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Experimental study on the performance of inverter air conditioner using R290

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ABSTRACT

R290, as an effective and environmentally friendly refrigerant, has great potentials in the application of air-conditioning. In this paper, the performance of inverter air conditioner (AC) using R290 is compared theoretically with that of other refrigerants. Moreover, the performance of a split AC was experimentally studied in both summer and winter condition with different ambient temperature. The results show that: In winter condition, the system EER varies from3.78 to 2.79 as the ambient temperature changes from 12℃ to -12℃; in summer condition, the system EER decreases from 2.26 to 1.91 as the indoor temperature increase from 29 ℃ to 43 ℃. The discharge temperature of inverter AC using R290 is far lower than that of R32. However, there is still great potential for improvement of supply air temperature control. This study provides reference for optimization of inverter AC using R290.

Keywords: R290; heat pump; inverter air conditioner; refrigerant comparison; discharge temperature; supply air temperature

NONMENCLATURE

Abbreviations	
AC	air conditioner
COP	coefficient of performance
EER	energy efficiency ratio
Symbols	
Q	cooling capacity (heating capacity) , W
S	Cross-sectional area of air duct outlet, m^2
h	Enthalpy, J kg-1
ρ_{ain}	inlet air density of the indoor unit
h_{aout}	outlet air enthalpy of the indoor unit air
φ	Relative humidity
W	Power consumption, W
ρ_{aout}	outlet air density of the indoor unit, kg m-3
h_{ain}	inlet air enthalpy of the indoor unit air, J kg-1
μ_{av}	The air velocity at the outlet of the air duct, m s-1

1. INTRODUCTION

With the deterioration of global warming, countries have strengthened the control of HFCs. As an environmentally friendly and efficient refrigerant, it has attracted attention in the field of air conditioning heat pumps [1]. In terms of unit performance research, Weier Tang tested an R290 air source heat pump with a nominal heating capacity of 13kW. The rated heating COP and rated cooling COP reached 3.27 and 2.8, respectively, meeting the requirements of relevant national regulations [2]. Zhang Yun used R290 to directly replace the working fluid R22 in the low-temperature heat pump system. After optimizing the compressor, the efficiency of the R290 heat pump system was increased by 6.65% compared with R22, and the exhaust temperature was reduced by 36% [3]. But on the other hand, A S Padalkar and Xi Xinyu replaced the R22 air conditioner with the R290 compressor and found that the EER dropped [4, 5]. Yang Chun and others tested the heating operation characteristics of the R290 variable frequency air source heat pump, and the system energy efficiency ratio reached 2.21 during the low temperature heating season when the average temperature was -0.75°C [6]. However, the current research on the performance of R290 inverter air conditioners basically focuses on standard operating conditions. There are few studies on a wider operating temperature range. In this paper, experiments are carried out to study an R290 split air conditioner with inverter. Moreover, the performance of the air conditioner under heating and cooling conditions is tested. The exhaust temperature and the air outlet temperature of the indoor unit are achieved. This paper provides reference for the performance optimization of the R290 inverter air conditioner.

2. EXPERIMENTAL SYSTEM INRODUCTION

In order to explore the actual performance of the R290 heat pump air conditioner, this article takes a split air conditioner with an inverter with a rated cooling capacity of 2600W as the experimental object and it was tested in an enthalpy difference chamber. A square air duct was installed at the air outlet of the indoor unit, and an anemometer was used to measure the wind speed at every interval of 45mm at the outlet, and finally the average wind speed was calculated; the outlet of the air duct was evenly arranged with 3 thermocouple measuring points and a relative humidity meter to obtain average outlet temperature and relative humidity.

$$Q = \mu_{av} S(|\rho_{aout} h_{aout} - \rho_{ain} h_{ain}|) \quad \text{Eq.（1）}$$

The calculation of cooling capacity (heating capacity) and energy efficiency ratio are shown in formula (1) and formula (2) respectively:

Where: Q—cooling capacity (heating capacity), W; ρ_{aout} 、 ρ_{ain} —outlet and inlet density of the indoor unit air respectively t, kg/m3;h_{aout}、 h_{ain}—the outlet and inlet enthalpy values of the indoor unit air, which are determined by temperature and relative humidity , J/kg; μ_{av} —The air velocity at the outlet of the air duct, m/s;S—Cross-sectional area of air duct outlet, m2;

$$EER = \frac{Q}{W} \quad \text{Eq.（2）}$$

Where: Q—cooling capacity (heating capacity), W; W—unit power consumption, W;

Thermocouples were arranged in the pipeline to monitor various temperatures, and the power consumption of the system was displayed by a power meter. The schematic of the experimental system is shown in Fig. 1.

