Review on application and research of trans-critical CO2 refrigeration system in food freezing and cold storage

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Abstract. As people pay more and more attention to environmental problems, the GWP and ODP of traditional halogenated hydrocarbon refrigerants are generally higher, and the natural refrigerants with low GWP are more mentioned. As a natural refrigerant, CO2 is excellent in safety and environmental protection. CO2 as a refrigerant also plays a role in various industries, especially in the food industry. In the actual use of CO2 trans-critical refrigeration system in food refrigeration, it is found that there are some defects in CO2 system. Therefore, in order to solve the problem of low efficiency in trans-critical CO2 cycle, this paper analyses the research of some technologies in trans-critical CO2 refrigeration system that can improve system performance, COP and refrigeration capacity, and summarizes the problems in recent years progress in energy efficiency. In this paper, the working principle, technical characteristics and the improvement of system performance of various improved technologies are discussed in detail, and the previous research is summarized.

1. Introduction

CO2, is an excellent natural refrigeration. With the gradual elimination of refrigerants that are harmful to the atmospheric environment and have negative effects on the greenhouse effect, CO2 has become the preferred alternative refrigerant in the refrigeration industry. From "Montreal Protocol" to "Stockholm Declaration", and then to the F-gas regulation of the European Union, this is the gradual attention of human beings to environmental problems, and also the general trend of green refrigeration.

Compared with other refrigerants, they usually have lower temperature under higher pressure in refrigeration cycle. Compared with popular HFCS, CO2 is cheaper and has more unique physical properties in latent heat, specific heat and density [1]. This is an excellent substitute for the use of expensive halogenated hydrocarbon refrigerants in the food industry. At present, the use of trans-critical CO2 has been on the right track. In the next step, the European Commission plans to revise f-gas regulations and reduce greenhouse gases to 55%, and in European market research, the complete conversion of natural refrigerants has become the mainstream of the European Union; in Japan, the CO2 system made by Panasonic will also be installed in Osaka port. When talking about the CO2 system of
Asian logistics, the general manager of German OEM said that the introduction of R744 technology is a question of whether the technology can be trusted by various manufacturers, and from the perspective of reliable technology, the success of CO2 system in Asian market is "about to be completed"; there are also many trans-critical CO2 systems used in China, especially in North China. The trans-critical CO2 system is used in Beijing’s indoor gymnasium and figured to skating on rink. In addition, three retail stores with trans-critical CO2 system have been added recently. After financial analysis, these systems are expected to save 25% of energy consumption compared with the previous R22 system.

Because of the large difference between high pressure and low pressure during the operation of the system, great throttling loss will occur in the expansion process under trans-critical conditions. This is very harmful to the performance of the system, which is also the reason for the low efficiency of trans-critical CO2, which limits the use of CO2 in refrigeration system. Faced with the phasing out of a variety of refrigerants occupying the market, coupled with many problems of CO2 system, which promote the continuous exploration of scientific researchers. Therefore, this paper reviews the existing research of trans-critical CO2 refrigeration cycle, hoping to provide some guidance for the improvement of the system.

2. Application of trans-critical CO2 refrigeration system in food refrigeration

The use of refrigeration technology in the food industry is an important aspect to ensure the quality of food and maintain a longer shelf life of food. This includes food processing, transportation and sales, etc. The following will describe the application of trans-critical CO2 refrigeration system in the food industry.

