosion may occur with a large charge of hydrocarbons in refrigeration units. The system performance of HFC152a is similar to that of HFC134a. However, it is not recommended to be used in refrigeration equipment due to...
flammmability. As a natural refrigerant, CO\textsubscript{2} has better performance in refrigeration systems,\textsuperscript{8} but the refrigeration equipment needs great changes because CO\textsubscript{2} runs in very high pressure cycles. 

Recently, HFO1234yf is a potential replacement refrigerant for HFC134a.\textsuperscript{9} The thermodynamic properties of HFO1234yf and HFC134a are similar.\textsuperscript{10,11} The ODP of HFO1234yf is 0, and the GWP is less than 1.\textsuperscript{1} Research\textsuperscript{12−14} mainly paid close attention to the system performance of HFO1234yf in vehicle air-conditioner systems. The tests mainly change different compressors and throttling devices and different forms of condensers and evaporators under different conditions. Research showed that the system performance of HFO1234yf was slightly lower than that of HFC134a. Relevant research introduced the internal heat exchanger to the vehicle air-conditioner system for the reason that it can improve the system performance. The results obtained by Cho et al.\textsuperscript{15} showed that the refrigerating capacity and COP of the HFO1234yf system with an internal heat exchanger were increased by 2% and 4%, respectively. Karber et al.\textsuperscript{10} studied the performance of HFO1234yf in household refrigerators and refrigeration devices. Research showed that, under the test conditions, the power consumption of HFO1234yf was 2.7% higher than that of HFC134a. Colombo et al.\textsuperscript{16} studied the running performance of HFO1234yf and R1234ze(E) in a water-to-water heat pump. Research showed that the heating capacity and the COP of HFO1234yf were decreased by 9.80% and 7.39%, compared to HFC134a, respectively. The main problem of HFO1234yf is that it has mild flammability and is classified as A2L by the ANSI/AIRAH standard.\textsuperscript{18} The flammability of HFO1234yf is low, but compared with non-flammable refrigerants, it may also bring some unsafe factors. In Europe, big car companies reported that HFO1234yf would explode in the process of car collision.\textsuperscript{19} Therefore, some companies are more inclined to use HFC134a on their self-developed cars. 

In order to reduce the flammability of HFO1234yf, a HFO1234yf/HFC134a mixture can be presented as a potential substitute due to the flame retardant HFC134a in it. Yang et al. studied the R513A in a household refrigerator.\textsuperscript{20} Research showed that the 24 h energy consumption of R513A was 4% lower than that of HFC134a. Meng et al.\textsuperscript{21} studied the running performance of HFC134a and R513A in a vehicle air-conditioner system under summer conditions. Research showed that the refrigerating capacity and COP of R513A are similar to those of HFC134a. The results showed by Mota-Babiloni et al.\textsuperscript{22,23} stated that the refrigerating capacities of R513A and R134a of the system with an internal heat exchanger were increased up to 5.6% and 3%, respectively. The COP of R513A and R134a of the system with an internal heat exchanger also increased up to 8% and 4%, respectively. From the research, R513A can be directly used in an HFC134a system without any modification. However, R513A, with a GWP of 572, can only be used as a transitional product because it does not meet the EU F-Gases Regulation.

At present, the introduction of 10−11% HFC134a into HFO1234yf is a feasible alternative to HFC134a. Aprea et al.\textsuperscript{24} and Lee et al.\textsuperscript{25} compared the performance of HFO1234yf/HFC134a (10/90%) and HFC134a in domestic refrigerators and in a heat pump test bench. Research showed that the heating capacity, refrigerating capacity, and COPs using the HFO1234yf/HFC134a mixture were basically equivalent to those of HFC134a. Meng et al.\textsuperscript{26} studied the mixture HFO1234yf/HFC134a (11/89%) in a vehicle air-conditioner system. The GWP value is 144, which meets the EU F-gas regulation. Research showed similar results to those of Aprea et al. and Lee et al.\textsuperscript{24,25}

Before the HFO1234yf/HFC134a mixture (89/11, by mass) refrigerant is accepted internationally, more research to explore the performance of the vapor compression systems is very necessary. In this paper, HFO1234yf/HFC134a was used to replace HFC134a in a vehicle air-conditioner system that introduces an internal heat exchanger. The research data can provide a new idea for the development of new refrigerants in the vehicle air conditioner system.

