

# Experimental results and analysis of throttling refrigeration with ternary mixed refrigerant

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**Abstract:** In-depth analysis of the influence of mixed working fluids on the thermodynamic performance of a throttling refrigeration cycle through experimental research. After optimizing the calculation of two ternary mixed working fluids with different compositions, the charging test is carried out, and the throttle characteristic curve of the mixed working fluid the law of temperature and pressure changes in the experiment was analyzed. The results show that: a mixed working fluid with a mixing ratio of 30.39mol% R14, 10.73mol% R170 and 58.87mol% R600A, at a pressure ratio of 2.5/0.1, a low temperature of -67.7°C is obtained, and the cooling time is 113.42min. The refrigeration system COP is 0.076; the mixing ratio is 30.39mol%R14, 15.73mol%R23 and 53.87mol%R600A mixed working fluid, in the case of a pressure ratio of 2.14/0.1, a low temperature of -76.4°C is obtained, and the cooling time is 160min, the refrigeration system COP is 0.106.

## 1 Introduction

With the continuous progress of science and technology, high-tech fields such as aerospace technology, energy chemical industry, military industry, and civilian industries such as low-temperature medical, freeze-drying and food cold chain are also increasingly demanding low-temperature environments below 240K. In particular, the small and medium-sized cryopreservation chambers used to preserve biological vaccines and biological tissue cells have become one of the research hotspots in recent years.

At present, the methods for obtaining temperature regions below 240K can be roughly divided into three categories: one is the more traditional multi-stage cascade refrigeration cycle, which can reach a minimum of 150K through three-stage cascade<sup>[1]</sup>. However, due to the large number of heat exchange equipment in the system, It will cause a large amount of inevitable cooling loss, low efficiency and high cost; the second is the use of multi-stage compression technology, which can reach the lowest 190K by increasing the compression ratio, but after the operation is stable, the refrigeration efficiency is low and the initial investment is high; the third is Multi-mixed refrigerant throttling refrigeration technology, the system is driven by an ordinary single-stage refrigeration unit, using non-azeotropic mixed refrigerant as the refrigerant, and can obtain 80-240K low temperature zone by recovering cold capacity or multi-stage throttling<sup>[2]</sup>. Simple structure, low price and high efficiency.

The multi-mixed refrigerant throttling refrigeration is divided into two technical methods, self-cascade refrigeration cycle and primary throttling refrigeration cycle<sup>[3]</sup>. The self-cascade refrigeration cycle needs to add a gas-liquid separator after the air cooler. After the separated high-temperature and high-pressure liquid working medium is throttled to cool the low-temperature working medium, the low-temperature working medium is throttling to produce cold energy. The refrigeration efficiency of the system largely depends on the performance of the gas-liquid separator, and the manufacture of an efficient gas-liquid separator is difficult and costly<sup>[4]</sup>.

Compared with the self-cascade cycle, a throttling refrigeration cycle does not need to install a gas-liquid separator. Although the system has a simple structure, the refrigeration efficiency is similar, and it has advantages in small and medium-sized low-temperature refrigeration systems<sup>[5]</sup>. However, high-efficiency cold energy recovery requires high physical properties of the mixed multi-element working fluid. Therefore, it is necessary to study the effect of the mixed multi-element refrigerant and its matching ratio on a throttling refrigeration cycle.

## 2 Materials and Methods

### 2.1 System introduction

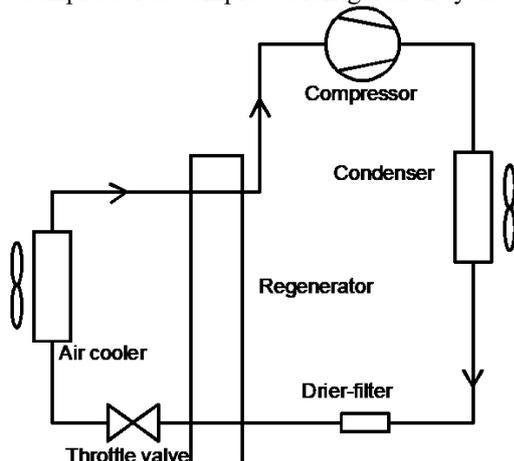
The test device is divided into two parts: a mixed refrigerant preparation system for precise preparation and

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charging of mixed refrigerants and a mixed refrigerant primary throttling refrigeration system for throttling refrigeration tests. The mixed refrigerant configuration system is mainly composed of vacuum pumps and electronic components. Composed of expansion valve, gas storage tank, electronic scale, PLC control cabinet and pressure sensor. For safety reasons, some high-pressure working fluids should also be equipped with pressure relief valves.