2.1. Processing of meat, fruits and vegetables, dairy products and aquatic products

With the gradual rise of trans-critical CO2 refrigeration system, the food industry has shown its positive side after trying to use the system. Its environmental protection and energy saving characteristics, lower refrigeration temperature and other characteristics of the system have attracted more and more attention of the food industry. Tassou [2] introduced a new CO2 trans-critical refrigeration system in the supermarket. The cold end of the system includes dairy products, meat products refrigerators and low-temperature refrigerators. Except for the high cost caused by the main parts not widely promoted, its performance is better than R404A refrigeration system in the actual use process. Danfoss has also reached a cooperation with organic food company Aarstiderne in the direction of using CO2 refrigeration system, and believes that organic food can better reflect the characteristics of energy-saving and environmental protection after using CO2 refrigeration system. Cui et al. [3] experimentally simulated the actual performance of a variety of CO2 supercharged refrigeration systems (full liquid evaporator + parallel compression, mechanical subcooling + parallel compression, full liquid evaporator + parallel compression + mechanical subcooling) in the middle temperature range of 0-4 °C to refrigerate and preserve dairy products, fruits and vegetables in the refrigerated display cabinet, and in the low temperature zone below 18 °C to refrigerate meat and aquatic products. Ahammed et al, [4, 5] use a trans-critical CO2 refrigeration system suitable for pasteurization and cooling of milk in dairy plant was analysed. The performance of CO2 system with ejector was compared with that of conventional CO2 system without ejector. It was found that the ejector and internal heat exchanger (IHX) used between gas coolers increased the productivity by 13%, and the results showed that CO2 system with ejector had more advantages in energy saving the big ones have advantages. Vutukuru [6] uses a solar assisted trans-critical CO2 refrigeration system in the processing of milk in order to achieve the function of heating, cooling and power generation. Bodys et al. [7] studied the refrigeration of aquatic products on ocean going fishing vessels. Using the cooling capacity generated by the trans-critical CO2 refrigeration system, on the one hand, it can cool the catches, on the other hand, it can store ice to further refrigerate the captured aquatic products, and in a warmer climate, there is no need to add an additional compressor.

2.2. Cold chain logistics

Food cold chain has always been a livelihood problem for people. Since the concept was put forward, it
has been in a high-speed development stage. However, the energy efficiency level and environmental protection characteristics of cold chain equipment in logistics still need to be improved. Cold chain logistics is a low-temperature supply chain system integrating refrigeration and logistics [3], which is used to maintain the shelf life of fresh food in the cold chain. According to statistics, about 40% of the food needs to be refrigerated, while 15% of the fossil fuel energy in the world is used for food transportation and refrigeration [8]. With the call of the European Union and the national emission reduction of chlorofluorocarbons, the food protection standard of cold chain is becoming higher and higher. At the same time, the improvement of cold chain can provide more excellent food in sense, which is beneficial to people's safety and health, and also reduces food loss [9].

Cold chain logistics is the main link of cold chain, and it is the key link to ensure the quality of food distribution and transportation. The application of refrigerated vehicles and refrigerated ships is also an important part of cold chain logistics. Refrigerated vehicles are the mainstream tool in land transport cold chain logistics. In 2017, Eurostat released a report "total number of related goods in the reporting countries", which said that by the end of 2016, the total number of refrigerated vehicles in Europe had exceeded 4 million, an increase of 1.6% over the previous year. For a long time, the energy use of mechanical refrigeration in refrigerated vehicles is one of the problems restricting its development. Artuso et al. [10] carried out dynamic modelling of refrigerated vehicle body, analysed its performance, summarized the factors affecting the average refrigeration of refrigerated vehicles, and predicted the next development direction. The research on the thermal drive of trans-critical CO2 refrigeration system by using the waste heat of internal combustion engine is considered as an effective means to improve the energy utilization rate in the transportation process. Liang et al. [11-13] studied a thermal drive refrigeration system based on supercritical CO2 power cycle and trans-critical CO2 refrigeration cycle, which uses the waste heat recovery of engine to realize the preservation and cooling of food in refrigerated vehicles, and is the most efficient. Finally, a new layout of the cooler shared by the two is proposed. The results show that the cycle after sharing one cooler can provide cooling for 105 M2 refrigerated vehicle. The transportation of marine food cold chain has always been a big part of cold chain logistics. The storage life of some seasonal fruits, meat or dairy products at a specific temperature is different. The CO2 system in the ship borne refrigeration system has been a relatively mature system. Hochhaus [14] has made a detailed description of the transportation of marine cold stored food, from the type of equipment on the refrigerated ship to the type of equipment. The development of food transportation by sea is summarized from the aspects of transportation and refrigerated containers. Pigani et al. [15] analysed the refrigeration system performance of several promising low GWP refrigerants under marine working conditions, and considered that CO2 was excellent in all aspects. Yu et al. [16, 17] the technology of combining supercritical CO2 power cycle and trans-critical CO2 refrigeration cycle is applied to the refrigerated ship, and the thermodynamic model is established, and the energy, exergy and economic analysis are carried out. The effects of key parameters such as gas cooler pressure, evaporation temperature and turbine inlet and outlet temperature on the system performance are studied. It is found that under the sea condition, the performance of the system is better at the lower evaporation temperature and the lower temperature. Under high gas cooler pressure, the advantages of IHX are fully used, which is conducive to the utilization of ship waste heat, and lower evaporation temperature has more refrigeration capacities. Xu et al. [18] reviewed the application progress and prospects of three different heat driven refrigeration systems for fishing vessels, summarized and compared the application of adsorption refrigeration system, absorption refrigeration system and jet refrigeration system on fishing vessels, and considered that the stability of adsorption refrigeration system on fishing vessels when using solid adsorbent was concerned, but its COP was relatively low. Due to the compact space, the adsorption bed with high cooling capacity is needed; the COP of the absorption system is high, but the absorption refrigeration system needs a stable free surface, which is sensitive to the fluctuation of the fishing boat, so the small channel heat exchanger and baffle are needed, and the reduction of the heat exchange channel and the addition of baffle will deteriorate the heat exchange performance. However, Bodys et al. [7] also pointed out that the space of fishing boat engine room is insufficient, and new equipment related to the improvement system needs to be further
considered. Moreover, in the design of various systems, the corrosion problem and the influence of ship motion (Marine Environment) also need to be considered [19, 20]. In terms of refrigerated containers, Lawrence et al. [21] studied a trans-critical CO2 Mobile refrigerated container system for military use, and refrigerated containers have been widely used in refrigerated vehicles and refrigerated ships.