2. THERMODYNAMIC CYCLE RESEARCH

Thermodynamic analysis of the vehicle air-conditioner system with an internal heat exchanger was carried out to simulate the performance of HFO1234yf/HFC134a, including refrigerating and heating conditions, as an alternative to HFC134a. The thermodynamic cycle calculation formula was cited from the literature.\textsuperscript{27−29} The thermodynamic parameters of each cycle point in the calculation process under various working conditions were derived from REFPROP 9.1.\textsuperscript{30} The assumptions made are as follows:

1. The condenser and evaporator temperatures are 45 and 5°C under refrigerating conditions, respectively.
2. The condenser and evaporator temperatures are 30 and −10°C under heating conditions, respectively.
3. The volumetric efficiency and isentropic efficiency of the compressor are 0.8 and 0.75, respectively.
4. The rotational speed and discharge volume of the compressor are 2000 RPM and 33 cc/rev, respectively.
5. There is no pressure drop in pipes, evaporators, condensers, and other auxiliary components.
6. The efficiency of the internal heat exchanger is 0.3.

The performance of HFO1234yf/HFC134a in a vehicle air-conditioner system with and without an internal heat exchanger compared with an HFC134a system without an internal heat exchanger under refrigerating and heating conditions are listed in the Table 1. In refrigerating conditions, as the internal heat exchanger is introduced in the system, the mass flow rate of HFO1234yf/HFC134a is decreased. This is

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Table 1. Influence on the System Performance of HFO1234yf/HFC134a

| Condition | Refrigerant | with/without internal heat exchanger | Mass flow rate (kg/h) | Power (kW) | Capacity (kW) | COP | Discharge temperature (°C) |
|-----------|-------------|-------------------------------------|-----------------------|-----------|--------------|-----|---------------------------|
| Cooling   | HFC134a     | without                             | 84.79                 | 0.93      | 3.20         | 3.45| 72.63                     |
|           | HFO1234yf/HFC134a | without                           | 99.93                 | 0.90      | 2.95         | 3.29| 63.72                     |
|           | HFO1234yf/HFC134a | with                               | 94.41                 | 0.91      | 3.08         | 3.39| 74.49                     |
| Heating   | HFC134a     | without                             | 46.56                 | 0.49      | 2.59         | 5.25| 49.74                     |
|           | HFO1234yf/HFC134a | without                           | 56.66                 | 0.50      | 2.57         | 5.16| 40.58                     |
|           | HFO1234yf/HFC134a | with                               | 54.31                 | 0.50      | 2.62         | 5.24| 49.57                     |
because the gas from the evaporator is further overheated, causing the decrease of suction density of the compressor. The refrigerating capacity of the HFO1234yf/HFC134a system with the internal heat exchanger is increased by approximately 4%. However, it is still lower than that of HFC134a by 2%. As the internal heat exchanger is introduced in the system, the COP of the HFO1234yf/HFC134a system is increased by approximately 3% and is slightly lower than that of HFC134a by 1.5%. The compressor discharge temperature of the HFO1234yf/HFC134a system is increased by 11°C. Under heating conditions, as the internal heat exchanger is introduced in the system, the mass flow rate of the HFO1234yf/HFC134a system decreases to a certain extent. The heat capacity of the HFO1234yf/HFC134a system is increased by approximately 2% and is higher than that of HFC134a by 1%. The COP of HFO1234yf/HFC134a is increased by approximately 1.5%, which is basically equal to that of HFC134a. In summary, the refrigerating capacity, refrigerating COP, heat capacity, and heating COP of HFO1234yf/HFC134a can be improved after the system is introduced an internal heat exchanger.

