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# The Influence of R1270/R600 Quality Components on the Performance of Dual Temperature Chiller Units

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**ABSTRACT**

For investigating the effect of the quality composition of CH refrigerant R1270/R600 (0.6:0.4) and (0.7:0.3) on the performance of a dual temperature chiller, the experiment measured at constant in and out temperatures of the refrigeration water. The results indicate that under the condensation and evaporation temperature remain constant, when the quality fraction of low boiling R1270 raises, the maximum total COP of the refrigeration system increases from 3.36 to 7.36, while the maximum COP at low temperatures does not change much, and the maximum COP at high temperatures increases from 2.02 to 5.95. The percentage of 1 evaporator capacity to total refrigeration capacity has decreased from the maximum value of 44.54% to 20.91%. The percentage of 2 evaporator capacity to total refrigeration capacity has increased from the maximum value of 68.52% to 83.19%. The compression ratio decreases. When the operating conditions changed, the maximum COP of the two components occurs at the temperatures of 1 chilled water are the highest and the temperatures of 2 chilled water are the lowest. The maximum consumption of the system compressor power is 0.99KW, and the maximum discharge temperature is 75.81℃. The finding can provide guideline for the application of the units as a substitute for refrigerants.

## 1. INTRODUCTION

As mankind developed and more advanced with the prosperity of the world, energy demand and greenhouse gas emissions are major challenges facing the world. Although energy efficiency continues to improve and the energy structure continues to improve, global energy consumption is still increasing as of 2023.The global construction sector consumes 15-40% of primary energy annually [1], while HVAC accounts for 30% -50% of building energy consumption [2]. Therefore, building energy conservation and environmental protection are the key to achieving China's carbon neutrality goal [3]. However, the cooling and dehumidification methods used in conventional air conditioning systems to uniformly handle heat and humidity loads have many problems [4], and there is an urgent need to research efficient, energy-saving, healthy, and comfortable independent heat and humidity treatment technologies, which have important practical significance for energy-saving air conditioning and achieving constant temperature, humidity, and oxygen indoor environments.

Independent heat and humidity treatment is one of the important energy-saving technologies in modern air conditioning [5]. Dual temperature cold source independent heat and humidity treatment technology uses vapor compression refrigeration to achieve air cooling and dehumidification. Due to the different water temperatures used for cooling and dehumidification in independent heat and humidity treatment technology, high-temperature cold sources are generally 15℃ -18℃, and low-temperature cold sources are generally 5℃ -9℃. Different mixed working fluids can be used to generate cold sources with different temperatures, which can be used for air dehumidification and cooling respectively, and can improve the comprehensive COP of cold sources [6-9]. Meanwhile, with the expand of refrigerants, after entering the 21st century, the main non azeotropic mixed refrigerants studied internationally include three types of mixed refrigerants: HFC, HFC/HC, and natural refrigerants (HC, R744, R717). HC mixed working fluid can be miscible with mineral oil and synthetic lubricating oil. therefore, there is no need to replace the lubricating oil in the existing HCFCs and HFC refrigerant systems. the excellent environmental and thermal properties of HC refrigerant will be the ultimate alternative to refrigerants [10, 11], Its ODP value is zero and its GWP value is low. And the liquid density is low, requiring less filling amount. R1270 has a high latent heat of phase change and a large unit cooling capacity [12]. Chien et al. [13] studied the feasibility of replacing R410A with R32/R1270, Zhang et al. [14] provided guidance for the safe and effective utilization of mixed refrigerants through research on R170/R1270, and Cai et al. [15] studied the energy-saving application of R1270 in commercial beverage machines. Calleja-Anta et al. [16] research suggests that R290/R600 can serve as a long-term and efficient alternative to R600a.

Verdnik and Rieberer [17] implemented the application of R600 in high-temperature steam compression heat pump cycles, Vasta et al. [18] studied the feasibility of R600a as a working fluid in heat pipes, and He et al. [19] studied the optimal composition of R600 and other mixed working fluids when maximizing COP. Sun et al. [20] studied the method of improving COP in high temperature rise heat pump water heaters using R1270/R600, and pointed out that the large slip temperature of the mixed working fluid plays an important role in reducing irreversible losses in condensation and heat recovery. Therefore, the research and application of R1270 and R600 and their mixed working fluids are becoming increasingly widespread [21-24]. Moreover, its environmental friendliness and safety are increasingly being valued by researchers. This article presents an experimental study on the CH mixed refrigerant of R1720/R600 in this unit. By changing the quality composition of the mixed working medium, constant condensing temperature, multiple evaporation temperatures, by measuring the parameters including water temperature, pressure, discharge temperature, etc. The finding can provide guideline for the application of the units as a substitute for refrigerants. To lay a solid foundation for future use in temperature and humidity independent air conditioning systems.

