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Study on the Performance of CO_2 Two-stage Rotary Compressor in Freezing Conditions

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ABSTRACT

This paper describes a new type CO_2 two-stage rotary compressor for cold storage and freezing of food. A two-stage compression form with an upper cylinder (first-stage) and a lower cylinder (second-stage), unique oil road structures and technical parameters have been used in the rotary compressor to increase the performance. The results indicating that the optimized CO_2 two-stage rotary compressor has a significant performance advantage, which the coefficient of performance (COP) increases by 4.4% ~ 6.7%.

1. INTRODUCTION

At present, domestic research and application of CO_2 are mainly focus on three aspects: automobile air conditioning, heat pump water heaters, cold storage and freezing of food. Among them, cold storage and freezing of food have great application potential. Due to the design storage temperature and cooling capacity is according to the application occasions, the refrigeration system of cold storage and freezing of food needs different types of compressor. In the range of small cooling capacity at medium and high temperatures (the evaporation temperature range is -15 ℃～10 ℃), the type of rotary compressor is one of the mainly used .

Jinghong Ning et al. (2011) used thermodynamic method to calculate the performance parameters of different type refrigeration cycle of CO_2 trans-critical two-stage compression for cold storage and freezing of food. By analyzing and comparing the performance parameters of the refrigeration cycles, they concluded that the CO_2 trans-critical refrigeration cycle with two-stage throttling and complete cooling in middle has some advantages, such as lower energy consumption, better running performance, lower initial investment and so on. Yefeng Liu et al. (2019) combined two-stage compression with CO_2 trans-critical cycle technology and designed a set of refrigerating cabinets which use a small CO_2 two-stage compression refrigeration cycle. Experimental comparison between the refrigeration system with a single-stage compression and a CO_2 two-stage compression proved that the use of CO_2 two-stage compression refrigeration system could improve system performance. The CO_2 two-stage rotary compressors applied in heat pump water heaters and achieved good results by some research organizations, such as SANYO Industrial Co. Ltd. and the University of Maryland et al. However, there are few studies on the application of CO_2 two-stage rotary compressors for cold storage and freezing of food at present.

This paper discusses a new type CO_2 two-stage rotary compressor which can be used in small cooling capacity at medium and high temperatures (the evaporation temperature range is -15 ℃～10 ℃) in cold storage and freezing of food, experimentally analyzes the variation of the performance of two compressor schemes and clarifies their advantages of the performance in freezing conditions.

2. COMPRESSOR STRUCTURES AND KEY PARAMETERS

2.1 Compressor Structures

Ying Wang et al. (2010) studied the characteristics of the channel roughness on flow resistance, and found that there will be greater losses when the fluid through a smaller cross-section and the inner wall of the flow passage coarser. As shows in Figure 1, due to the limit of the size, structures and processing conditions of the rotary compressor, there is a similar flow channel (red frame position) inside the pump of conventional CO_2 two-stage rotary compressor.

