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# Experimental Investigation on One-time Heating R32 Two-stage Air Source Heat Pump Water Heater

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**Abstract**

A one-time heating R32 two-stage air source heat pump water heater was experimentally studied under various working conditions, and compared with a static heating type. The tested results show that when the inlet water temperature and the outlet water temperature are fixed, the heating COP is almost unchanged with the increase of the heating capacity; when the heating capacity is fixed, the heating COP decreases with the increase of the inlet water temperature or the outlet water temperature; the condensation temperature of one-time heating type is much lower than that of the static heating type, and also lower than the outlet water temperature. A one-time heating two-stage compression cycle can effectively reduce the discharge temperature and broaden the operating range of the R32 air source heat pump water heater, and improve the reliability of R32 compressor under low ambient temperature and high outlet water temperature conditions.



*Keywords: R32; heat pump water heater; one-time heating; static heating*

## 1. Introduction

With the improvement of living standards, the water heater has become an indispensable living facility in people's lives. Air source heat pump water heater (HPWH) is increasingly popular for its energy saving and environmental protection. At present, most of refrigerants for use in the domestic HPWHs are R22 and R134a, and a few R410A. R22 is listed as a phased-out refrigerant for its ODP (ozone depletion potential) above zero, while R134a and R410A acting as transitional refrigerants will be phased out for their relatively high GWP (greenhouse effect potential). R32 is one of components of R410A and is classified as A2L safety class according to the standard ANSI/ASHRAE 34-2013[1]. ODP and GWP of R32 is zero and 675, respectively. A large number of experimental researches and theoretical analyses on R32 and its system have been carried out [2~5]. The results show that R32 is a good alternative refrigerant in terms of climate impact and safety use. Theoretical analysis [2~3] shows that the energy efficiency ratio (EER) of R32 compression cycle is improved by 5.3% and the cooling capacity is improved by 12.7% compared with R410A. Tu et al [4] carried out a drop-in test to compare R32 with R410A in a fixed speed room air conditioner. The results show that the cooling capacity and EER are improved by 8.04% and 3.27%, respectively, under rated cooling condition, while the charge of R32 is reduced by 24%. Mei et al [5] carried out a comparative experimental study on the cycle characteristics of R32 and R410A in air-cooled chillers. The results show that the cooling capacity of R32 is about 10% higher than that of R410A, and EER is slightly increased. Huang et al [6] pointed out that R32 is more suitable for one-time heating HPWH than R410A.

However, the discharge temperature of R32 is about 10~25℃ higher than that of R410A. The high discharge temperature problem is more prominent on R32 HPWH due to its high condensation temperature. The high discharge temperature can cause a series of reliability issues, including accelerating the

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decomposition of lubricant oils, the deterioration of various non-metallic materials in compressor, and the reduction of viscosity of lubricant oil. According to theoretical analysis, when the evaporation temperature is -20℃ and the condensation temperature is 45℃, the discharge temperature can be kept below 135℃ as long as the suction vapor quality of compressor is controlled to 0.93 [7]. That is, the high discharge temperature problem can be solved by reducing the suction vapor quality of the compressor. For two-stage air source HPWH with vapor injection system [8], the high discharge temperature problem can be solved by vapor injection under low ambient temperature.

Reducing the suction vapor quality of the compressor can reduce the discharge temperature effectively. However, the capacity and EER decrease with the decrease of the suction vapor quality of the compressor [9]. If the discharge temperature can be reduced by reducing the condensation temperature, then the high discharge temperature problem of R32 can be solved, moreover the system energy efficiency can be improved.

According to the national standard on HPWH [10-11], the HPWH has three types based on the heating mode, which are the static heating type, the circulating heating type and the one-time heating type. The one-time heating type means that the initial cold water reaches the target water temperature through the heat exchanger of the HPWH once. In this paper, the characteristics of the one-time heating R32 HPWH are researched to provide guidance for design.