## 2. PARAMETERS

### 2.1 Basic parameters

This refrigeration system of CH type dual temperature chiller uses a mixture of R1270 and R600 refrigerants with different boiling points, where R1270 is a low boiling point refrigerant and R600 is a high boiling point refrigerant. The basic parameters of each simpler element can refer to Table 1.

**Table 1.** Basic parameters [25]

| Refrigerant | Boiling Point /℃ | Density/ g/cm$^3$ | Molecular Weight | Critical Temperature /℃ | Critical Pressure /Mpa | Latent Heat /kj/kg | Ozone Depletion Potential | Global Warming Potential | Security Classification |
|---|---|---|---|---|---|---|---|---|---|
| R1270 | -47.70 | 0.514 | 42.08 | 91.10 | 4.55 | 439.50 | 0 | 20 | A3 |
| R600 | -0.50 | 0.551 | 58.12 | 151.90 | 3.79 | 386 | 0 | 20 | A3 |

### 2.2 Pressure

A good refrigeration system requires appropriate operating pressure, and the saturated vapor pressure of the refrigerant can reflect the system pressure. From Figure 1, it could see that the saturated vapor pressure of R1270/R600 (0.7:0.3) increases with temperature, and at the same temperature, its pressure is between the R134A and R22 pressure values. At 55℃, the pressure is 1.5MPa, which can ensure system safety.

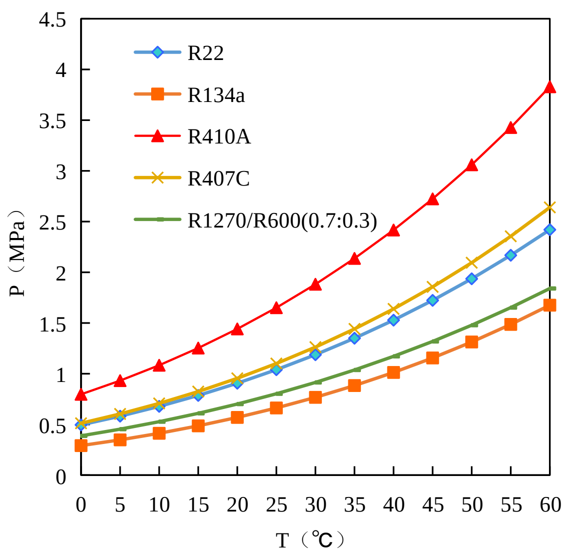



**Figure 1.** Saturated vapor pressure [26]

### 2.3 Temperature slip

Due to the different boiling points of R1270 and R600, there is temperature slip in the mixed working medium in the heat exchanger. The refrigeration system of the dual temperature chiller uses the temperature slip of the mixed working medium to simultaneously produce 1 and 2 temperature chilled water.

From Figure 2, it can be seen that at the same pressure, as the R1270 quality composition increases, the slip temperature first increases and then decreases. When the pressure increases from 0.1MPa to 2.0MPa under the same quality component, the slip temperature decreases, and the maximum temperature slip of R1270/R600 is 20.65℃.