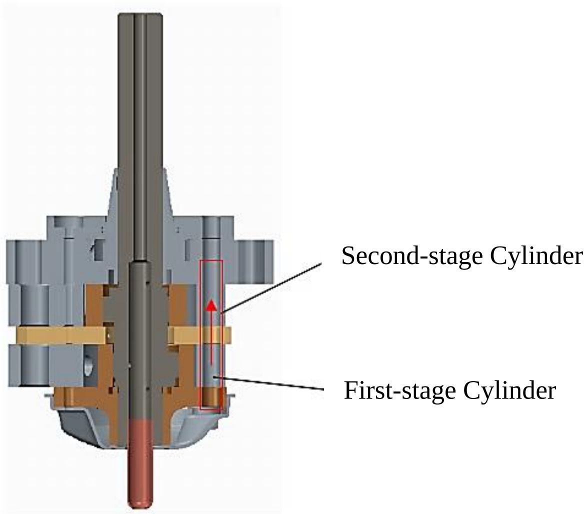
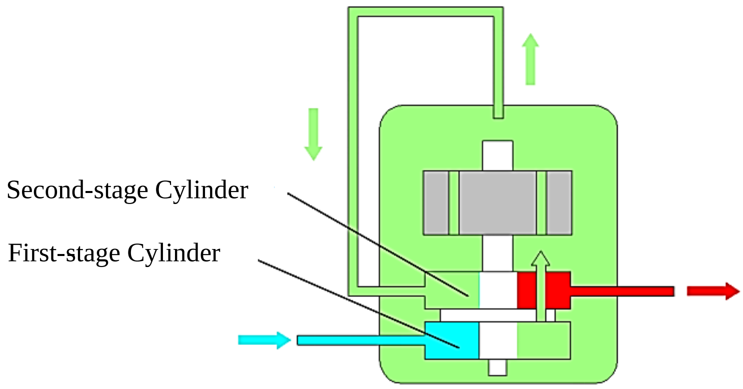
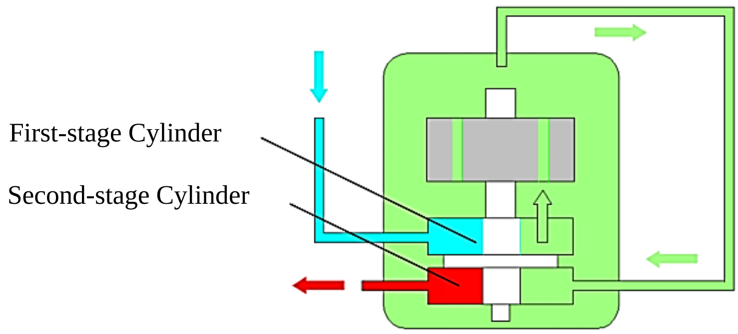


Figure 1: Internal flow channel of conventional pump



(a): The structure of conventional CO_2 two-stage rotary compressor



(b): The structure of new type CO_2 two-stage rotary compressor

Figure 2: The structures of the conventional and new type CO_2 two-stage rotary compressors

Figure 2 shows the internal structures of conventional and new type CO_2 two-stage rotary compressors, both of which are two-stage compression structures. The difference between the conventional compressor and the new compressor is the using of the second-stage cylinder that be arranged below the first-stage cylinder. The refrigerant is compressed by the first-stage cylinder and discharges into the airtight housing directly. Compared with the conventional compressors, the new type CO_2 two-stage rotary compressor can avoid flowing through the relatively rough small channels inside the pump and the flow loss can be reduced. Table 1 shows the specifications of the new type CO_2 two-stage rotary compressor.

Table 1: Specifications of the new type CO_2 two-stage rotary compressor

Work volume(cc)	19
Rated power (w)	7500
Motor type	DC inverted frequency
Back pressure type	Medium back pressure
Compression type	Two-stage
Oil type	PAG

2.2 Oil Road Structures

Kun Yang *et al.* (2016) analyzed the compatibility of PAG and CO_2 used in this paper and concluded that they have good mutual solubility. The oil dissolved in CO_2 will enter the compressor pump to each friction pair. However, the pressure of the housing is the first-stage discharge pressure and the pressure of the second-stage cylinder is the condensing pressure which is higher than the first-stage discharge pressure. Under the action of a larger pressure difference, the oil is difficult for the lubricant in the housing to enter the second-stage cylinder for conventional oil road structures.

