

# Experimental Study on The Heating Performance of R32 Heat Pump using Natural Cold Source

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**Abstract:** The compression heat pump has high exhaust temperature when evaporation temperature is low, which seriously affects the stability of the operation of the unit, especially the R32 engineering quality. This paper presented a method to improve the thermal performance of low temperature and established the experimental table. In this paper, the compression heat pump refrigerant is R32. The heat pump was studied under sub-cooling and normal conditions, exhaust temperature, heat production, the change rule of the parameters such as heat COP.

**Keywords:** Heat pump; Sub-cooling; R32; COP.

## I. INTRODUCTION

Energy is an important material foundation for the survival and development of human society [1]. Global economic growth and population growth have led to a growing demand for energy. Heat pump technology is a new energy technology that has attracted worldwide attention in recent years. The heat pump technology can save a great deal of high grade energy. Air conditioning is an indispensable part of human life and work environment. According to the literature, global average building energy consumption accounts for about 37% of the total energy consumption [2], and China's building energy consumption is about 40% [3] of total energy consumption [4]. In total energy consumption, air conditioning system consumes the largest proportion. In order to improve the efficiency of refrigeration and thermal energy efficiency, the over-cooling technology is widely used in the steam compression refrigeration system in low-temperature fields [5]. There are several main types of cold weather: cooling of the environment, cooling of the suction pipe and the use of external mechanical cooling [6-7]. According to the national conditions of China, an R32 refrigerant alternative is proposed, but the excessive exhaust temperature restricts its promotion, especially in the field of heating. In this paper, the heat pump system with R32 is adopted to improve the thermal performance of heat pump, and its theoretical analysis and experimental research are carried out. Experimental results presentation, in evaporation temperature  $-20^{\circ}\text{C} \sim 5^{\circ}\text{C}$  respectively and the sub-cooling flow mass increase  $0.005\text{m}^3/\text{h}$ . In the evaporation temperature is  $-20^{\circ}\text{C} \sim 5^{\circ}\text{C}$ , sub-cooling flow mass increase  $0.005\text{m}^3/\text{h}$  each protection the heat flow average 2.5% lower. At the same evaporation temperature, the heating COP decreases with the increase of the sub-cooling flow mass.

## II. MATERIALS AND METHODS

### A. How the system works

The working principle of heat pump system using natural cold source is shown in figure 1. Compared with the single stage, the cooling device is added, and the cold source is from the low temperature environment. When it is cold running, it is used to introduce some cold source medium from the low temperature environment to improve the heat making, especially in low ambient temperature.

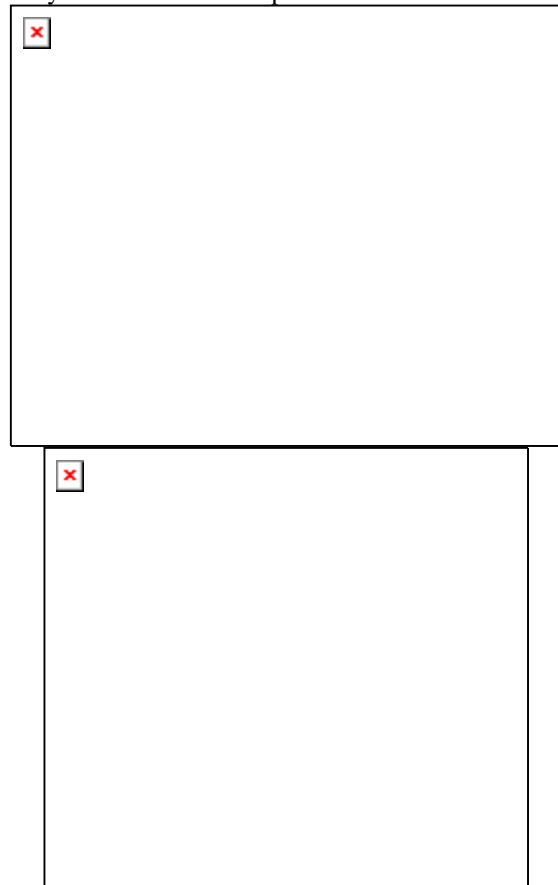


Fig. 1. Sub-cooling cycle and  $\lg p-h$  diagram

### B. Calculation model

Calculation process conditions:

- 1) The system works under steady state conditions;
- 2) Condensation temperature  $40^{\circ}\text{C}$ , the Evaporating temperature range  $-20 \sim 0^{\circ}\text{C}$ ;
- 3) The degree of superheat  $0 \sim 10^{\circ}\text{C}$ ;
- 4) Indicate the efficiency of 0.8;

Fig. 1 shows the  $\lg p-h$  diagram of the sub - cooling cycle  $1'-2s-3-4-5'-5-1'$ . Process's 3-4 in order to liquid refrigerant

the temperature of the throttle super cooler, 4-5' for throttling process.

1) No sub - cooling cycle

Unit quality refrigerating quantity

$$q_0 = h_1 - h_5 = h_1 - h_3 \quad (1)$$

Unit volume refrigerating capacity

$$q_{zv} = (h_1 - h_5) / v_1 = q_0 / v_1 \quad (2)$$

Theory than work

$$W_0 = h_{2s} - h_1 \quad (3)$$

Indicating specific work

$$W_i = W_0 / \eta_i \quad (4)$$

Unit heat load of condenser

$$q_k = h_{2s} - h_3 \quad (5)$$

Performance coefficients of the refrigeration cycle

The theoretical value

$$COP_0 = \frac{q_0}{W_0} = \frac{h_1 - h_5}{h_{2s} - h_1} \quad (6)$$

Indicated value

$$COP_i = \frac{q_0}{W_i} \quad (7)$$

The heating

$$Q_{heat} = cm\Delta t = c\rho v\Delta t \quad (8)$$

Type in the:

$c$ —The specific heat of water, J/(kg.K);

$\rho$ —The density of water, kg/m<sup>3</sup>;

$v$ —Volume flow in water unit time, m<sup>3</sup>/s

$\Delta t$ —The temperature difference of the cooling water

$$\Delta t = t_{m-out} - t_{m-in} \quad (9)$$

$t_{m-in}$ —Average temperature of cooling water inlet, °C ;

$t_{m-out}$ —Average temperature of cooling water outlet, °C.

The performance coefficient of the heat cycle of the heating  $COP_{heat}$

$$COP_{heat} = \frac{Q_{heat}}{W_i} \quad (10)$$

(2) the heat pump cycle that is sub - cooling

Unit quality refrigerating quantity

$$q_{0-sub} = h_1 - h_5 = h_1 - h_4 \quad (11)$$

Unit volume refrigerating capacity

$$q_{zv} = (h_1 - h_5) / v_1 = q_{0-sub} / v_1 \quad (12)$$

Theory than work

$$W_{sub} = W_0 = h_{2s} - h_1 \quad (13)$$

Instructions than work

$$W_i = W_{sub} / \eta_i \quad (14)$$

Unit heat load of condenser

$$q_{k-sub} = h_2 - h_3 \quad (15)$$

The thermal load of the coolers

$$q_{gl} = h_3 - h_4 \quad (16)$$

The performance coefficient of the loop

The theoretical value

$$COP_{sub} = \frac{q_{0-sub}}{W_{sub}} = \frac{h_1 - h_5}{h_{2s} - h_1} \quad (17)$$

The heating  $Q_{subheat}$

$$Q_{subheat} = cm\Delta t = c\rho v\Delta t \quad (18)$$

The performance coefficient of the hot  $COP_{subheat}$  cycle

$$COP_{subheat} = \frac{Q_{subheat}}{W_{sub}} \quad (19)$$

Fig. 2 shows the change of the exhaust temperature with the degree of sub-cooling. It can be seen from figure 2 that the lower the temperature of the exhaust temperature, the lower the temperature of evaporation and the higher the exhaust temperature. In the evaporation temperature at 0°C, -10°C and -20°C, every increase 1°C degree of sub-cooling, exhaust temperature drop an average of 1.19°C. The effect of sub-cooling on the exhaust temperature is more obvious when the evaporation temperature is lower.