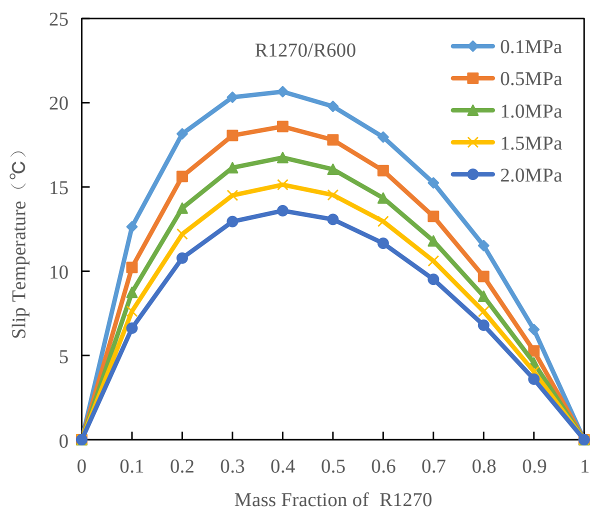


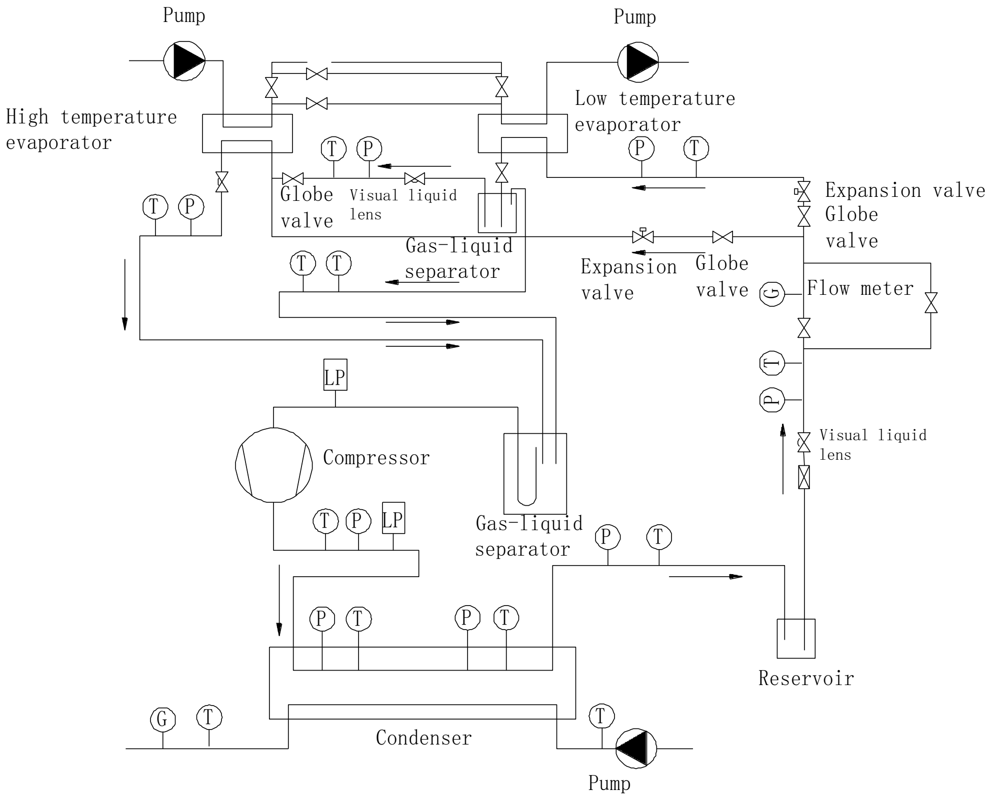

**Figure 2.** Slip temperature under various pressures [26]

## 3. PERFORMANCE EXPERIMENT

### 3.1 Experimental principle and apparatus

From Figure 3(a), it can be seen that the R1270/R600 refrigeration circuit includes a compressor, condenser, liquid storage dryer filter, electronic expansion valve, low-temperature evaporator (evaporator 1), and high-temperature evaporator (evaporator 2). There are also cooling water pumps and tanks, 1 chilled water and 2 chilled water pumps and tanks.

From Figure 3(b), it can be seen that the data acquisition system is used to collect parameters such as temperature measurement points, water flow rate, pressure measurement points, and power. For maintaining a constant water temperature at the inlet and outlet of the condenser and evaporator, it is necessary to control the electric heating regulator and adjust the valve water volume.




(a)

(b)

**Figure 3.** Experimental device (a) Principle diagram (b) Device diagram

The refrigeration system adopts a mixed working fluid mass composition of R1270/R600 (0.6:0.4) and (0.7:0.3). The parameter data of the dual temperature chiller unit can see equations from (1)-(5).

$$Q_L = c_p G_L \left( t_{L,\text{ in}} - t_{L,\text{ out}} \right) \tag{1}$$

$$Q_H = c_p G_H \left( t_{H,\text{ in}} - t_{H,\text{ out}} \right) \tag{2}$$

$$COP_L = \frac{Q_L}{P} \tag{3}$$

$$COP_H = \frac{Q_H}{P} \tag{4}$$

$$\alpha = \frac{Q_L}{Q_H} \tag{5}$$

$C_p$-specific heat capacity of water, kj/(kg·°C),
COP-coefficient of performance,
G-water flow rate, $m^3/s$,
P-power of compressor, kw,
Q-refrigeration capacity, kw,
$\alpha$-ratio of 1 to 2 refrigeration capacity,

*L*-evaporator 1,
*H*-evaporator 2,
*in*-inlet,
out-outlet.