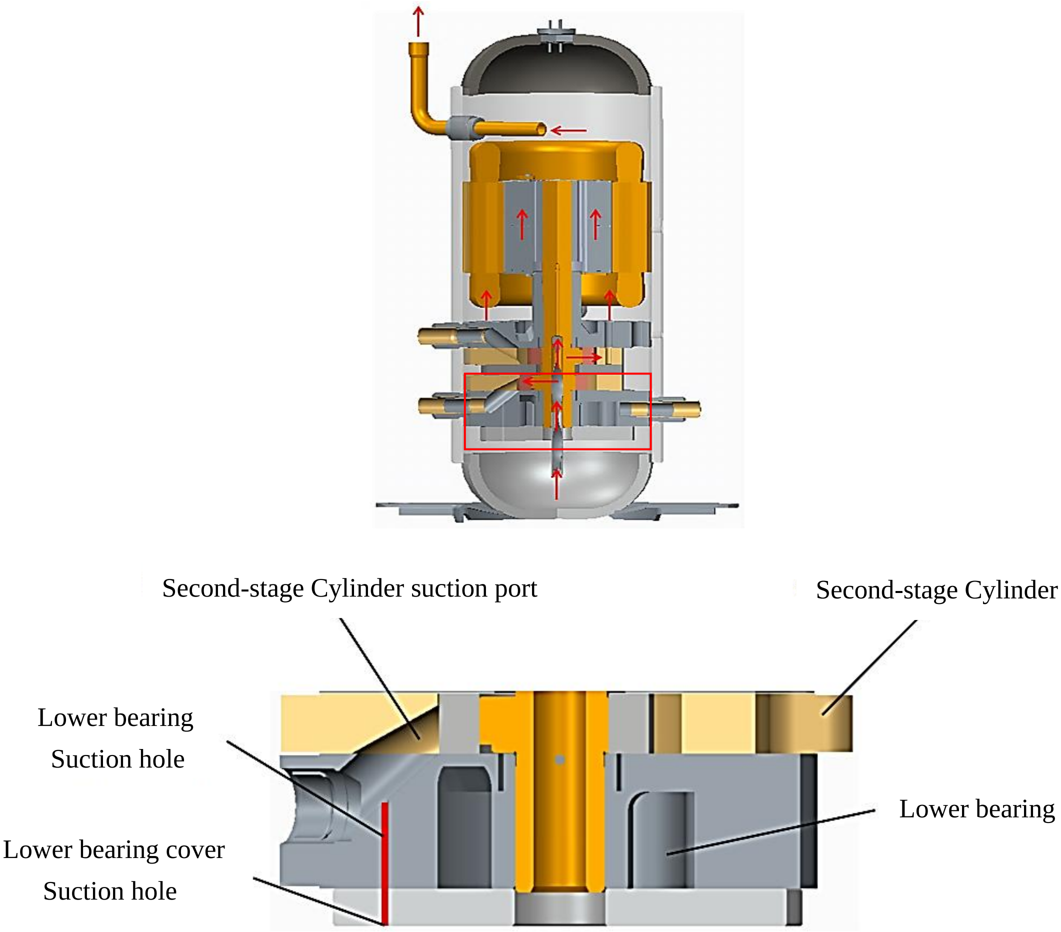


Figure 3: The oil road structures of new type CO_2 two-stage rotary compressor

Figure 3 shows the difference between the oil road structures of the conventional and the new type compressor. In the new type compressor, the oil suction hole is set in the lower bearing and the lower bearing cover, and the top of the second-stage cylinder will be covered with oil. Due to the periodic pulsation of the inlet pressure of the second-stage cylinder, the pressure in the housing is intermittently higher than the second-stage cylinder suction port. Therefore, with the effects of the pressure difference, the oil will be suck into the suction port of the second-stage cylinder and enter the interior of the second-stage cylinder.