2.3. Commercial supermarket

As the last part of the food cold chain, supermarket stores the most refrigerated display cabinets and low-temperature freezers in the world. At the same time, CO2 is also recognized as the most promising working fluid in supermarket application. After a series of development, the trans-critical CO2 refrigeration system for commercial use has become the leading HFC technology [22]. In the research of Gull et al. [23], from two aspects of annual energy consumption and environmental impact, comparative analysis was made on different commercial refrigeration systems. Eight configuration schemes (traditional and improved R744 booster refrigeration system, two R744 booster refrigeration system with mechanical subcooling, a R744 booster refrigeration system with parallel compression and two solutions which combined the parallel compression and the mechanical subcooling) were studied the progress of trans-critical CO2 refrigeration system compared with R744 / R134a cascade system is analysed. Similarly, purohit et al. [24] compared the research results of five kinds of CO2 booster systems (standard booster system (baseline), a booster system with parallel compressor, submerged cryogenic evaporator booster system, expander booster system with power recovery, and a booster system with parallel compressor, submerged evaporator and power recovery) in the commercial supermarket, and evaluated according to the payback period of investment. Which system has the most obvious energy saving potential. These systems also represent the research direction of trans-critical CO2 in the commercial super direction in recent years. In table 1 for details.

CO2 trans-critical refrigeration system has been widely studied in the field of commercial supermarkets, and at present, the research in the field of commercial supermarkets is gradually approaching to the joint direction of commercial supermarkets heating system on the basis of meeting the requirements of refrigerated food. Ge et al. [25] analysed and predicted the seasonal performance of CO2 refrigeration system, and considered that the demand for refrigerated food is very important in summer with high ambient temperature, but in winter with low ambient temperature, the need for continuous output of a large amount of heat in the environment is a more important direction to be considered. Therefore, an 80kwe micro gas turbine trigeneration system was experimentally integrated into the supermarket, and the energy consumption of the system was increased on the basis of meeting the requirements of food refrigeration, more than 90% of electric energy and heating in winter are also solved.

Table 1. Researches on improved technology of trans-critical CO2 refrigeration cycle in supermarkets

| Reference        | Technology                        | Baseline                | Improved     | Direction                  | Year |
|------------------|-----------------------------------|-------------------------|--------------|----------------------------|------|
| FIDORRA et al. [26] | Parallel compression             | R744/R134a cascade      | 0°C 5.9%     | Operating costs            | 2015 |
| TSAMOS [27]      | Parallel compression              | Booster system          | London 3.6%  | Annual energy saving       | 2017 |
| FREDSLUN [29]    | Multi-ejector (equipped with two stage compression) | Parallel compression | UK 10-15%   | energy saving              | 2018 |
| GULLO [30]       | R744/R134a cascade refrigeration system | Similar                |              |                            | 2016 |
| PUCROHIT [31]    | mechanical subcooling             | R404A refrigeration system | Seville 5.7% | Annual energy saving       | 2017 |
| GIROTTO et al. [32, 33] | Plate Type Heat Exchanger       | shell-and-tube heat exchanger | Teheran 8.9% |                            | 2017 |

New Delhi 5.2%  
Structure  
Evaporator capacity
3. **Research on trans-critical CO2 refrigeration system**

Due to the special working condition (high temperature and high pressure) of trans-critical CO2 cycle, there is always the problem of low efficiency, which leads to one of the reasons why the cycle system cannot be widely used. In order to solve this problem, several schemes that have been solved and used in the system will be introduced below.