### 3.2 Error analysis

The instruments used in the experiment have certain errors, and the uncertainty is calculated using the uniform distribution method to represent the actual measurement accuracy. The calculation of uncertainty is shown in Eq. (6), and the uncertainty of measurement value is shown in Table 2.

$$f_{t,tol} = \sqrt{f_{t,1}^2 + f_{t,2}^2 + \cdots + f_{t,n}^2} \tag{6}$$

In the formula, $f_{t,tol}$ represents the uncertainty of the computational complexity; $f_{t,n}$ is the uncertainty of the measured values contained in the computational complexity.

**Table 2.** Uncertainty of equipment and measurement values

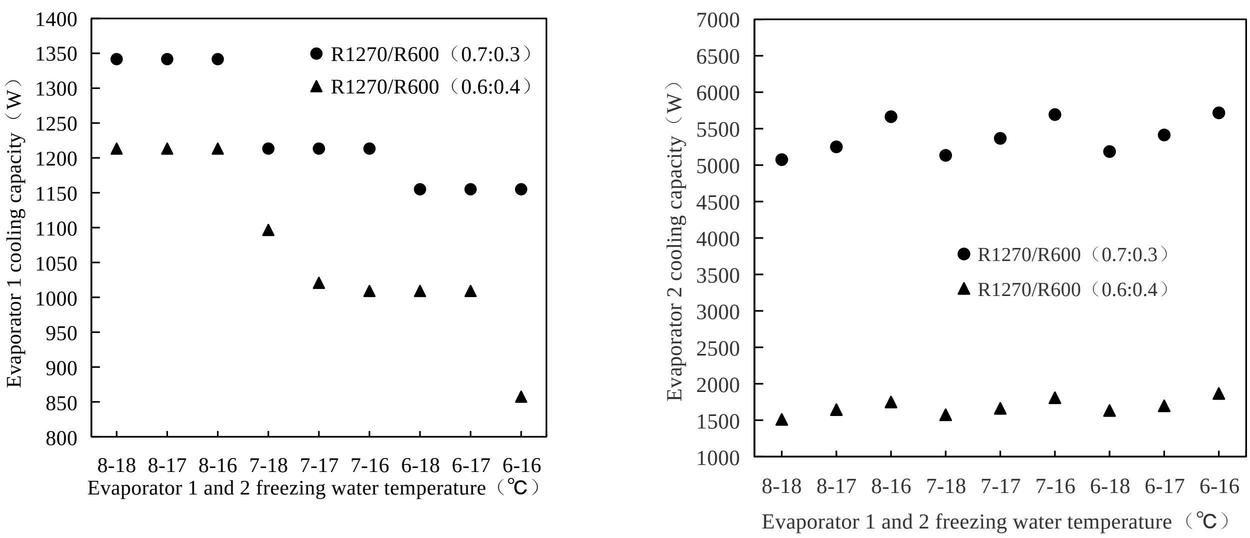
| | | Model | Parameter | Uncertainty/% |
|---|---|---|---|---|
| Equipment | Data collector | Agilent34972A | DC voltage /V | 0.11 |
| | Pressure transmitter | MCMPM4730 | Pressure /MPa | 0.25 |
| | Pt100 | OMEGA | Temperature /℃ | 0.1 |
| | Flowmeter | LWGY-10 | Flow/($m^3$/h) | 0.5 |
| | Thermostat | AZBILSDC35 | Temperature /℃ | 0.1 |
| | Power meter | Wenguang Electric 20/5 | Power/KW | 0.5 |
| Measurement values | Pressure | - | Pa | 0.27 |
| | Temperature | - | ℃ | 0.52 |
| | Flow | - | $m^3$/h | 0.60 |
| | Power | - | KW | 0.60 |
| | COP | - | | 0.72 |

### 3.3 Data analysis

In this operating condition, the inlet and outlet water temperature of the cooler is 32℃/37℃. From Figure 4-8, it can be seen that, examples 7-16 on the X axis represent the inlet and outlet water temperatures of evaporator 1 at 7℃/12℃ and evaporator 2 at 16℃/21℃.