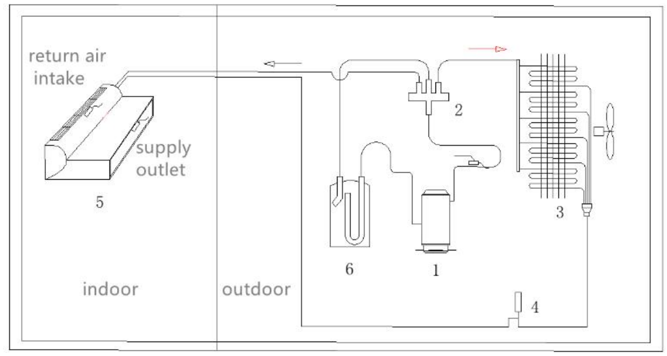

Fig.1 Schematic of experimental setup

1 Compressor 2 Four-way reversing valve 3 Outdoor heat exchanger 4 Electronic expansion valve 5 Indoor unit and air duct 6 Gas-liquid separator

3. RESULTS AND ANALYSIS

3.1 heating test

The air conditioner performance changes with the ambient temperature as shown in Fig. 2. On the whole, the heating capacity decreases with the decrease of the ambient temperature, while the electric power consumption increases with the decrease of the ambient temperature. However, when the heating capacity is above 2 ℃ , the heating capacity decays slowly, and the ambient temperature decreases from 12 ℃ to 2 ℃. The heating capacity drops from 5.3kW to 4.84kW, with a drop of only 8.7%. In the process of decreasing from 2°C to -12°C, the heating capacity attenuation is more serious, which decreases by 22.6% (with a baseline of the heating capacity at 12°C). The energy efficiency ratio decreases from 3.78 to 2.99 in the range of 12°C to 2°C, and decreases to 2.19 at -12°C, and drops by 20.8% and 21.2% respectively in these two intervals. And the change is relatively uniform. The electrical power consumption of the inverter air conditioner decreases as the temperature rises during the test. In the range of -12°C to 2° C, the electrical power consumption changes more slowly. When the ambient temperature rises from -12°C to 2°C, the electrical power consumption drops by only 4%, and when the temperature rises from 2°C to 12°C, the electrical power consumption drops by 13.3%. The low EER in this experiment may be related to the compressor capacity matching of the unit and the control of the system.

The change of exhaust gas with ambient temperature is shown in Fig. 3. The exhaust temperature basically shows a linear increase from 39.9°C to 62.75°C in the ambient temperature range of -

12°C to 7°C. When it is between 7°C and 12°C, the exhaust temperature decreases slightly. The exhaust temperature of R290 under rated heating conditions is 62.75°C, which is close to 67.2°C under the same operating conditions in the literature [10], and much lower than 102.13°C under the same operating conditions of R32.

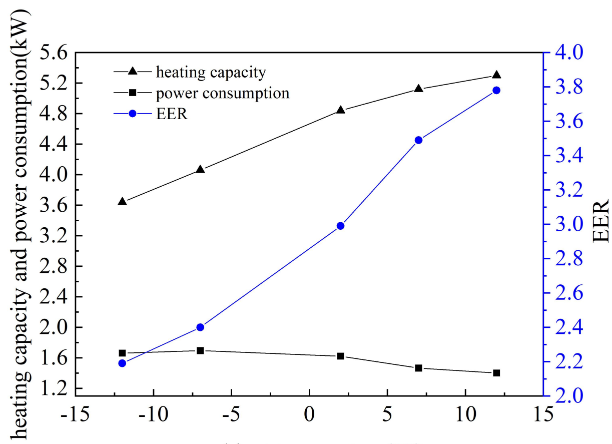

Fig.2 Performance of AC at heating condition with different ambient temperature

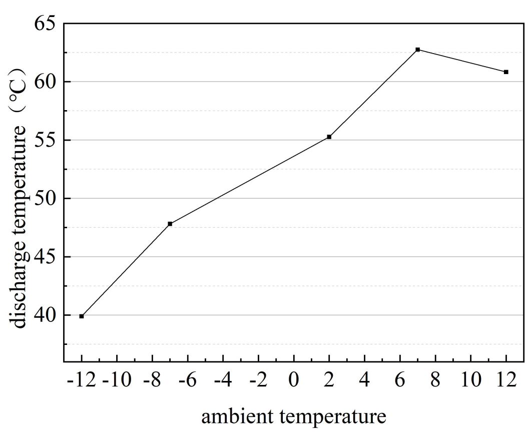

Fig.3 Discharge temperature at heating condition with different ambient temperature