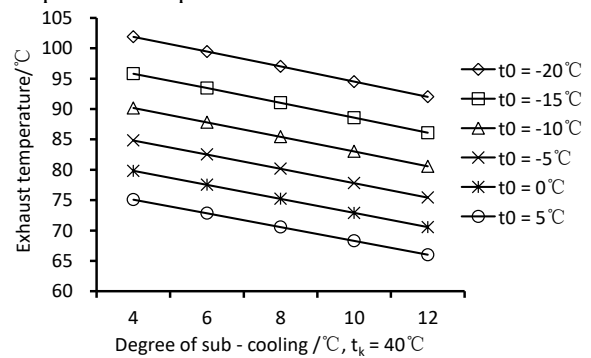


Fig. 2. The variation of discharge temperature with Sub - cooling of suction vapor

Fig. 3 shows the change of the thermal  $COP_{subheat}$  with evaporation temperature. Can be seen from figure 3, the evaporating temperature increased when heating  $COP_{subheat}$ , evaporation temperature when -20°C ~ 0°C with super-cooling degree is 8°C when heating  $COP_{subheat}$  increased by an average of 53.8%.

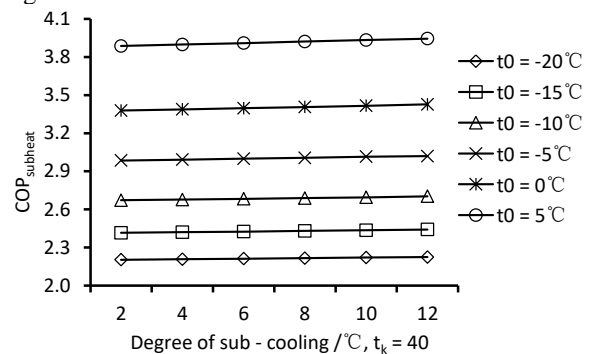


Fig. 3. The heat COP with of sub-cooling system

### C. Experimental study

Fig. 4 shows a diagram of the experimental installation of a sub-cooling heat pump system using natural cold source. System includes: 1 - the scroll compressor, 2 - oil separator, 3 - condenser, 4 - depending on the liquid mirror, 5 - dry filters, 6 - super cooler, 7 - expansion valve, 8 - evaporator, 9 - chilled water flow meter, 10 - freezer water tank, 11 - 14 and electric heater, 12 - cooling water pump, 13- condenser cooling water tank 15 - cooling water pump, 16 - cooling water flow meter. When the system is running, the cold circulation can be achieved by introducing a portion of chilled water from the freezing water to refrigerant liquid.