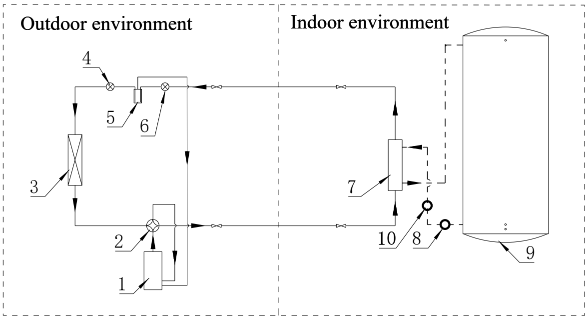
## 2. Experiment and data analysis

### *2.1. Experiment*

The one-time heating R32 HPWH experimental system is shown in Fig.1, which consists of the heat pump system and the water system. The detailed information is shown in Table 1. The heat pump consists of a two-stage rotary compressor, a tube-in-tube condenser, an electronic expansion valve, an evaporator and a flash tank. The water system consists of a water tank, a water pump and the tube-in-tube condenser. Fig.2 shows a cross-sectional view of the tube-in-tube condenser, which is a counterflow heat exchanger and optimized based on the characteristics of one-time heating HPWH and R32 heat transfer characteristics.

The experiment was carried out on the water-enthalpy laboratory, which includes a indoor chamber and an outdoor chamber. The compressor, the evaporator, the electronic expansion valve and the flash tank of the heat pump system were placed in the outdoor chamber, and the water system was placed in the indoor chamber. The tested conditions and water temperature are listed in Table 2.

In the experiment, the inlet water temperature and the outlet water temperature of the tube-in-tube condenser were measured by Pt100, the circulating water flow rate was measured by a magnetic flowmeter, and the pressure and the temperature of the heat pump system were measured by the pressure sensor and T-type thermocouple respectively. The uncertainties of the instruments are listed in Table 3.




1—Compressor，2—Four-way valve，3—Evaporator，4、6—Electronic expansion valve，5—Flash tank，7—Tube-in-tube condenser，8—Water pump，9—Water tank，10—Magnetic flow meter

Fig. 1. The one-time heating R32 HPWH experimental system

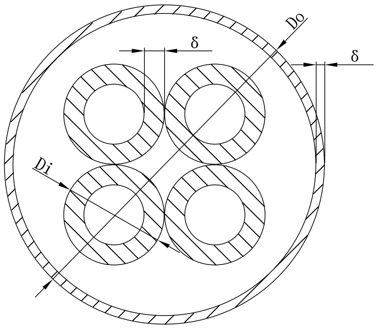



Fig. 2. The cross-sectional view of the tube-in-tube condenser

Table 1. Information of one-time heating R32 HPWH

| | |
|---|---|
| Compressor | Two-stage compressor with a displacement of 12cm$^3$/rev |
| Condenser | Tube-in-tube, Do=12.7mm, δo=0.34mm, Di=4mm, δi=0.8mm |
| Evaporator | Fin-and-tube heat exchanger with the tube diameter of 7mm |
| Electronic expansion valve | DPF(T01)1.6 with a diameter of 1.6mm |
| Flash tank | Self made |
| Refrigerant | R32 |
| Water tank | 200L |
| Water pump | LX-0.36/10-A with a rated flow of 0.36m$^3$/h and a rated input power of 10W |

Table 2. Test conditions

| Conditions | Outdoor Chamber | Indoor Chamber | Inlet Water Temperature (IWT) | Outlet Water Temperature (OWT) |
|---|---|---|---|---|
| | ℃ | ℃ | ℃ | ℃ |
| Condition 1 | 20 | 20 | 15~39 | 45~65 |
| Condition 2 | 7 | 20 | 9~39 | 45~65 |
| Condition 3 | -20 | 20 | 9~39 | 45~65 |

Table 3. Uncertainties of instruments

| Instruments | Range | Uncertainty |
|---|---|---|
| Pt100 | 0~60℃ | ±0.1℃ |
| Flowmeter | 0~30L/min | ±0.35% |
| Pressure sensor | 0~5MPa | ±0.5% |
| T-type thermocouple | -50~150℃ | ±0.5℃ |

### *2.2. Data analysis*

The heating capacity and the heating COP are calculated based on the parameters of the water, the equations are as follows.

$$Q_w = \rho_w V_w C_{P,w}(T_{w,out} - T_{w,in}) \quad (1)$$

$$COP = Q_w / W_{input} \quad (2)$$

Where, $Q_w$ is the heating capacity, $\rho_w$ is the density of water, $V_w$ is the water volume flow rate, $C_{P,w}$ is the specific heat of water, $T_{w,in}$ is the inlet water temperature of tube-in-tube condenser, $T_{w,out}$ is the outlet water temperature of tube-in-tube condenser, $W_{input}$ is the input power(including the power of the heat pump system and the power of water pump).