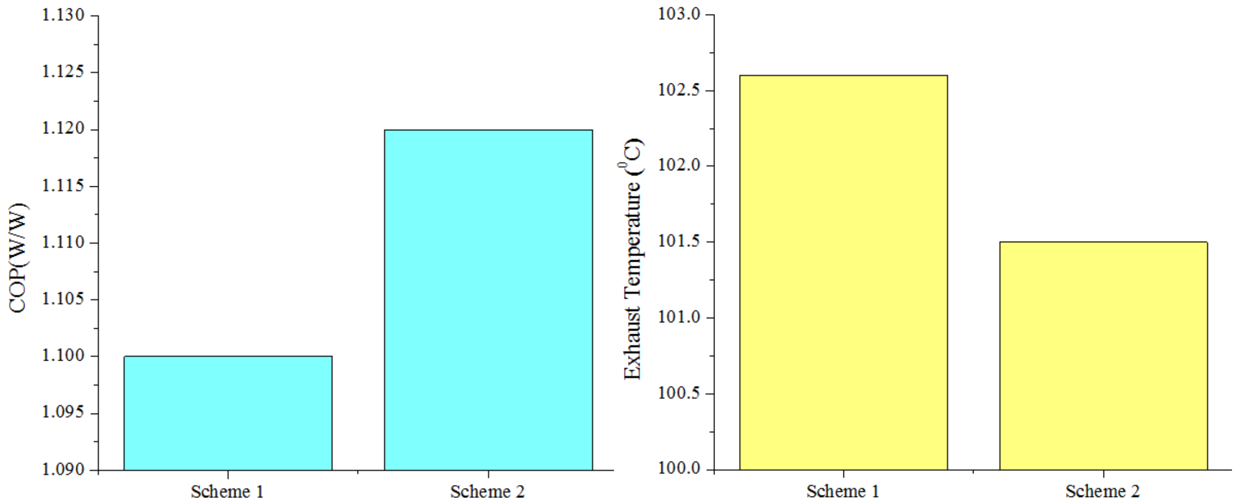


Figure 4: COP and discharge temperature for both schemes

Table 2 is the oil road schemes. As shows in Figure 4, the comparison between the without oil suction hole and with oil suction hole, the test results show that the COP increased by 1.8% and the discharge temperature reduced by 1.1 ℃. This phenomenon indicates that the second-stage cylinder lubricated effectively when the suction hole are added to the lower bearing and lower bearing cover.

Table 2: Oil road schemes

Oil road schemes	Lower bearing suction hole	Lower bearing cover suction hole
Scheme 1	Without	Without
Scheme 2	With	With

2.3 Volume Ratio

The volume ratio is the ratio of the working volume of the second-stage and first-stage cylinders of the two-stage compressor. It is one of the key parameters affecting the performance of two-stage compression.

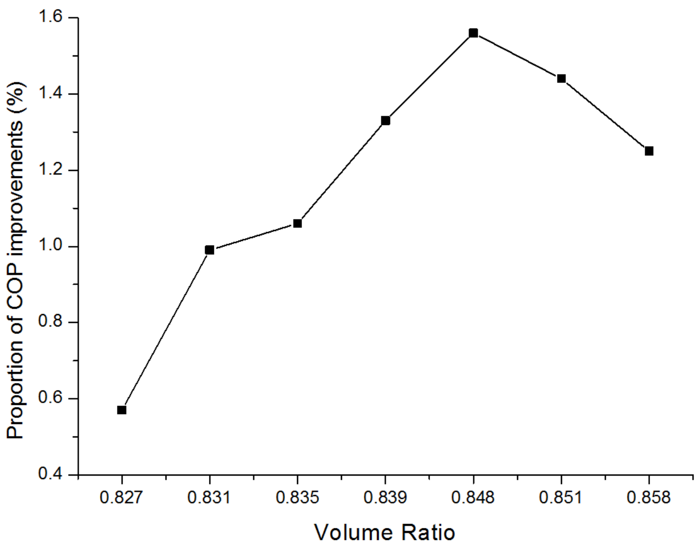


Figure 5: Variation curve of COP improvements proportion with volume ratio under freezing conditions

Qi Liu *et al.* (2014) theoretically calculated the performance parameters of the R410A two-stage compressor and the results showed that when the evaporation temperature range is 3 ℃~9 ℃, the condensing temperature range is 35 ℃~50 ℃, the range of volume ratio is 3/4~4/5 and the cycle refrigeration coefficient is closer to the maximum refrigeration coefficient. According to the partial calculation method of volume ratio described in the paper, the theoretical analysis of the two-stage throttling intermediate incomplete cooling cycle applied to the CO_2 two-stage rotary compressor. The result shows that the volume ratio of the optimal COP of the compressor corresponding to different operating conditions is not the same. In the freezing conditions, as shows in Figure 5, the proportion of COP increases first and decreases with the increasing of the volume ratio, it shows a parabolic trend. The optimal volume ratio range is 0.839～0.851 and the best COP of volume ratio is 0.848.

3. TEST SCHEMES AND RESULTS

3.1 Compressor Performance Test Facility

As show in Figure 6 to 7, the experiments are carried out on the compressor performance test facility in GREE, which is based on GB/T 29030-2012《Volume Type CO_2 Refrigeration Compressor (Group)》. The main parameters which need to be measured include suction pressure / temperature, discharge pressure / temperature, mass flow and power etc. The range of cooling capacity is from 0.8kW～8 kW.