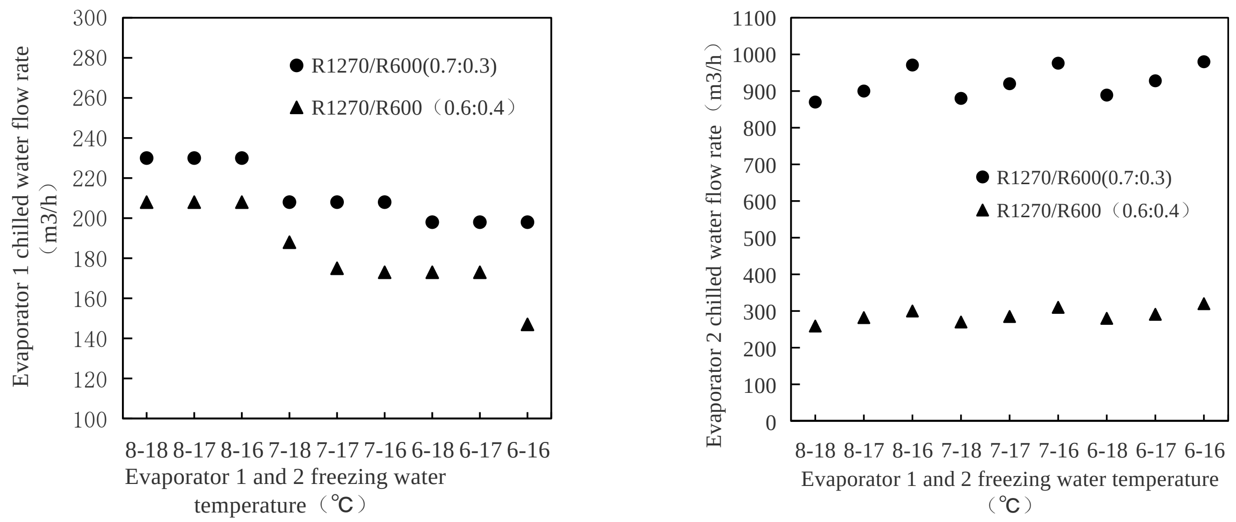
3.3.1 Changes in the mass composition of the mixed medium, while keeping other parameters unchanged

From Figures 4-8, it can be seen that with other parameters remaining constant, as the quality of R1270 increases, both the 1 and 2 refrigeration capacities of the R1270/R600 refrigeration system increase. The amount of 1 and 2 frozen water has also increased. The maximum value of COP1 does not change significantly, while the maximum value of COP2 increases from 2.02 to 5.95. The compressor power increases, with a maximum power of 0.99KW, and the discharge temperature decreases. The maximum discharge temperature is 75.81℃. The suction and discharge pressures both increase, and the compression ratio decreases. The total cooling capacity increased and the maximum total COP increased from 3.36 to 7.36. The percentage of 1 refrigeration capacity to total refrigeration capacity has decreased from the maximum value of 44.54% to 20.91%. The percentage of 2 refrigeration capacity to total refrigeration capacity has increased from the maximum value of 68.52% to 83.19%. The compression ratio decreases. Experimental results have shown that R1270/R600 (0.7:0.3) performs better in dual temperature chillers compared to R1270/R600 (0.6:0.4).



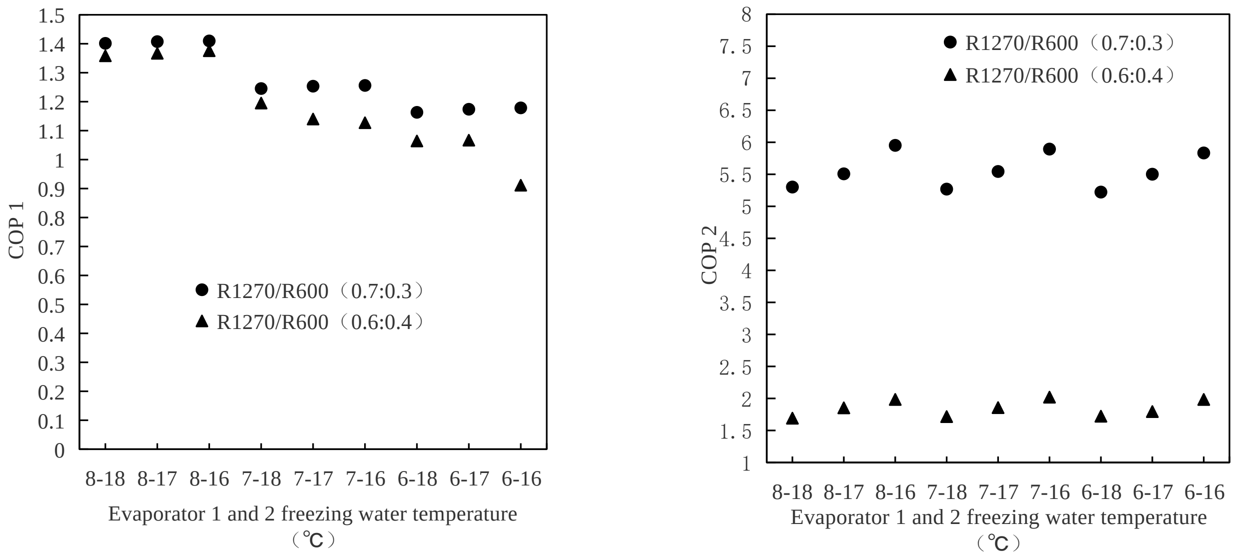

(a) (b)