## 3. Result and discussion

### *3.1. Characteristics under different conditions*

Fig.3 shows the curves that the COP changes with the heating capacity. Under different conditions, the heating capacity has little effect on the COP. Analyses are as follows. The increase of the heating capacity is achieved by increasing the rotary speed of the compressor. As the increase of the rotary speed of the compressor, the refrigerant mass flow rate increases, the heat exchange capacity of the evaporator and the condenser increase. The heat transfer of the refrigerant in both evaporator and condenser enhance due to the increase of the refrigerant mass flow rate increases. The heat exchange temperature difference in both evaporator and condenser increase due to the increase of the heat exchange capacity. Because the inlet water temperature and the outlet water temperature keep constantly, so the condensation temperature increases and the evaporation temperature decreases. But the enhancement of the heat transfer weakens the increase of the condensation temperature. Meanwhile, because the inlet water temperature and the outlet water temperature are fixed, the water flow rate increases with the increase of the heating capacity, which enhances the heat transfer on the water side of the condenser, further suppresses the increase of the condensation temperature. Therefore, the change of the condensation temperature is not obvious. The enhancement of the heat transfer of the refrigerant in the evaporator weakens the decrease of the evaporation temperature, so the change of the evaporation temperature is not obvious. Thus, the change of the pressure ratio is not obvious (Fig.4) and the increase of the specific compression work is not obvious. The change of the temperature and the pressure of the refrigerant at the inlet and the outlet of the condenser are not obvious, so the change of the refrigerant specific enthalpy difference between the inlet and the outlet of the condenser is not obvious. Therefore, the input power of the compressor increases with a definite proportion with the increase of the heating capacity. Because the input power of the water pump is very small in comparison with the compressor, so the change of the COP is not obvious.

Fig.5 and Fig.6 show the curves that the COP changes with inlet water temperature and outlet water temperature. In Fig.5, the COPs decrease with the increase of the inlet water temperature when the outlet water temperature is fixed. Analyses are as follows. The heat exchange temperature difference between the refrigerant and the water of the condenser keeps constantly when the heating capacity is fixed, the average temperature on the water side of the condenser increases with the increase of the inlet water temperature, then the condensation temperature increases (Fig.7), and the COP decreases. In Fig.6, under the same condition, when the inlet water temperature is fixed, the higher the outlet water temperature is, the lower the COP is. For the same reason, the condensation temperature increases (Fig.8) with the increase of the average temperature on the water side of the condenser, then the COP decreases. At the same time, it can be seen that when the outdoor ambient temperature decreases, the influence of the inlet water temperature or the outlet water temperature on the COP becomes smaller.