3.1. **Flash gas bypass**

Flash gas bypass was first proposed to overcome the problem of two-phase flow distribution from header to tube in evaporator. For CO2 refrigeration system, micro-channels are used to bear ultra-high pressure, which makes the gas-liquid distribution problem more serious [34]. After the flash gas bypass is implemented, the steam part of the throttled refrigerant is re-introduced into the compressor to avoid entering the evaporator. In this way, when the refrigerant flows into the evaporator, it presents a complete liquid phase, and the heat absorbed by the refrigerant is significantly increased. The basic circulation diagram of flash gas bypass is shown in figure 1.

![Figure 1. Basic circulation diagram of evaporator with flash gas bypass configuration and flash steam bypass. [1]](image)

3.2. **Parallel compression**

Compared with flash gas bypass, parallel compression uses an auxiliary compressor on the basis of the main compressor to re-compress the throttled flash gas into the gas cooler, which is superior to the use of a single main compressor in performance, and is also a hot spot of recent research. Many researchers believe that [23, 35-37] using an auxiliary compressor can effectively improve the performance of the CO2 refrigeration system. In the refrigeration cycle, the irreversibility of the throttle region is the highest. Gullop et al. [36] observed the experimental data from the perspective of thermodynamics and found that parallel compression can significantly reduce the failure rate of the throttle region. At the same time, gullop et al. [37] think that only using the traditional exergy method will lead to some misleading results. After using the more advanced exergy analysis method for CO2 parallel compression booster refrigeration system, they think that the auxiliary compressor is mainly improved by reducing the irreversibility of other components, especially the components related to gas cooler/condenser. In addition, they [23] also studied the R744/R134a cascade refrigeration system (basic), a R744 booster system with parallel compression and a variety of schemes combining two kinds of parallel compression and mechanical subcooling, and finally comprehensively evaluated the improvement of system efficiency brought by parallel compression. Chesia et al. [38] used the thermodynamic model to analyze the parallel compression cycle with flash steam tank theoretically and practically, and compared it with the CO2 single-stage throttling compression system. Compared with the basic CO2 cycle, the COP value of the ideal cycle can be increased by more than 30%, and the cooling capacity of the system can be increased to more than 65%. The predicted trend of the theoretical parameters is also confirmed in the actual experiment, but the absolute value is low due to the efficiency of the gas-liquid separator and the pressure loss of the system along the pipeline. The results show that the efficiency of gas-liquid separator
decreases with the increase of inlet flow rate. Fritschh [39] compared the energy efficiency of the parallel compression system with that of the flash steam injection system, and proposed in which case the parallel compression system could be used to improve the energy efficiency ratio. Through three key parameters, it is concluded that parallel compression can meet the economic conditions (gas cooler outlet temperature \( > 27.5 \, ^\circ\text{C} \) (including supercritical conditions); evaporation temperature \( < -7 \, ^\circ\text{C} \); the possibility of achieving intermediate pressure up to 45bar) At least 10\% efficiency improvement. Similar to the research of HEJ et al. [40], it is proposed that the parallel compressor is advantageous when the outlet of the gas cooler is at a higher temperature or the evaporation temperature is at a lower temperature. For the diagram of parallel compression cycle in figure 2.

![Figure 2. Schematic diagram of parallel compression cycle. [1]](image)