**Figure 4.** Refrigeration capacity (a) 1 refrigeration capacity; (b) 2 refrigeration capacity



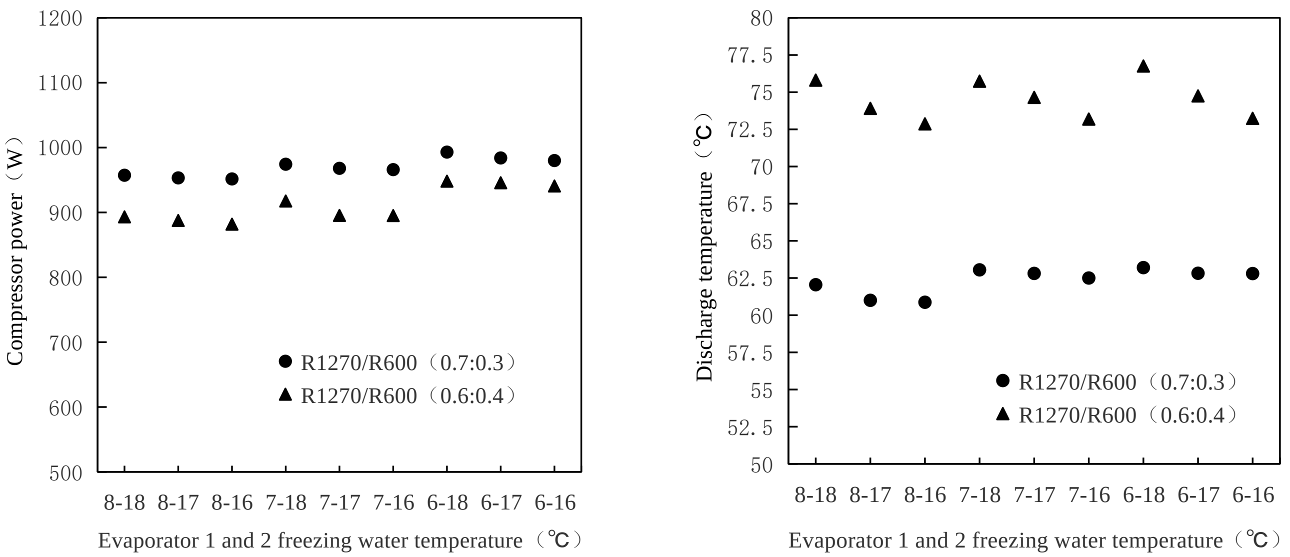

(a) (b)

**Figure 5.** Water flow rate (a) 1 water flow rate; (b) 2 water flow rate

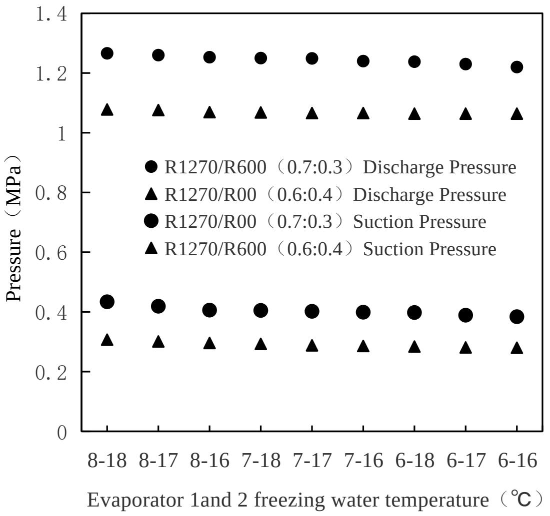



(a) (b)

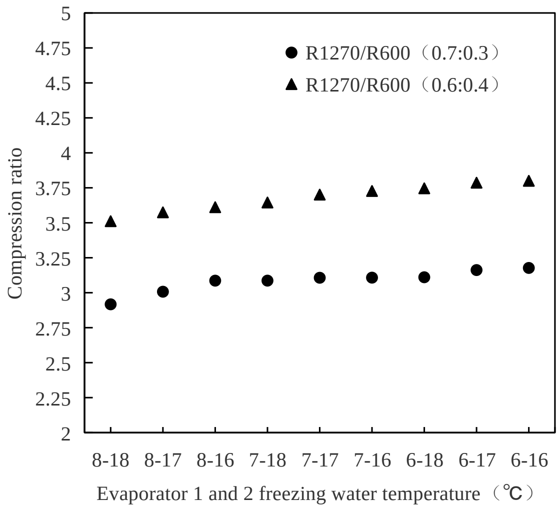
**Figure 6.** COP (a) COP1; (b) COP2




(a) (b)