3.2 Refrigeration test

The performance of refrigeration and air conditioning changes with ambient temperature as shown in Fig. 4. When the ambient temperature changes from 29°C to 43°C, the compressor power consumption fluctuates slightly, but it is basically maintained at around 1.5kW; the cooling capacity and energy efficiency ratio decrease as the ambient temperature rises. During the refrigeration condition test, when the ambient temperature is 48°C, the electrical power consumption and cooling capacity drop sharply. This is because the operating condition at 48°C has exceeded the maximum allowed operating temperature of 43°C specified in the national standard. At this time, the exhaust temperature is too high and high-frequency operation is difficult to maintain. Because the frequency is positively correlated with the power consumption, the frequency drops and the power consumption decreases. When the ambient temperature increases from 29°C to 43°C, the cooling capacity drops from 3.33kW to 2.96kW, with a decrease of 11.1%. Regarding power consumption, there is a general upward trend, but the operating condition of the 29°C is similar to that the 35°C; the power consumption increases from 1.473kW to 1.546kW, with an increase of only 5%. For the EER, except for the 35°C operating condition and that of 40°C, the EER is basically the same, the decrease is generally linear, varying from 2.26 to 1.91.

The reason for the low EER of the R290 air conditioner under refrigeration conditions is that the air outlet temperature is too low, which will be explained in detail later.

The change of exhaust gas with ambient temperature is shown in Figure 5. On the whole, the exhaust temperature increases with the increase of the ambient temperature. The ambient temperature rises from 29°C to 48°C, and the exhaust temperature increases from 58.7°C to 74.3°C. The change process is relatively uniform. When the ambient temperature is 48°C, although the compressor frequency drops, the exhaust temperature does not drop significantly. The exhaust temperature under the rated refrigeration condition is 67.7℃, which is very close to the exhaust temperature of the R290 system under the same operating conditions of literature [6], in which is 65.7℃, far lower than the 97.31℃ of the R32 system under the same operating conditions. The abovementioned has proved that R290 has a great effect on reducing the exhaust temperature.

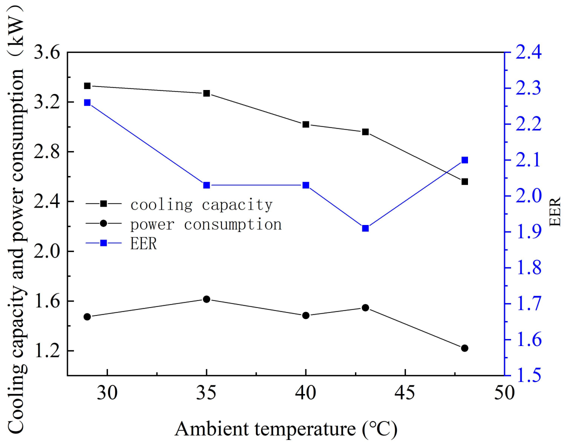

Fig.4 Performance of AC at cooling condition with different ambient temperature

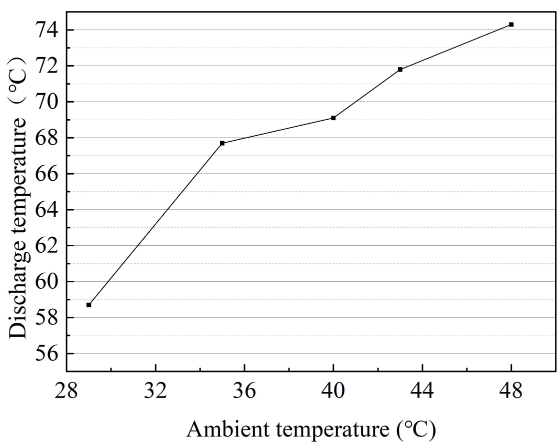

Fig.5 Discharge temperature at cooling condition with different ambient temperature