3. EXPERIMENT

The performance test of a vehicle air-conditioner system is carried out in a multifunctional enthalpy difference laboratory, as shown in Figure 1. The wet- and dry-bulb temperatures of the indoor and outdoor room are controlled by a temperature and humidity control device. In the air flow measurement channel, the air volume is measured by the pressure difference method and the enthalpy difference of the air before and after the heat exchanger is measured by the temperature and humidity. The measured heat exchange of air can be obtained by multiplying the two parameters, thus obtaining the refrigerating capacity and heat capacity. In this process, the combined standard uncertainty is 11.5 W and expanded uncertainty is 23.01 W.

The vehicle air-conditioner system is mainly composed of an inverter compressor, in-car condenser, in-car evaporator, out-car heat exchanger, internal heat exchanger, electronic expansion valves, accumulator, mass flow meters, and solenoid valves (SV). The main components of the vehicle air-conditioner system are shown in Table 2. The structure and parameter of the internal heat exchanger are shown in Figure 2 and Table 3, respectively.

| Table 2. Component Parameters of Experimental Device |
| components | specifications | structure |
|-------------|----------------|-----------|
| out-car heat exchanger | 507.8 (W) × 393 (H) × 16 (D) | microchannel parallel flow |
| in-car condenser | 252 (W) × 250 (H) × 40 (D) | microchannel parallel flow |
| in-car evaporator | 223.6 (W) × 159.8(H) × 24(D) | microchannel parallel flow |
| compressor | exhaust volume is 33 cc/rev | swash plate type |

![Figure 2. Structure of the internal heat exchanger.](image)

![Figure 1. Experimental device diagram. (1) Compressor, (2) in-car condenser, (3, 11) coriolis mass flow meter (4, 6) electronic expansion valve, (5) internal heat exchanger, (7) out-car heat exchanger, (8) accumulator, (9) in-car evaporator, (10) air volume box, and (12) temperature control box.](image)
compressor inlet. In refrigerating and heating conditions, the system with an internal heat exchanger was left with SV9 and SV10 on and SV11 off, while the system without an internal heat exchanger was left with SV9 and SV10 off and SV11 on.

Temperature and pressure sensors are set at the inlet and outlet of each heat exchanger to measure the operating parameters on the refrigerant side. The compressor can be driven by frequency conversion, and the operating power is measured by a high-precision digital wattmeter. The opening of the electronic expansion valve can be controlled by itself.

The uncertainty of the measuring instrument is shown in Table 4. In both conditions, the effective data of the experiment were recorded when the optimal COP was obtained by adjusting the opening of the electronic expansion valve.

The comparison of refrigerating and heating conditions is shown in Figure 3b. The test results show that as the internal heat exchanger is introduced in the system, the refrigerating capacity of the HFO1234yf/HFC134a system increases by 2~4%, which is slightly higher than that of the R134a original system. This is because, after the introduction of an internal heat exchanger, HFO1234yf/HFC134a has a higher super-refrigerating degree before entering the electronic expansion valve, which obviously increases the latent heat of the refrigerant in the evaporator so as to compensate for the loss of the mass flow rate reduction.

The comparison of COP under refrigerating conditions is shown in Figure 3c. It can be seen that the COP of the HFO1234yf/HFC134a system with an internal heat exchanger increases by 3% and 1% under low and medium-heat load conditions, respectively, which is averagely lower than that of R134a by 6.5%. Under low and medium-heat load conditions, the increased COP of the HFO1234yf/HFC134a system with an internal heat exchanger is mainly because of the increase of refrigerating capacity. However, under high-heat load conditions, the COP of HFO1234yf/HFC134a system with an internal heat exchanger decreased by 2%, which is by average lower than that of R134a by 4.5%. This is because the power of the compressor of the HFO1234yf/HFC134a system with an internal heat exchanger increases under high-heat load conditions.