### 3.3. Ejector
CO2 system usually operates under high exhaust pressure, and large throttling loss will occur in the expansion process of CO2 system to reach the predetermined evaporation pressure under trans-critical conditions [41]. This kind of throttling loss damages the system performance greatly. For this phenomenon, the ejector can effectively recover the expansion work of the system due to throttling loss, and can effectively improve the operation performance of the system [42]. The ejector also has the characteristics of low price, no moving parts and can handle two-phase flow without damage [22]. On the basis of these characteristics, the research on the ejector has attracted the attention of many researchers in recent years. Liu et al. [43] experimentally studied the ejector efficiency in CO2 refrigeration system with ejector, and found that the ejector efficiency depends on the geometry and operating conditions. Based on CFD simulation, Banasiak et al. [42] studied the irreversibility of flow in CO2 two-phase injector, and theoretically simulated the expansion work of the system due to throttling. On the other hand, when evaluating the performance of the ejector, more attention should be paid to the overall geometry of the ejector, rather than optimizing the individual size or shape of a part. In addition, the author also proposed that the traditional ejector with constant geometry cannot accurately control the discharge pressure [44]. Therefore, two control methods have been adopted: one is that Banasiak et al. [44] used multi injector rack (parallel injector) instead of standard high-pressure expansion valve to adjust the discharge pressure of parallel compression system after experimental verification, and practice has proven that this method can easily and accurately adjust the discharge pressure for variable load and environmental conditions; the other is used by [45] the utility model relates to a convergent power nozzle, which has a movable conical needle to adjust the flow areas of the power nozzle and the suction nozzle. The two strategies were compared by Smolkaj et al. [46]. The results show that the efficiency of the ejector with good design of the former is stable in a high range and easy to predict. For the controllable geometry injector, these devices show excellent performance in a certain range. When the throat of the power nozzle is reduced by about 35\%, the efficiency is 25\% higher than that of the fixed geometry. At the same time, however, the authors show that it is difficult
to determine the position of the tapered needle (the insertion distance of the needle) under all operating conditions. According to the technology mentioned above, the main findings of related technologies in recent years are shown in table 2.

Table 2. research of ejector in trans-critical CO₂ refrigeration cycle

| Reference          | Evaluation                                                                 | Findings                                                                                                                                                                                                                                                                                                                                 |
|--------------------|----------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| FANGTIANS(2016)    | Effect of Ejector and Throttle Valve on Performance in trans-critical CO₂    | On the basis of using an ejector instead of a throttle valve, it was found that the exergy loss of the system was reduced and the COP increased significantly. In addition, the ejector ratio has a great influence on the COP of the trans-critical carbon dioxide refrigeration cycle. |
|                    | Refrigeration Cycle                                                       |                                                                                                                                                                                                                                                                                                                                                                                                   |
| CEN (2012) [48]    | Use two ejectors to recover expansion work                                  | Compared with the traditional single-ejector expansion CO₂ cycle, the new double-ejector cycle can recover more expansion losses, thereby further improving system performance.                                                                                                                                                                           |
| BANASIAK(2014)     | The CFD-based numerical simulation analyzes the irreversibility of the flow  | A new factor for evaluating ejector performance is proposed, and the optimization of ejector should be reflected in the entire ejector geometry.                                                                                                                                                                                                 |
|                    | in the ejector in the CO₂ system                                           |                                                                                                                                                                                                                                                                                                                                                                                                   |
| BAI(2015) [49]     | An improved double evaporator and double jet CO₂ supercritical refrigeration | In the dual-temperature refrigeration cycle, the two-stage ejector improves the system performance more effectively than the single-stage ejector, and the increase in the maximum system coefficient of performance (COP) and system (exergy) efficiency is more than that of the single-stage ejector. |
|                    | cycle is proposed.                                                         |                                                                                                                                                                                                                                                                                                                                                                                                   |
| BODYS(2016) [50]   | Simulate the change of the overall efficiency of the ejector when there is  | The use of a vortex generator at the inlet of the power nozzle can improve the efficiency of the ejector, but it is limited to the case of high speed, and the best performance only appears at the inlet of the power nozzle.                                                                                                                                               |
|                    | no vortex generator in the system composed of multiple ejector modules      |                                                                                                                                                                                                                                                                                                                                                                                                   |
| BAI(2017) [41]     | Using energy and exergy analysis methods to evaluate the system performance | The dual jet cycle has higher coefficient of performance (COP) and system (exhaust) efficiency than the single jet refrigeration cycle, and it is proposed that the largest exergy damage of the cycle is the gas cooler, followed by the jet which accounts for 28.9% of the system exergy damage rate. |
|                    | of dual ejector and single ejector refrigeration cycles                    |                                                                                                                                                                                                                                                                                                                                                                                                   |
| HUAI(2017) [51]    | The first expansion valve is used to control the pressure on the high-pressure | Analyze the influence of geometry and working conditions on ejector performance and COP. Under the conditions of constant working conditions, the relationship between the entrainment ratio and the system COP and the conditions of constant geometric parameters, with the increase of the outlet pressure and temperature of the air cooler, the change trend of the entrainment rate and this throttling method Performance comparison with traditional refrigeration system under the above two conditions. |
|                    | side, and the second expansion valve is replaced by a two-phase flow         |                                                                                                                                                                                                                                                                                                                                                                                                   |
|                    | injector to restore the expansion work of the system                       |                                                                                                                                                                                                                                                                                                                                                                                                   |
| PALACZ(2017) [52]  | Introduced the shape optimization of four kinds of carbon dioxide injectors | After considering the six geometric parameters in the optimization process, it is concluded that the shape change trend when the equipment efficiency is |
maximized is similar, and the turbulence intensity of the mixing section is reduced, and the expansion in the mixing chamber is smoother