The main principles of the primary throttling refrigeration system with multiple mixed refrigerants are as follows:

The compressed multi-element mixed working fluid enters the air cooler for cooling (Fig1). After passing through the filter drier, it exchanges heat with the gas-liquid two-state mixed working fluid after passing through the evaporator in the regenerator. The high-pressure and high-temperature working fluid is further cooled, and the temperature of the low-pressure working fluid gradually increases. The reheated high-pressure working fluid enters the capillary tube for throttling and flows into the evaporator to absorb the cold energy. After passing through the regenerator, it returns to the compressor to complete a refrigeration cycle.



**Fig1** Flow chart of the single stage cycle using mixed refrigerants

## 2.2 Experimental design

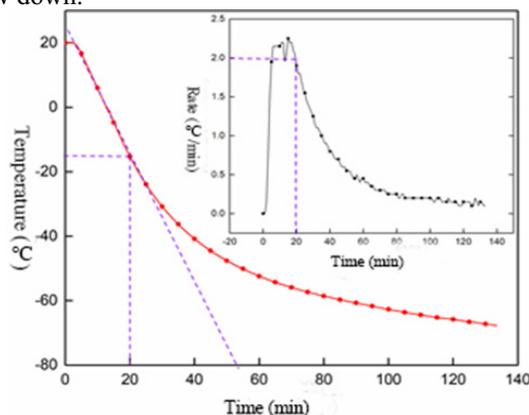
The experiment uses a 50L ultra-low temperature refrigerator, the shell uses polyurethane foam to heat the heat exchanger arranged inside the shell, the thickness of the insulation layer is 100mm, and the thermal conductivity is 0.024W/(m·K). The internal dimensions of the box are 420×350×300mm<sup>3</sup>, and the inner wall is a stainless steel plate with a thickness of 1mm. The refrigeration device adopts semi-hermetic piston compressor, air-cooled air cooler, filter drier, regenerator, capillary throttling element, evaporator and GP10 paperless data acquisition instrument, which form a multi-mixed working fluid for a throttling refrigerating system.

## 3 Results & Discussion

### 3.1 R14/R170/R600A throttling refrigeration test results and analysis

The mixed working fluid ratio optimization method is used to optimize the mixed working fluid composed of R14/R170/R600A, and the final optimal ratio of the mixed working fluid is 30.39mol%R14, 10.73mol%R170 and 58.87mol%R600A, below This mixed working fluid is referred to as TRU1 for short.

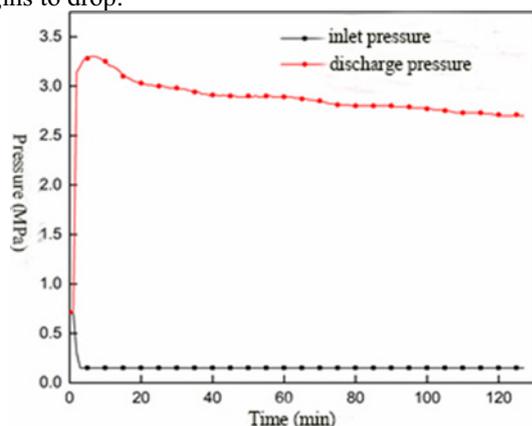
Fig2 shows the temperature change curve in the low-temperature refrigeration box after the ternary mixed working fluid TRU1 is charged. It can be seen from the figure that after 113 minutes of operation of the refrigeration system, the temperature in the box gradually dropped from 23°C to -65°C, and then stabilized, but did not reach the target temperature of 180K. The main reason is that the suction and discharge pressure of the compressor is relatively large, so in the actual cycle, the refrigerant flow is small, and the cooling capacity is low; the second is that the pipeline and the environment have a large heat exchange temperature difference during the actual operation of the system, Resulting in a large loss of cooling capacity, greatly reducing the system's heat recovery efficiency. After the system has been running for 8 minutes, the cooling rate reaches its maximum value, but at this time the system has just been running and has not yet reached a steady state; when the system has been running for 20 minutes, the cooling rate has gradually slowed down after reaching the second peak. The main reason is that when the temperature inside the box drops to around 257K, the temperature change of the refrigerant TRU1 after throttling gradually decreases, the heat exchange temperature difference decreases, the heat recovery effect gradually weakens, and the cooling capacity gradually decreases; at the same time, as the box temperature The decrease of the cooling capacity of the box increases, which further causes the cooling rate to slow down.