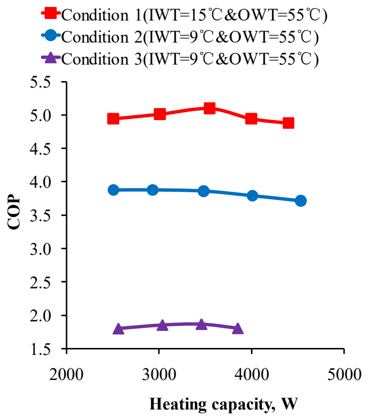



Fig. 3. Curves of the COP with the heating capacity

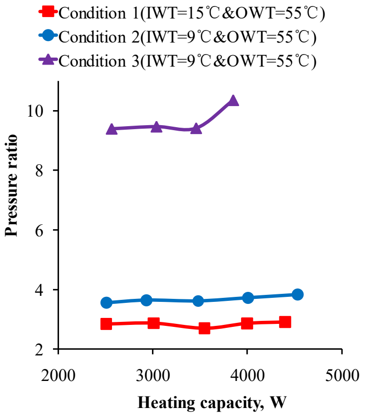



Fig. 4. Curves of the pressure ratio with the heating capacity

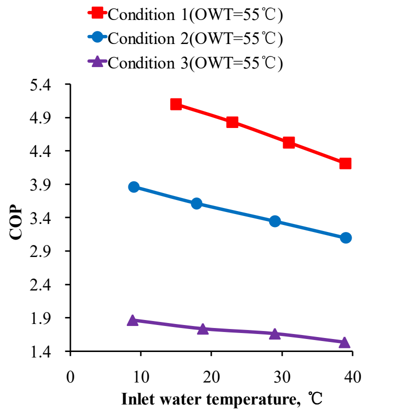



Fig. 5. Curves of the COP with the inlet water temperature

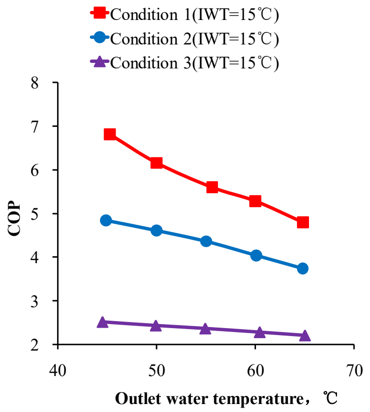



Fig. 6. Curves of the COP with the outlet water temperature

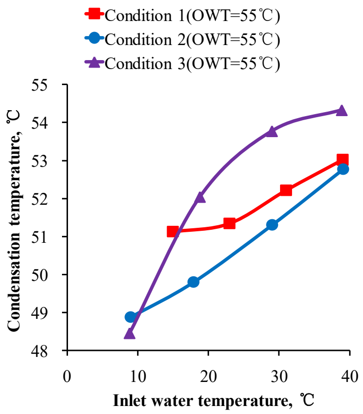


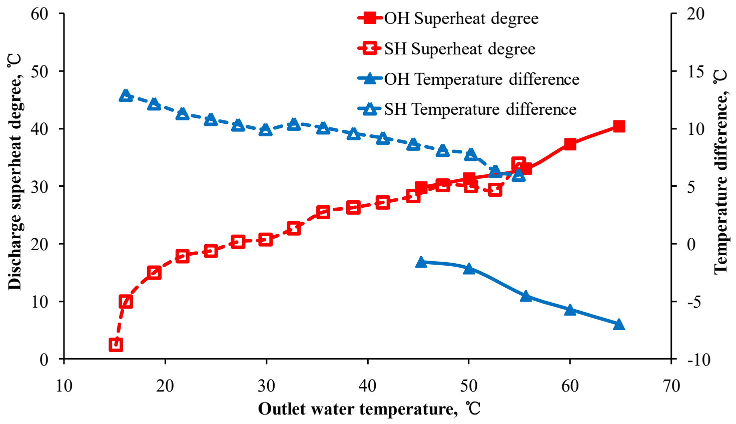
Fig. 7. Curves of the condensation temperature with the water temperature

### *3.2. Characteristics of system parameters*

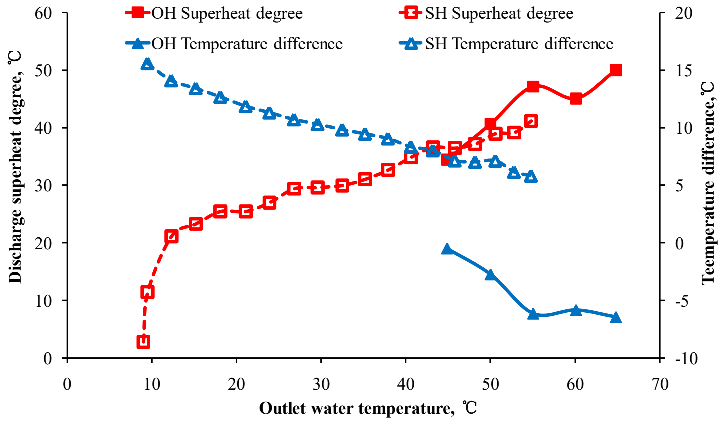
Fig.8 shows the discharge superheat degree (the temperature difference between the discharge temperature and the condensation temperature) and the temperature difference between the condensation temperature and the outlet water temperature changing along with the outlet water temperature under different conditions for the one-time heating(OH in figure) R32 HPWH, and the static heating(SH in figure) R32 HPWH is added for comparison, the discharge temperature curves are shown in Fig.9. For the static heating type, the inlet water temperature means the initial water temperature and the outlet water temperature means the final water temperature. It can be seen as follows.