The comparison of the mass flow rate of the HFO1234yf/HFC134a system with and without an internal heat exchanger under refrigerating conditions is shown in Figure 4. The test result shows that the average mass flow rate of the HFO1234yf/HFC134a system with an internal heat exchanger decreases by approximately 5% under all heat load conditions. This is because the refrigerant is further overheated after the introduction of an internal heat exchanger, resulting in an increase in the gas specific volume of the refrigerant at the compressor inlet, thus causing a decrease in the mass flow rate.

The comparison of the compressor volumetric efficiency and global efficiency of the HFO1234yf/HFC134a system with and without an internal heat exchanger under refrigerating conditions is shown in Figure 5. The compressor volumetric efficiency has a downward trend after the introduction of an internal heat exchanger under all heat load conditions. This is because the introduction of an internal heat exchanger causes an additional pressure drop of the refrigerant at the compressor inlet, leading to an increase of the compression ratio. Under the same conditions, with the increase of the compressor speed, the volumetric efficiency of the compressor will have a maximum value. When the compressor speed is greater than or less than the optimal value, the volumetric efficiency of the compressor will decrease. As seen from the Figure 5, The

### Table 4. Measured Parameters and Equipment Uncertainty

| measured parameters  | sensor                        | uncertainty |
|----------------------|-------------------------------|-------------|
| temperatures         | K-type thermocouples          | ±0.3 K      |
| pressures            | piezoelectric pressure transducers | ±7 kPa   |
| mass flow rate       | Coriolis mass flow meter      | ±0.22%      |
| power of compressor  | digital wattmeter             | ±0.5%       |
| compressor rotation speed | capacitive sensor       | ±1%         |

During test period, the enthalpy value of the refrigerant side can be obtained by the measured temperature and pressure. The product of the enthalpy difference of the refrigerant into the heat exchanger and the mass flow can be used to obtain the refrigerating capacity and heating capacity. During the test period, the difference in heat exchange capacity between the air side and the refrigerant side was approximately 5%.

The refrigerating and heating conditions are divided into nine working conditions (see Tables 5 and 6), respectively. Three heat load conditions were simulated under refrigerating and heating conditions.

### 4. RESULTS AND DISCUSSION

#### 4.1. Refrigerating Condition

The comparison of power of the compressor under refrigerating conditions is shown in Figure 3a. The test results show that, as the internal heat exchanger is introduced in the system, the power of the compressor of the HFO1234yf/HFC134a system is increased by approximately 2% at low and medium-heat load conditions and 5% at high-heat load conditions. The increase of power of the compressor is mainly due to the increase of unit compression specific power. The power of the compressor of an HFO1234yf/HFC134a system increases at high-heat load conditions mainly because, as shown in Figure 5, the compressor global efficiency of HFO1234yf/HFC134a decreases larger after the system is introduced an internal heat exchanger.

The comparison of refrigerating capacity is shown in Figure 3b. The test results show that as the internal heat exchanger is introduced in the system, the refrigerating capacity of the HFO1234yf/HFC134a system increases by 2~4%, which is slightly higher than that of the R134a original system. This is because, after the introduction of an internal heat exchanger, HFO1234yf/HFC134a has a higher super-refrigerating degree before entering the electronic expansion valve, which obviously increases the latent heat of the refrigerant in the evaporator so as to compensate for the loss of the mass flow rate reduction.

The comparison of COP under refrigerating conditions is shown in Figure 3c. It can be seen that the COP of the HFO1234yf/HFC134a system with an internal heat exchanger increases by 3% and 1% under low and medium-heat load conditions, respectively, which is averagely lower than that of R134a by 6.5%. Under low and medium-heat load conditions, the increased COP of the HFO1234yf/HFC134a system with an internal heat exchanger is mainly because of the increase of refrigerating capacity. However, under high-heat load conditions, the COP of HFO1234yf/HFC134a system with an internal heat exchanger decreased by 2%, which is by average lower than that of R134a by 4.5%. This is because the power of the compressor of the HFO1234yf/HFC134a system with an internal heat exchanger increases under high-heat load conditions.