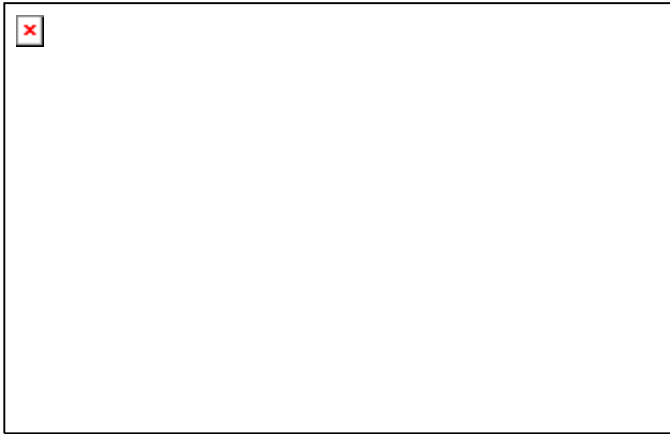


Fig. 4. Experimental testing bench

In this paper, R32 is used to study the experiment and compare the performance of the single-stage mode with the cold mode. In order to better evaluate the performance of the prototype system, the instrument was calibrated. The boot process is as follows: firstly, connect the power of the control cabinet, start and adjust the cooling water system, and open the compressor when the water system is adjusted, and open the data acquisition system. During the experiment, the single-stage compression cycle experiment was carried out after a period of stable working condition. After the unit has been stable for a period of time under the experimental setting conditions, it has been turned on separately. Need to direct measurement parameters include: suction temperature, pressure, exhaust temperature, pressure, condenser import and export, import and export temperature and pressure, cooling water temperature, cooling water flow, sub-cooling temperature and pressure, compressor power. To the amount of indirect measurement for:  $\Delta t$  import and export of cooling water temperature difference and heat Q, heating COP.

**D. Results and discussions**

Fig. 5 shows the change of the exhaust temperature with the sub-cooling flow mass. It can be seen from figure 5 that under the same evaporation temperature, the sub-cooling flow mass increases and the exhaust temperature decreases. The evaporation temperature lower, the more obvious the decreasing trend of the sub-cooling flow. In evaporation temperature  $-20^{\circ}\text{C} \sim 5^{\circ}\text{C}$  respectively and the sub-cooling flow mass increase  $0.005\text{m}^3/\text{h}$ . Average reduce exhaust temperature corresponding  $1.7^{\circ}\text{C}$  to  $3^{\circ}\text{C}$ .

Fig. 6 shows the variation of heat flow with sub-cooling flow mass. It can be seen from figure 6 that, under the same evaporation temperature, the increase of sub-cooling flow mass will decrease the heat production. In the evaporation temperature is  $-20^{\circ}\text{C} \sim 5^{\circ}\text{C}$ , sub-cooling flow mass increase  $0.005\text{m}^3/\text{h}$  each protection the heat flow average 2.5% lower. In the evaporation temperature for  $-10^{\circ}\text{C}$ , sub-cooling flow mass increase of the heating flow mass to most reduce. Evaporation temperature within the range  $-10^{\circ}\text{C} \sim 5^{\circ}\text{C}$ , the best sub-cooling flow mass is  $0.015\text{m}^3/\text{h}$ ; Evaporation temperature in the  $-20^{\circ}\text{C} \sim -15^{\circ}\text{C}$ , the heat flow with the change of sub-cooling flow mass effect is not obvious.