**Fig2** The changing of refrigeration system temperature with time

Fig3 shows the change curve of the compressor suction and discharge pressure after the ternary mixed working fluid TRU1 is charged. It can be seen from the figure that after the system is running, the compressor suction pressure quickly drops to 0.1MP, while the discharge pressure quickly rises to 3.3MP, and as the

system continues to run, the discharge pressure begins to drop, and at 20 minutes, it drops. The trend slowed down and eventually stabilized at around 2.5MP, which was 24% lower than the maximum pressure. The main reason is: when the system is just started up and running, most of the mixed working fluids exist in the pipeline in gaseous form. At this time, the specific volume is large. After capillary throttling, part of the gaseous working fluid will be trapped in the high-pressure pipeline. The suction pressure rises rapidly. Then the system temperature gradually decreases, the working fluid specific volume decreases, and the exhaust pressure begins to drop.

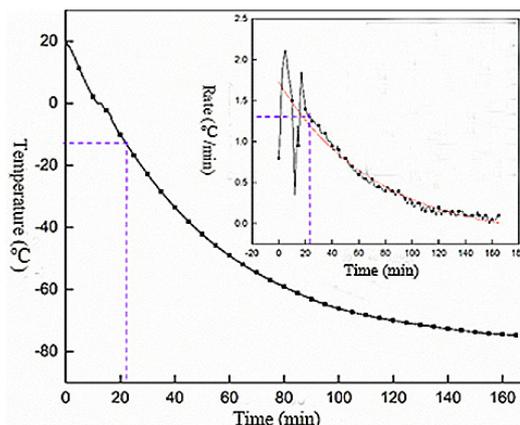


**Fig3** Pressure change curve of mixed refrigerant throttling refrigeration system

### 3.2 R14/R23/R600A throttling refrigeration test results and analysis

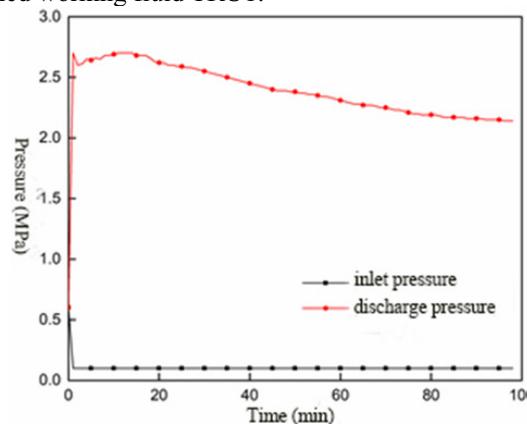
The mixed working fluid composed of R14/R23/ R600A is optimized, and the optimal ratio of the final mixed working fluid is 30.39mol% R14, 15.73mol% R23 and 53.87mol% R600A, which is referred to as TRU2 hereinafter.

Fig4 shows the temperature change curve in the low-temperature refrigeration box after the ternary mixed working fluid TRU2 is charged. It can be seen from the figure that after the system has been running for 95 minutes, the temperature in the box has dropped from 20°C to -65°C. After the operation is stable, the refrigeration system can reduce the temperature in the box to -76.4°C. The cooling rate curve of the low temperature box appears to be close to an exponential function outside of fluctuations, and the cooling speed changes from fast to slow. The reason for the fluctuation is that after the system runs for 11 minutes and reaches 0°C, it has not reached the steady state operation, and due to the high humidity in the cabinet, small droplets adhere to the internal surface of the cabinet, which is not treated in time. When the freezing point is reached, the air and liquid. The drop releases a lot of condensation heat, causing fluctuations in the cooling rate of the box.



**Fig4** The changing of refrigeration system temperature with time

Fig5 shows the change curve of the suction and discharge pressure of the compressor in the low-temperature refrigeration box after the ternary mixed working fluid TRU2 is charged. It can be seen from the figure that after the refrigeration system is started, the suction pressure of the compressor decreases rapidly and then remains stable; the discharge pressure rises rapidly, reaching the peak value of 2.7MP, because the system has just run, the system fluid supply is unstable, causing the discharge pressure to appear. After a short period of fluctuation, after 10 minutes, the exhaust pressure began to gradually decrease. When the box temperature reached a stable level, the exhaust pressure stabilized at 2.14MP. The reason for pressure reduction is similar to that of the mixed working fluid TRU1.