The comparison of the mass flow rate of the HFO1234yf/HFC134a system with and without an internal heat exchanger under refrigerating conditions is shown in Figure 4. The test result shows that the average mass flow rate of the HFO1234yf/HFC134a system with an internal heat exchanger decreases by approximately 5% under all heat load conditions. This is because the refrigerant is further overheated after the introduction of an internal heat exchanger, resulting in an increase in the gas specific volume of the refrigerant at the compressor inlet, thus causing a decrease in the mass flow rate.

The comparison of the compressor volumetric efficiency and global efficiency of the HFO1234yf/HFC134a system with and without an internal heat exchanger under refrigerating conditions is shown in Figure 5. The compressor volumetric efficiency has a downward trend after the introduction of an internal heat exchanger under all heat load conditions. This is because the introduction of an internal heat exchanger causes an additional pressure drop of the refrigerant at the compressor inlet, leading to an increase of the compression ratio. Under the same conditions, with the increase of the compressor speed, the volumetric efficiency of the compressor will have a maximum value. When the compressor speed is greater than or less than the optimal value, the volumetric efficiency of the compressor will decrease. As seen from the Figure 5, The

### Table 5. Operating Conditions of Refrigerating Condition

| heat load number | RPM (rev/ min) | indoor room | outdoor room |
|------------------|----------------|-------------|--------------|
|                  | dry bulb temperature (°C) | relative humidity (%) | air mass flow rate (kg/ min) | dry bulb temperature (°C) | air mass flow rate (kg/ min) |
| low              | 1/2            | 2000/3000   | 27           | 45           | 5.5           | 30           | 28           |
|                  | 3              | 4000        | 27           | 45           | 8.2           | 8.2           | 30           | 31.8         |
| medium           | 4/5            | 2000/3000   | 25           | 45           | 5.5           | 38           | 31.8         |
|                  | 6              | 4000        | 25           | 45           | 8.2           | 8.2           | 38           | 31.8         |
| high             | 7/8/9          | 2000/3000/4000 | 38           | 45           | 8.2           | 43           | 31.8         |
The volumetric efficiency of the compressor has not reached the maximum value at 2000 rev/min, so the volumetric efficiency increases with the increase of the rotating speed at 3000 rev/min. Global efficiency is a complex variable, which includes isentropic efficiency, electrical efficiency, and mechanical efficiency. It establishes the relationship between the minimum power consumption required by the compressor to compress the refrigerant under specific working conditions and the actual power consumption. As shown in Figure 5, the compressor global efficiency showed a downward trend after the introduction of an internal heat exchanger, and the decrease is obvious under high-heat load conditions. Under high-heat load conditions, the compressor discharge temperature of the system without an internal heat exchanger is relatively high. After the introduction of the internal heat exchanger, the refrigerant gas is further overheated, resulting in

Table 6. Operating Conditions of Heating Condition

| heat load | condition number | RPM (rev/min) | dry bulb temperature (°C) | air mass flow rate (kg/min) | dry bulb temperature (°C) | air mass flow rate (kg/min) |
|-----------|-----------------|---------------|---------------------------|-----------------------------|---------------------------|----------------------------|
| low       | 1               | 2000          | 10                        | 5                           | 10                        | 19                         |
|           | 2/3             | 3000/4000     | 10                        | 8                           | 10                        | 40                         |
| medium    | 4               | 2000          | 5                         | 5                           | 0                         | 19                         |
|           | 5/6             | 3000/4000     | 5                         | 8                           | 0                         | 40                         |
| high      | 7               | 2000          | -5                        | 5                           | -5                        | 19                         |
|           | 8/9             | 3000/4000     | -5                        | 8                           | -5                        | 40                         |