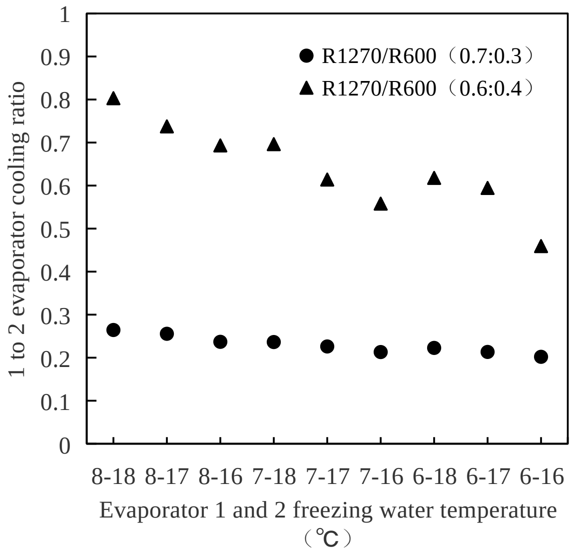



(c)

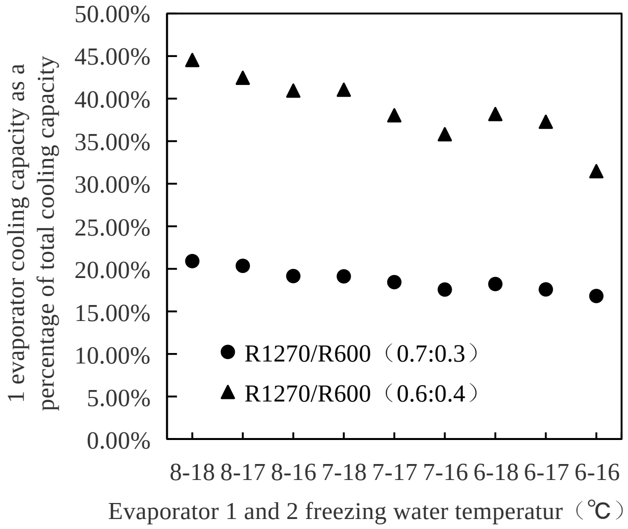



(d)

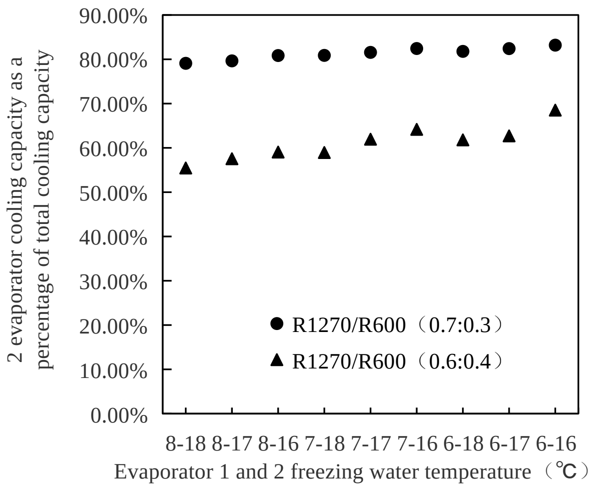
**Figure 7.** Other parameters (a) Power consumption; (b) Discharge temperature; (c) Suction and discharge pressure; (d) Compression ratio




(a)




(b)




(c)

**Figure 8.** Refrigeration capacity percentage (a) 1 to 2 evaporator cooling ratio; (b) 1 evaporator to total refrigeration capacity; (c) 2 Evaporator to total refrigeration capacity

3.3.2 The water temperature of the 2 evaporator decreases, other parameters remain unchanged

From Figures 4-8, it can be seen that when the operating conditions change, other parameters remain unchanged, the water temperatures of the 2 evaporator decrease, and the 1 evaporator capacity and 1 freezing water volume of the two mass components R1270/R600 decrease, while the 2 evaporator capacity and 2 freezing water volume increase. The COP1 shows a decreasing trend. The COP2 shows a growing tendency. The compressor power decreases. The discharge temperature decreases. Both suction and discharge pressures decrease. The compression ratio increases. The refrigeration capacity ratio of 1 and 2 evaporators and the percentage of 1 evaporator capacity to total refrigeration capacity are decreasing. The percentage of 2 evaporator capacity to total refrigeration capacity increases. Experimental results have shown that the optimum operating conditions for R1270/R600 components occur when the temperatures of 1 chilled water are the highest and the temperatures of 2 chilled water are the lowest. At that point, the COP value of the refrigeration system is at its most.