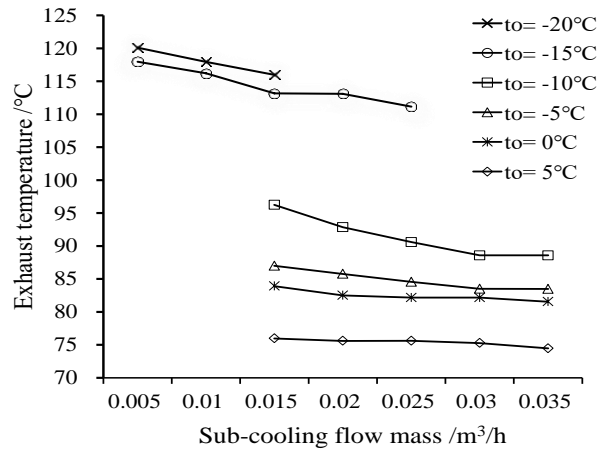


Fig. 5. The variation of discharge temperature with sub-cooling flow

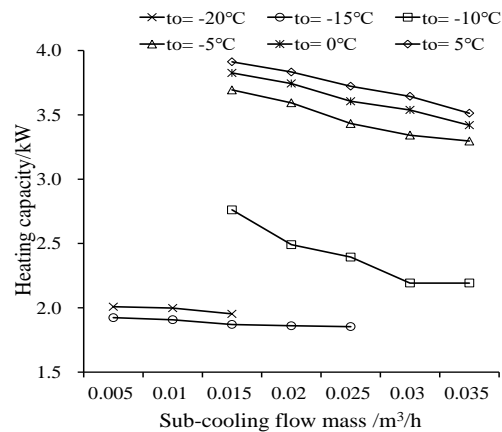


Fig. 6. The variation of heating capacity with sub-cooling flow mass

Fig. 7 shows the change in the sub-cooling flow mass of the heating COP. It can be seen from figure 7 that the change trend of COP is basically in line with the change trend of heat production. At the same evaporation temperature, the heating COP decreases with the increase of the sub-cooling flow mass. In evaporation temperature at  $-10^{\circ}\text{C}$ , the increase of the sub-cooling flow mass to reduce impact on the heating COP, the largest in the evaporation temperature is  $-20^{\circ}\text{C}$  to  $-15^{\circ}\text{C}$  and sub-cooling flow mass when the heating COP of minimal impact. In the evaporation temperature for  $-10^{\circ}\text{C} \sim -5^{\circ}\text{C}$  condition, best too sub-cooling flow mass is  $0.015\text{m}^3/\text{h}$ , at  $-15^{\circ}\text{C}$  and  $-20^{\circ}\text{C}$  condition, heating COP does not change significantly with the too sub-cooling flow mass. The reason is that the sub-cooling flow mass increases, the liquid sub-cooling increases, but at the same time the condensing pressure decreases, the production heat decreases, the compressor power increases, and the heating COP decreases.

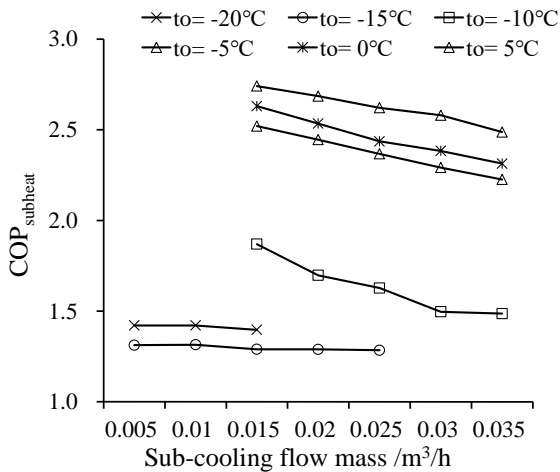


Fig. 7. The variation of heating COP with sub-cooling flow mass

Fig. 8 shows the variation of the exhaust temperature with the evaporation temperature. The figure 8 shows that the evaporation temperature is lower exhaust temperature higher, when the low evaporation temperature below -20°C, single stage compressor system and overheating exhaust temperature is too high, the system run deterioration can't even run, only in extreme sub-cooling system mode to the safe operation, and after sub-cooling exhaust temperature of 120.6°C. In the evaporation temperature of -15°C ~ 5°C, sub-cooling system of exhaust temperature than ordinary single-stage run by 4°C ~ 6°C, the evaporating temperature 5°C, sub-cooling system of exhaust gas temperature most decrease, the most obvious exhaust temperature is 68°C only. After the condenser has been added, it has obvious effect on the high exhaust temperature when the system is running at low temperature.