Figure 3. HFO1234yf/HFC134a system with an internal heat exchanger (IHX) in comparison with HFO1234yf/HFC134a and R134a systems without an internal heat exchanger under refrigerating conditions. (a) Power of compressor. (b) Refrigerating capacity. (c) Coefficient of performance.
medium-heat load conditions, the power of the compressor rate, and compressor global efficiency. Under low and refrigerating conditions, the power of the compressor is related to the refrigerant unit compression specific power, mass flow rate, and compressor global efficiency. Under low and medium-heat load conditions, the power of the compressor increases because the unit compression specific power increases after the introduction of an internal heat exchanger. At high-heat load conditions, combined with Figure 8, it can be seen that the compressor global efficiency increases obviously after the HFO1234yf/HFC134a system is introduced an internal heat exchanger, which makes the compressor power show a downward trend.

The comparison of heating capacity under heating conditions is shown in Figure 6b. Test results show that the heating capacity of the HFO1234yf/HFC134a system with an internal heat exchanger increases by 2–5% under all heat load conditions, which is basically equal to that of R134a. After the introduction of an internal heat exchanger, the enthalpy of HFO1234yf/HFC134a at the outlet of compressor increases. Because of the thermophysical properties of R1234yf/R134a, the increasing enthalpy of HFO1234yf/HFC134a gas at the compressor outlet leads to an increase in latent heat of condensation, which can compensate for the loss of the reduction of the mass flow rate.

The comparison of COP under heating conditions is shown in Figure 6c. Test results show that the COP of the HFO1234yf/HFC134a system with an internal heat exchanger increases by 2–6%, which is slightly smaller than that of R134a under all heat load conditions. Under low and medium-heat load conditions, the COP of the HFO1234yf/HFC134a system with an internal heat exchanger increases due to the increase of heat capacity. At high-heat load conditions, the increase of heat capacity and the decrease of the power of the compressor result in the increase of COP. Under low-temperature conditions, the COP of the HFO1234yf/HFC134a system with an internal heat exchanger rises obviously.

The mass flow rate of the HFO1234yf/HFC134a system with and without an internal heat exchanger under heating conditions is shown in Figure 7. The test results show that the average mass flow rate of the HFO1234yf/HFC134a system with and without an internal heat exchanger decreases by approximately 10% under all heat load conditions. The compressor volumetric efficiency and global efficiency of the HFO1234yf/HFC134a system with and without an internal heat exchanger under heating conditions is shown in Figure 8. The compressor volumetric efficiency of HFO1234yf/HFC134a at the outlet of compressor increases. The compressor volumetric efficiency of HFO1234yf/HFC134a with an internal heat exchanger increases due to the introduction of an internal heat exchanger, which makes the compressor power increase. As shown in Figure 8, the compressor global efficiency showed an upward trend after the introduction of an internal heat exchanger under all heat load conditions. It can be seen from Figure 8 that the volumetric efficiency of the compressor has reached or exceeded the maximum value at 3000 rev/min, so the volumetric efficiency decreases with the increase of the speed (4000 rev/min). As shown in Figure 8, the compressor global efficiency showed an upward trend, and the increase is obvious under high heat load conditions. At low temperature, the system without an internal heat exchanger has a lower compressor suction temperature, causing an increase in the viscosity of the lubricating oil. Lubricating oil with a large viscosity leads to poor mobility and large friction resistance between components. After the introduction of an internal heat exchanger, the refrigerant gas is further overheated, which causes the increase of the compressor suction temperature, thus the temperature of the lubricating oil in the compressor increases. At this condition, the fluidity of the lubricating oil increases, leading to decrease of the parts friction resistance. As a result, the compressor global efficiency increases.