When the discharge superheat degrees are equivalent, the temperature differences between the condensation temperature and the outlet water temperature of the one-time heating R32 HPWH are always less than the static heating type and also less than zero. This indicates that, the condensation temperature of the one-time heating R32 HPWH is much lower than the static heating type and lower than the outlet water temperature. Taking Fig.8(c) as an example, the condensation temperature of the one-time heating R32 HPWH is 10℃ lower than the static heating type, but the discharge superheat degrees of the two types are comparative, that is, the discharge temperature of the one-time heating R32 HPWH is about 10℃ lower than the static heating type. Analyses are as follows. The tube-in-tube condenser is a counter flow heat exchanger, which is helpful to fully utilize the heat of the superheated refrigerant gas to heat the water, so that the target water temperature can be achieved at a condensation temperature lower than the target water temperature. This is very beneficial to reduce the discharge temperature of R32, broaden the operating temperature range, and also increase the COP.

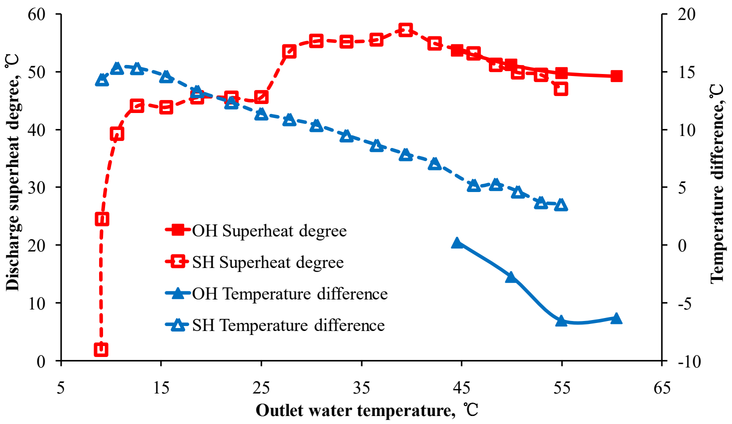
For the one-time heating R32 HPWH under condition 1, as the outlet water temperature increases, the discharge temperature increases, the discharge superheat degree increases and the absolute value of the temperature difference between the condensation temperature and the outlet water temperature increases. This can be explained that, when the outlet water temperature is relatively lower, the condensation temperature is relatively lower, the discharge temperature is relatively lower and the discharge superheat degree is relatively smaller, the heat of the superheated refrigerant gas is not enough to achieve the target water temperature under a relatively lower condensation temperature, so the absolute value of the difference between the condensation temperature and the outlet water temperature is relatively smaller. Along with the increase of the outlet water temperature, the condensation temperature increases, the discharge temperature increases and the discharge superheat degree becomes larger, the heat of the superheated refrigerant gas increases, and so the absolute value of the temperature difference between the condensation temperature and the outlet water temperature increases.




(a) Condition 1 (Inlet water Temperature =15°C)




(b) Condition 2 (Inlet water Temperature = 9°C)




(c) Condition 3 (Inlet water Temperature =9°C)

Fig. 8. Temperature curves of the heating process

For the one-time heating R32 HPWH under condition 3, with the increase of the outlet water temperature, the discharge temperature increases, the discharge superheat degree decreases, and the absolute value of the temperature difference between the condensation temperature and the outlet water temperature increases firstly and then keeps constantly. This can be explained that, the evaporation temperature is very lower and the discharge temperature is very high under low outdoor ambient temperature, when the discharge temperature exceeds the allowable limit value(in this paper, the allowable limit value is 100℃), specific measures must be taken to reduce the discharge temperature, the discharge superheat degree decreases accordingly and the heat of the superheated refrigerant gas decreases. For this reason, no other than to rise the condensation temperature, the target water temperature can be achieved. Thus, the condensation temperature increases with an equivalent value with the increase of the outlet water temperature, and the absolute value of the temperature difference between the condensation temperature and the outlet water temperature keeps constantly.