3.3.3 The water temperature of the 1 evaporator decreases, other parameters remain unchanged

From Figures 4-8, it can be seen that when the in and out water temperatures of the 1 evaporator decrease, the 1 evaporator capacity of both components R1270/R600 decreases while the 2 evaporator capacity increases. The COP1 shows a decreasing trend, while the COP2 shows a growing tendency. The compressor power increases. The discharge temperature rises. Both suction and discharge pressures decrease. The compression ratio add. The refrigeration capacity ratio of 1 and 2 evaporators and the percentage of 1 cooling capacity to total refrigeration capacity both show a decreasing trend. And the percentage of 2 evaporator capacity to total refrigeration capacity increases.

3.3.4 Applicability of R1270/R600 refrigeration system

Through the performance analysis of the R1270/R600 mixed refrigerant refrigeration system, it can be seen that the mixed refrigerant variable temperature refrigeration system has different characteristics and high practicality. The adjustable range of the 1 to 2 evaporator cooling capacity ratio of R1270/R600 is between 0.20-0.80. The ratio of 1 evaporator cooling capacity to total cooling capacity ranges from 16.81% to 44.54%, while the ratio of 2 evaporator cooling capacity to total cooling capacity ranges from 55.46% to 83.19%. For different components of the same component, the ratio of 1 to 2 evaporator cooling capacity will also have the same trend of change. Therefore, the R1270/R600 mixed medium is suitable for air conditioning applications with high heat to humidity ratios. Although the 1 evaporator cooling capacity of hydrocarbon refrigerants is relatively low, they exhibit superior performance with suction and discharge pressures less than 2.1 MPa, discharge temperatures below 100℃, compressor power consumption less than 0.99kw, and compression ratios between 2.77-3.66. A professionally designed high compression ratio compressor can be used to improve its performance. The non azeotropic mixture refrigerant variable temperature refrigeration system can meet the needs of various air conditioning conditions by changing the composition and composition of the mixture refrigerant without changing the equipment. Therefore, with the emergence of new and more refrigeration technologies, non azeotropic mixture refrigerant variable temperature refrigeration systems have high application value. There will be a broader application space.

## 4. CONCLUSIONS

CH class medium R1270/R600 is used for dual temperature chillers. Both quality components have high 2 evaporator capacity, low system pressure of the refrigeration, and moderate discharge temperature. Its value is high in this refrigeration cycle. The specific conclusions are as bellow:

(1) At the same operating conditions, when the mass composition of R1270 increases. The maximum total COP of the R1270/R600 refrigeration system increased from 3.36 to 7.36, with little change in the maximum COP1 and an increase in the maximum COP2 from 2.02 to 5.95. The percentage of 1 evaporator capacity to total refrigeration capacity has decreased from the maximum value of 44.54% to 20.91%. The percentage of 2 evaporator capacity to total refrigeration capacity has increased from the maximum value of 68.52% to 83.19%. The compression ratio decreases.

(2) The optimum operating conditions for R1270/R600 mixture during variable operating conditions occur, when the inlet and outlet temperatures of 1 chilled water are the highest, and the inlet and outlet temperatures of 2 chilled water are the lowest. At that time, the COP value of the refrigeration system is at its most.

(3) The refrigeration system using CH class mixed refrigerant R1270/R600 reduces the compressor power consumption and lowers the discharge temperature. The maximum compressor power consumption is 0.99KW, and the maximum discharge temperature is 75.81℃.

(4) The maximum slip temperature of the R1270/R600 components is 20.65℃, requiring the system to operate with a larger amount of chilled water to enhance the heat transfer of the heat exchanger, especially at the 2 evaporator where the heat transfer characteristics are obvious. This system can be used in air-conditioned areas with different heat to humidity ratios.

(5) The working fluid studied in this article can be adjusted by composition and operating temperature, and is suitable for air conditioning areas with various heat to humidity ratios (0.2-0.8). The refrigeration system will be optimized in the future to enhance the efficiency of the heat exchanger and improve the COP of the unit.

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