![Figure 4](https://doi.org/10.1021/acsomega.2c03309) Comparison of the mass flow rate of the HFO1234yf/HFC134a system with and without an internal heat exchanger under refrigerating conditions.

![Figure 5](https://doi.org/10.1021/acsomega.2c03309) Comparison of the compressor volumetric efficiency and global efficiency of the HFO1234yf/HFC134a system with and without an internal heat exchanger under refrigerating conditions.

a higher compressor discharge temperature. The higher compressor discharge temperature decreases the viscosity of the lubricant, leading to a greater friction loss of the compressor components. Under high-heat load conditions, the rapid decrease of the compressor global efficiency leads to a large increase in the power of the compressor, which is one of the factors leading to the decrease of COP.

### 4.2. Heating Conditions

The comparison of power of the compressor under heating conditions is shown in Figure 6a. The average power of the compressor of the HFO1234yf/HFC134a system with an internal heat exchanger is higher than that of R134a by 8% under all conditions. After the introduction of an internal heat exchanger, the power of the compressor of HFO1234yf/HFC134a has little change. The power of the compressor of HFO1234yf/HFC134a with an internal heat exchanger shows an upward trend under low and medium-heat load conditions, however, showing a slight downward trend at high-heat load conditions. Similar to refrigerating conditions, the power of the compressor is related to the refrigerant unit compression specific power, mass flow rate, and compressor global efficiency. Under low and medium-heat load conditions, the power of the compressor
Figure 6. HFO1234yf/HFC134a system with internal heat exchanger in comparison with HFO1234yf/HFC134a and R134a systems without an internal heat exchanger under heating conditions. (a) Power of compressor. (b) Refrigerating capacity. (c) Coefficient of performance.

Figure 7. Comparison of the mass flow rate of the HFO1234yf/HFC134a system with and without internal heat exchanger under heating conditions.

Figure 8. Comparison of the compressor volumetric efficiency and global efficiency of the HFO1234yf/HFC134a system with and without internal heat exchanger under heating conditions.
5. CONCLUSIONS
In this study, a new refrigerant HFO1234yf/HFC134a was studied in vehicle air-conditioning system under refrigerating and heating conditions. The operation performance parameters of the HFO1234yf/HFC134a system with an internal heat exchanger in comparison with HFO1234yf/HFC134a and R134a without an internal heat exchanger were studied. Based on the test results, the following conclusions can be drawn:

Under refrigerating conditions, the refrigerating capacity of the HFO1234yf/HFC134a system with an internal heat exchanger is increased by 2–4%, which is slightly larger than that of R134a. The COP of the HFO1234yf/HFC134a system with an internal heat exchanger is increased not largely. However, it tends to decrease at high-temperature conditions. The average compressor volumetric efficiency and global efficiency of the HFO1234yf/HFC134a system with an internal heat exchanger are decreased by approximately 3% and 5%, respectively.

Under heating conditions, the heating capacity of the HFO1234yf/HFC134a system with an internal heat exchanger is increased by 2–5%, which is basically equal to that of R134a. The COP of HFO1234yf/HFC134a system with an internal heat exchanger is increased with a maximum increase of 6% at low-temperature conditions. The average compressor volumetric efficiency and global efficiency of the HFO1234yf/HFC134a system with an internal heat exchanger are decreased by approximately 3% and 5%, respectively. The average compressor global efficiency of the HFO1234yf/HFC134a system with an internal heat exchanger is increased by approximately 4%.

ACKNOWLEDGMENTS
This work is supported by Young Backbone Teacher of Zhongyuan University of Technology (project no. 2022XQG05), Science and Technology Guidance Project of China National Textile and Apparel Council (project no. 2019072), Major Science and Technology Projects in Henan Province in 2022 (project no. 221100320100), Scientific Research Team Project of Zhongyuan University of Technology (project no. K2022TD004), and Discipline Strength Improvement Plan of Zhongyuan University of Technology (project no. SD202240 and GG202216)

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