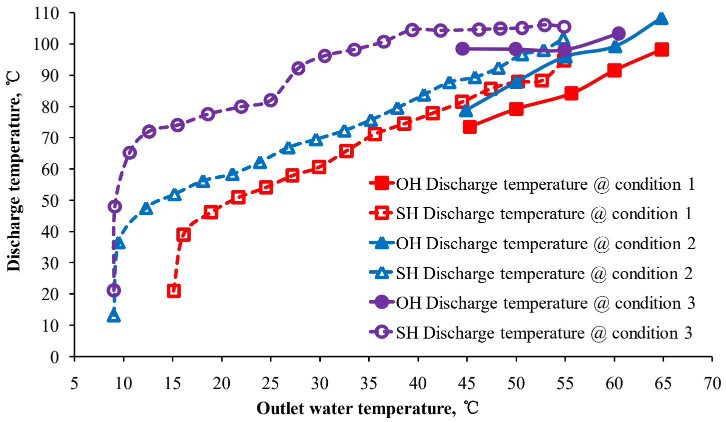



Fig. 9. Curves of the discharge temperature

## 4. Conclusions

A one-time heating R32 two-stage air source HPWH was experimentally studied under various working conditions, and compared with a static heating type. Conclusions are as follows. For the one-time heating R32 HPWH, the COP is almost unchanged when the inlet water temperature and the outlet water temperature are fixed and the heating capacity increases with the increase of the rotary speed of the compressor; when the heating capacity is fixed, the COP decreases with the increase of the inlet water temperature or the outlet water temperature; when the outlet water temperature is fixed and the discharge superheat degree is comparative, the condensation temperature of the one-time heating R32 HPWH is about 10℃ lower than the static heating type and also lower than the outlet water temperature; under normal temperature conditions, the absolute value of the temperature difference between the condensation temperature and the outlet water temperature increases with the increase of the outlet water temperature; under low temperature conditions, the absolute value of the temperature difference between the condensation temperature and the outlet water temperature increases firstly and then keeps constantly with the increase of the outlet water temperature.

The characteristic of the one-time heating R32 HPWH that the condensation temperature is lower than the outlet water temperature can be fully utilized to reduce the discharge temperature, broaden the operating temperature range and improve the compressor reliability under low ambient temperature and high outlet water temperature.

## References

[1] ANSI/ASHRAE Standard 34-2013, Designation and safety classification of refrigerants.
[2] Zhu M S, Shi L. Exploration of using R32 to substitute for R22 in household/commercial air-conditioning. Refrigeration and Air-conditioning (in Chinese) 2009; **9(6)**: 31-34
[3] Shi L, Zhu M S. Re-analysis on using R32 to substitute for R22 in household/commercial air-conditioning. Journal of Refrigeration (in Chinese) 2010; **31(1)**:1-5
[4] Tu X P, Liang X F, Zhuang R., 2011.Study of R32 refrigerant for residential air-conditioning applications, The 23$^{th}$ IIR International Congress of Refrigeration, Beijing, China, paper #259.
[5] Mei K, Li M, Liang L J. Comparative research on the cycle performance of R32 & R410A. Refrigeration and Air-conditioning (in Chinese) 2011; **11(2)**:56-59
[6] Huang Y Y, Wang J, Yin Q, et al. Experimental study of R32 air source heat pump water heater. Refrigeration and Air-conditioning (in Chinese) 2011; **11(2)**: 69~72
[7] Yajima R, Yoshimi A, Piao C C. Measures to reduce the discharge temperature of R32 compressor. Refrigeration and Air-conditioning (in Chinese) 2011; **11(2)**:60-64.
[8] Wang T, Wang F, Chen H Q, et al. Feasibility of R32 Using in enhanced Vapor Injection Heat Pump Water Heater. Building Energy Efficiency (in Chinese) 2017; **45(1)**:139~144
[9] Zheng B, Liang X F, Wu Y W, et al. Study on the influence of wet compression on R32 system performance. Refrigeration and Air-conditioning (in Chinese) 2014; **14(2)**:45-49
[10]GB/T 23137-2008, Heat pump water heater for household and similar application.

[11] GB/T 21362-2008, Heat pump water heater for commercial & industrial and similar application.