3.3 *Thermal comfort*

In addition to performance parameters and exhaust temperature, the air outlet temperature of the indoor unit is one of the important parameters of the air conditioner, which affects the comfort of the human body and the economy of the unit. Fig. 6 shows the change in the average outlet temperature of the indoor unit during refrigeration and heating condition. Regardless of whether it is refrigeration condition or not, the higher the ambient temperature, the higher the air outlet temperature. Under heating conditions, the air outlet temperature range is 39.4-48.5°C. Literature [18] points out that in order to meet the comfort requirements of air conditioners and reduce the vertical temperature difference, the outlet air temperature should be controlled within 39-41°C. When the outdoor temperature of the tested unit is above 2°C, the outlet air temperature is higher than the recommended temperature, which not only has poor comfort, but also leads to high condensing pressure to and low efficiency, which has great room for improvement. Under cooling conditions, the outlet air temperature range is 7.4-12°C, while the outlet temperature of air-conditioning is usually in the range of 15 to 25°C. Too low air outlet temperature comes at the cost of low evaporating temperature, thus low evaporating temperature will reduce the efficiency of the air conditioning system, which explains the low cooling efficiency in the test. From the experimental results, by optimizing the wind speed and the heat transfer effect of the indoor heat exchanger, it will be beneficial to control the air outlet temperature of the existing R290 inverter air conditioner at a comfortable and economical level.

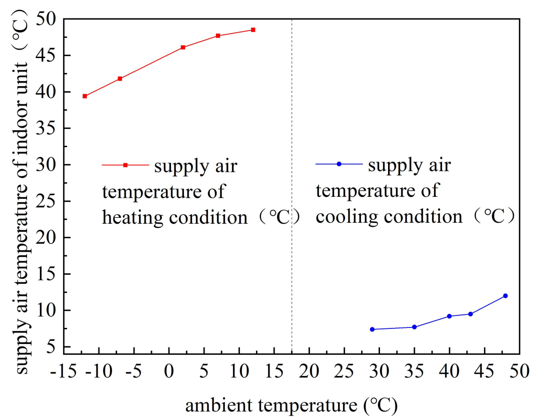

Fig.6 Outlet air temperature of indoor unit with with different ambient temperature

4. CONCLUSION

There are relatively few researches on the performance of R290 household air conditioners with inverter in the domestic and foreign experimental studies.In this paper, the cycle characteristics of the R290 system are analyzed theoretically, and the heating capacity (cooling capacity), power consumption and energy efficiency ratio of a certain R290 inverter air conditioner are tested at different ambient temperatures.. Conclusion can be made as follow:

1) The COP of the R290 system and the R134a system is very close under air conditioning conditions, while R32 is very close to R410A. R290 always maintains a higher COP under air conditioning conditions, and the attenuation of heating capacity with evaporating temperature changes is better than that of refrigeration.

2) Under heating conditions, the heating capacity of the R290 inverter household air conditioner decreases rapidly at low ambient temperature, and the electrical power consumption changes slowly at low ambient

temperature. When the ambient temperature changes from 12°C to -12°C, the energy efficiency ratio changes more evenly from 3.78 to 2.79;

3) Under cooling conditions, when the ambient temperature is from 29°C to 43°C, the cooling capacity of the R290 inverter household air conditioner drops from 3.33kW to 2.96kW, but the cooling power fluctuates around 1.5kW, and the energy efficiency ratio drops from 2.26 to 1.91 ；

4) The exhaust temperature of the R290 household air conditioning system is much lower than R32, but the supply air temperature is not economical and comfortable, and there is still room for improvement in the control of the air temperature.

REFERENCE

[1] WU D, HU B, Wang R Z. Vapor compression heat pumps with pure Low-GWP refrigerants. Renewable and Sustainable Energy Reviews 2021;138： 110571.

[2] TANG W E, HE G G, ZHOU S , et al.. The performance and risk assessment of R290 in a 13 kW air source heat pump. Applied Thermal Engineering 2018; 144: 392-402.

[3] ZHANG Y, LIU C C, CHEN X N, et al. .Performance Study and Optimization on Alternative Refrigerant R290 in R22 Low Temperature Heat Pump System. Journal of Refrigeration 2019;40(03): 72-78.

[4] PADALKAR A S, MALI K V, RAJADHYAKSHA D D, et al. .Performance Assessment of Air Conditioners with HC-290. Bulletin de l'Institut International du Froid 2010;90(4): 25-31.

[5]XI X Y, ZHUANG C L, FU B H, et al.. Experimental Investigation of R290 as an Alternative in Heat Pump Air Conditioner for Heating. Journal of Building Energy Efficiency 2017;45(02): 25-28.

[6] Yang Chun, Chen Xiaoning, Luo Yajun, et al..Research on heating operation characteristics of R290 variable frequency air source heat pump in cold regions, China Household Electrical Appliances Association; 2019.