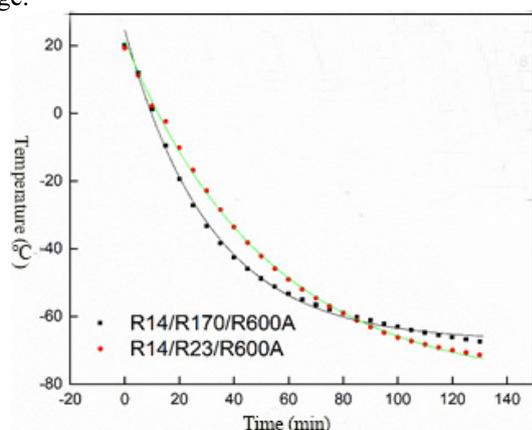


**Fig5** Pressure change curve of mixed refrigerant throttling refrigeration system

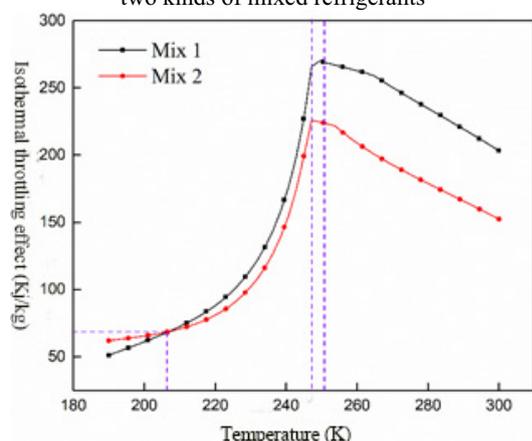
### 3.3 Compare TRU1 and TRU2

Fig6 shows the temperature changes in the two ternary mixed working fluid boxes. As can be seen from the figure, in the refrigeration system filled with TRU1 working fluid within 82 minutes of system operation, the temperature in the low-temperature box is lower, so at -60°C~0°C, the cooling capacity of TRU1 is better than TRU2. As the operating time of the system increases, the refrigeration system filled with TRU2 working fluid can reach a lower temperature, and the temperature drop rate is greater than that of TRU1. Fig7 is the isothermal throttling effect diagram of two ternary mixed working

fluids. From the figure, it can be seen that when the temperature is higher than 206K, the isothermal throttling effect of TRU2 is lower than that of TRU1, so TRU1 has a stronger cooling capacity in this temperature range.



**Fig6** Fitting curve of refrigeration system temperature using two kinds of mixed refrigerants



**Fig7** Isothermal throttling effect curves of two kinds of mixed refrigerants

TRU1 and TRU2 two ternary mixed refrigerant refrigeration systems, the lowest temperature in the low temperature box can reach  $-67.7^{\circ}\text{C}$  and  $-76.4^{\circ}\text{C}$  respectively; when the initial box temperature is the same and drops to  $-65^{\circ}\text{C}$ , the TRU2 mixed refrigerant is charged. Compared with the refrigeration system filled with TRU1 mixed refrigerant, the cooling time of the refrigeration system is reduced by 16%, the limit temperature is reduced by  $8.7^{\circ}\text{C}$ , and the COP of the refrigeration system is increased by 39.5%.

## 4 Conclusions

1. Using the mixed working fluid TRU1 with a ratio of 30.39mol%R14, 10.73mol%R170 and 58.87mol% R600A, a low temperature of  $-67.7^{\circ}\text{C}$  is obtained at a pressure ratio of 2.5/0.1, and the refrigeration system COP is 0.076;

2. Using the mixed working fluid TRU2 with a ratio of 30.39mol% R14, 15.73mol% R23 and 53.87mol% R600A, at a pressure ratio of 2.14/0.1, a low temperature of  $-76.4^{\circ}\text{C}$  is obtained, and the refrigeration system COP is 0.106;

3. TRU1 is more suitable for medium and high

temperature refrigeration systems, while TRU2 is more suitable for low temperature refrigeration systems.

## Acknowledgments

Integration and Demonstration Application of Key Technologies for Low-temperature Storage of Rice

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