Figure 6: Compressor performance test facility

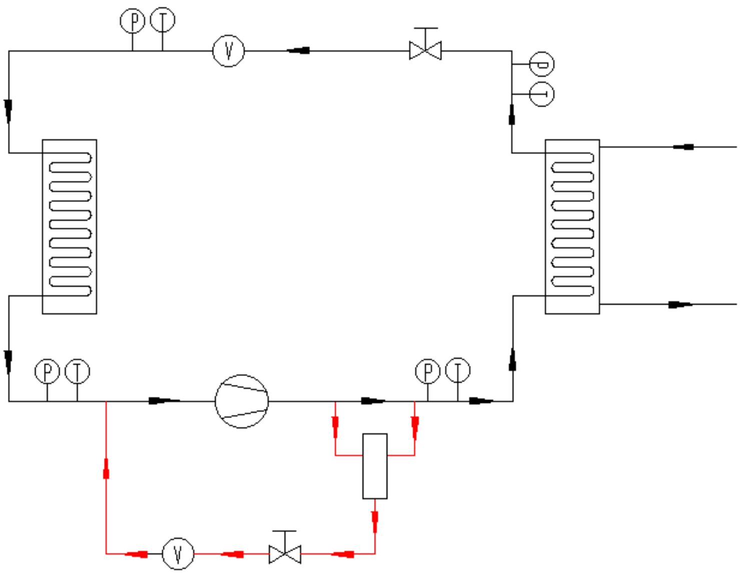


Figure 7: Simplified schematics of test facility

3.2 Test Schemes

As shows in Table 3, there are two schemes for comparative test of two-stage CO_2 compressors from GREE. The test conditions are freezing conditions with evaporation temperature of -10 ℃, suction temperature of 0 ℃ and discharge pressure of 9.8 MPa.

Table 3: Compressor schemes

Compressor schemes	Compression type	First-stage cylinder	Second-stage cylinder	New oil road structures	Volume ratio
Conventional type	Two-stage	Down	Up	Without	0.750
New type	Two-stage	Up	Down	With	0.848

3.3 Results and Discussions

Figures 8 to 11 show the variation curves of the cooling capacity, power, COP and discharge temperature with the change of frequency of conventional type and new type compressors in freezing conditions. In the entire range of frequency, the cooling capacity, power and discharge temperature of two schemes will increase with frequency, while the COP slightly decreases, and the overall trend is similar.

The comparison result between the two schemes shows that the cooling capacity increase by 1.1%～3.6%, the power reduces by 0.7%～2.9%, the discharge temperature reduces by 3 ℃～6 ℃ and the COP increases by 4.4%～6.7%, which indicates the new type CO_2 two-stage compressor has significant performance advantage.

The reasons for the above mentioned advantages are the new type CO_2 two-stage rotary compressor has much less flow resistance of CO_2 and the second-stage cylinder has been well lubricated by oil, so the friction loss is reduced, the mechanical efficiency will be improved and the discharge temperature will be lower. Moreover, the leakage channel of the pump also can be well sealed by oil, the leakage of CO_2 under large pressure difference can be reduced and the volumetric efficiency will be improved effectively. Meanwhile, the adoption of the suitable volume ratio for freezing conditions can reasonably distribute the pressure ratio of the first-stage cylinder and second-stage cylinder for the compression efficiency. So the COP of new type CO_2 two-stage rotary compressor improves obviously.