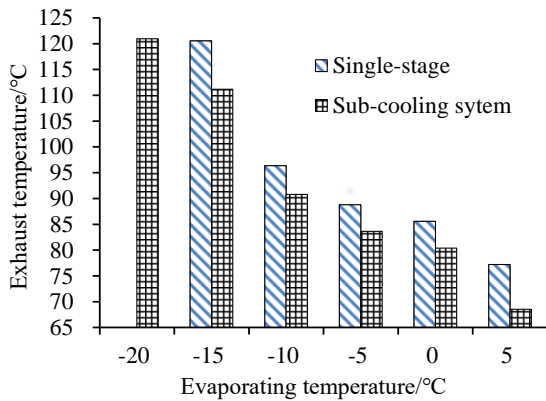


Fig. 8. The variation of discharge temperature with evaporating temperature

Fig. 9 shows the change rule of heat control with evaporation temperature. It can be seen from figure 9 that in the same operation mode, the heat production increases with the increase of evaporation temperature. However, when the system is in sub-cooling operation mode, compared with ordinary single-stage operation mode at different evaporative temperatures, the heat production is reduced. In evaporation temperature -15°C ~ 5°C, sub-cooling of heating is the average 5%. When the evaporation temperature -10 and -15°C, sub-cooling of heating is the average decreases correspondingly 6.6%, 12%.

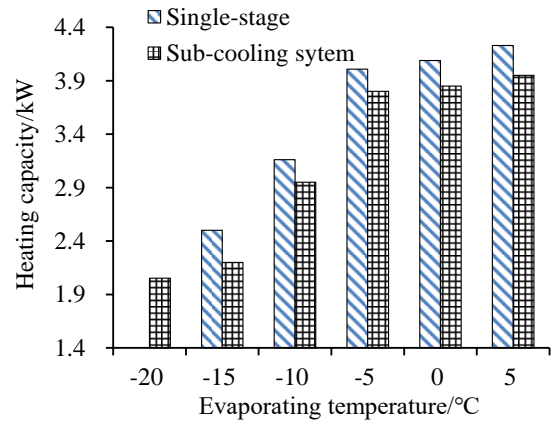


Fig. 9. The variation of heating capacity with evaporating temperature

Fig. 10 shows the change rule of the heat COP with evaporation temperature. It can be seen from figure 10 that, with the increase of evaporation temperature, the single-stage operation and the sub-cooling running system heat COP is on the rise. But compared with single-stage operation, the sub-cooling running mode is heat COP lower. In the evaporation temperature of -15°C ~ 5°C, after sub-cooling heating COP decrease average 3.2%. when the evaporation temperature -10 and -15°C, sub-cooling of heating COP is the average decreases correspondingly 7.3%, 10.6%.

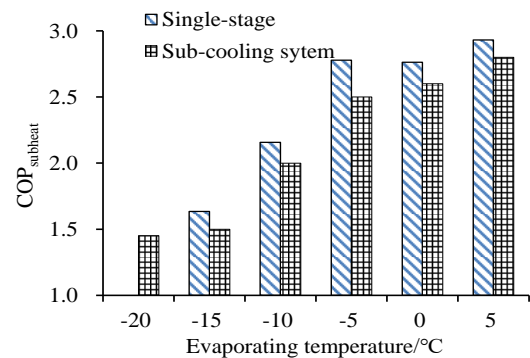


Fig. 10. The variation of heating COP with evaporating temperature

### III. CONCLUSION

In this paper, the thermal performance of heat pump using natural cold source is studied. The results are as follows:

1) It is obvious that the exhaust temperature of the system is lower than that of the sub-cooling system, which is suitable for high exhaust temperature system and operation of the refrigerant such as R32. With the increase of sub-cooling flow mass, the exhaust temperature decrease more and more.

2) The optimal sub-cooling flow mass value of natural cold source is in sub-cooling operation. Evaporation temperature within the range -10°C ~ 5°C, sub-cooling flow mass is 0.015m<sup>3</sup>/h when the heating and heating COP to obtain the maximum; Evaporation temperature in the -20°C ~ -15°C, the heating and heating COP along with the change of sub-cooling flow mass effect is not obvious.

3) Under the same conditions, the heating and heating COP of the sub-cooling system compared with the single-stage system is slightly reduced. When the evaporation temperature of -15°C to reduce, the most obvious decrease by 12% and 10.6%, respectively.

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