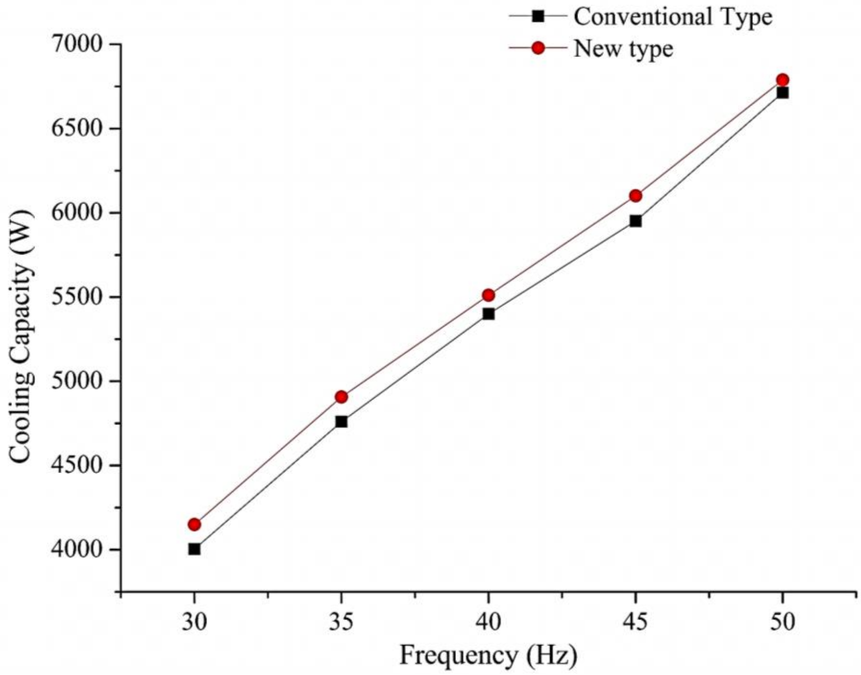


Figure 8: Variation curves of cooling capacity of two schemes with the changing of frequency

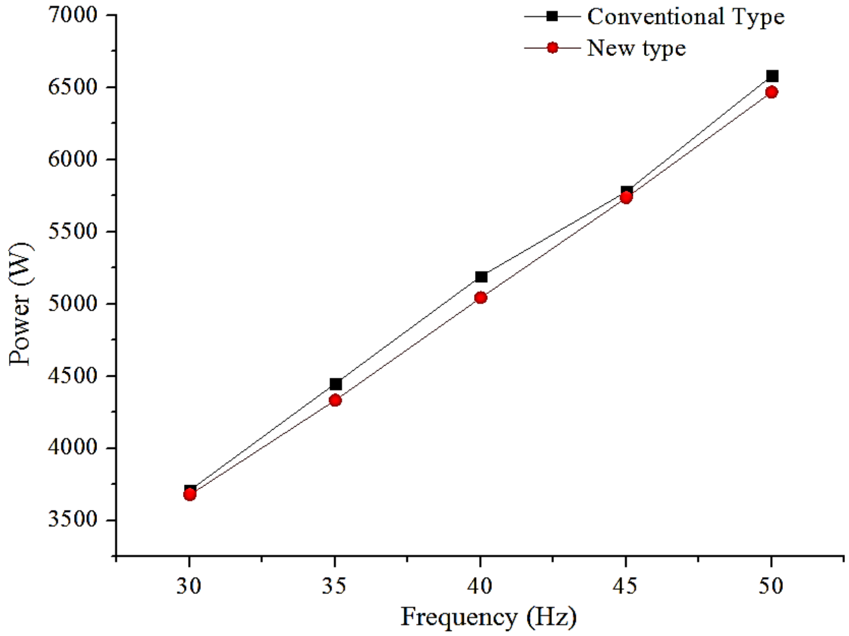


Figure 9: Variation curves of power of two schemes with the changing of frequency

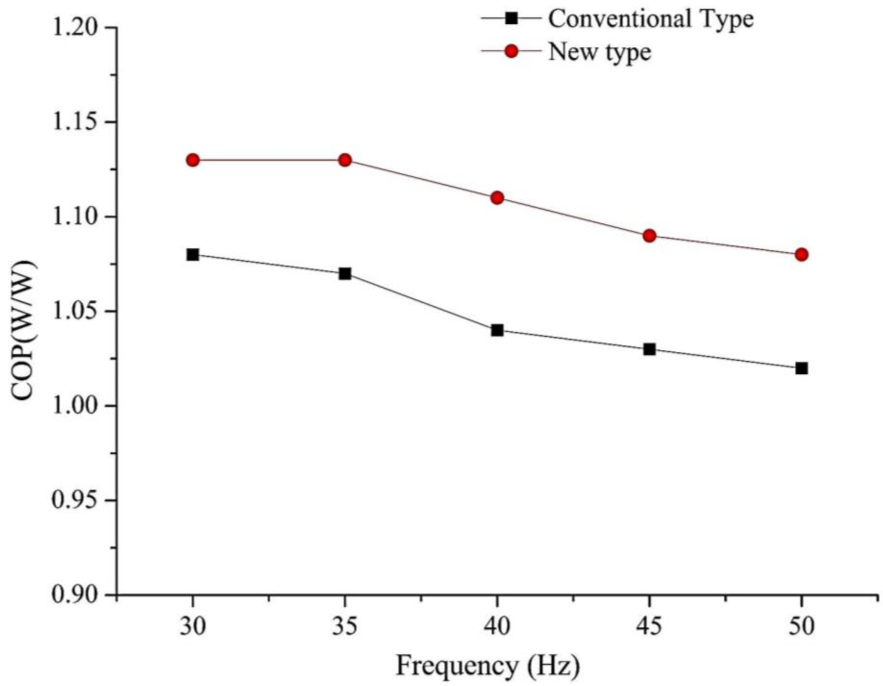


Figure 10: Variation curves of COP of two schemes with the changing of frequency

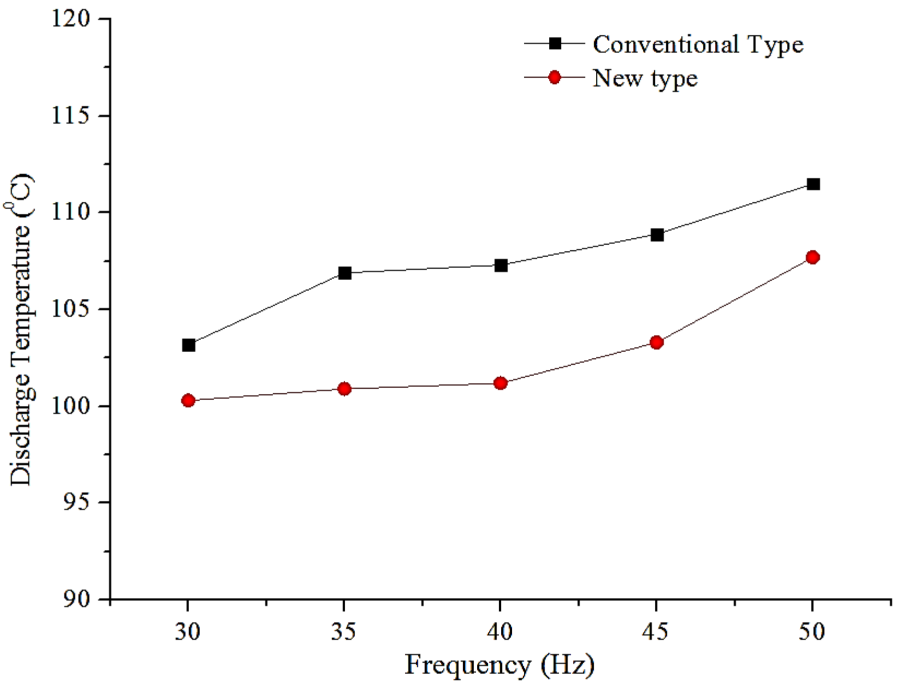


Figure 11: Variation curves of discharge temperature of two schemes with the changing of frequency

4. CONCLUSIONS

This paper describes the technical characteristics of new type CO_2 two-stage rotary compressor and compares the test results with conventional CO_2 two-stage rotary compressor in freezing conditions. The results show that:
(1) Adding oil suction holes in the lower bearing and the lower bearing cover can reduce the discharge temperature and improve COP of the compressor effectively.
(2) The two-stage compression form with an upper cylinder (first-stage) and a lower cylinder (second-stage), including oil suction holes and using the best volume ratio can improve COP of the compressor significantly.

NOMENCLATURE

COP	Coefficient of performance	(W/W)
CO_2	Carbon dioxide	
EEV	Electronic expansion valve	
P	Pressure of the CO_2	(MPa)
T	Temperature of the CO_2	(℃)
m	Volumetric flow rate	(m^3/min)
Rpm	Speed	(Revolutions/min)
V	Specific volume	(m^3)
ΔP	Pressure difference	(MPa)
η_{vol}	Volumetric efficiency	

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