ZHENG(2017) [53] Using a two-stage evaporator design, by changing the second evaporator chilled water volume flow, ejector area ratio to evaluate the air cooler pressure, mass flow, ejector injection ratio and pressure rise ratio, system cooling capacity and COP, etc. Performance

The reduction of ejector area ratio is beneficial to increase the gas cooler pressure, ejector ejection rate, and system refrigeration capacity and COP. In addition, when the ejector area is relatively large, the increase in the opening of the expansion valve is conducive to the improvement of the ejection ratio

ZHU(2017) [54] A comprehensive experimental study on the ejector performance, pressure rise ratio and efficiency of the trans-critical carbon dioxide injection expansion system under different primary flow pressure, secondary flow pressure and back pressure conditions

A new mass balance coefficient $\beta$ is introduced. As the mass balance coefficient increases, the entrainment ratio and COP both decrease

LI(2019) [55] Using pressure measurement method and direct photography method to observe the axial pressure and internal flow field of trans-critical CO2 ejector under different nozzle divergence angle and secondary flow pressure conditions

The nozzle pressure decreases with the increase of the nozzle divergence angle. When the divergence angle is greater than 2.0°, the primary flow changes from under-expansion state to over-expansion state

HE(2020) [56] Based on the numerical simulation method of the uniform balance model, the analysis of the ejector flow field structure and the local exergy damage distribution reveals the mechanism of the influence of key geometric parameters on the macro performance of the ejector under the overall working condition

The outlet area of the main nozzle, the convergence angle of the premixer and the nozzle outlet position are strongly coupled. The nozzle outlet diameter is the main factor affecting the entrainment process and pressure increase; the nozzle outlet position affects the interaction of the primary and secondary flows of the premixer; The convergence angle of the premixer will affect the interaction of the secondary flow

3.4. Subcooling
In the CO2 refrigeration system, the supercritical fluid at the outlet of the gas cooler enters the expansion device for throttling. This process is affected by the ambient temperature, so the performance of the evaporator is also limited in this aspect. In order to break this limitation, the subcooling device added at the outlet of the gas cooler can effectively improve the efficiency of the system. Nowadays, there are mainly two kinds of subcooling technology widely studied: Thermoelectric subcooling and mechanical subcooling.

3.4.1. Thermoelectric subcooling (Peltier effect). For thermoelectric effect, it mainly uses the principle of Peltier effect to subcool CO2 refrigerant by using the temperature difference generated by adding direct current to semiconductor. Sánchez [57] Under the optimal operating conditions, a thermoelectric subcooling system was used to change the power supply voltage and heat dissipation capacity of thermoelectric module. The COP and cooling capacity of the system were increased by 9.9% and 16% respectively, and it is verified that there is an optimal voltage to maximize COP. Dai et al. [58] proposed a new system of trans-critical CO2 refrigeration cycle combining thermoelectric subcooler with expander. After comparing with traditional compression cycle, expansion cycle (from high pressure to medium pressure), expansion cycle (from medium pressure to low pressure) and thermoelectric subcooling cycle, it was found that installing an expander between liquid storage tank and evaporator could improve the coefficient of performance of the system more significantly, and it is more stable than
other cycles. Astrain et al. [59] proposed a new type of CO2 cycle system with thermoelectric subcooling, which can supply power to thermoelectric modules in the cycle to maximize the efficiency of the system. The results show that compared with the CO2 basic cycle of a small air cooler, the COP of the thermoelectric modules is increased by 20%, and the cooling capacity is increased by 25.6%. Liu et al. [60] proposed a trans-critical CO2 cycle with thermoelectric subcooler and ejector. By optimizing the subcooling temperature and exhaust pressure, a new maximum coefficient of performance was obtained. Compared with the traditional CO2 cycle, CO2 cycle with thermoelectric subcooler and CO2 cycle with ejector, the new cycle has higher COP and lower exhaust pressure. Compared with the basic cycle, its COP is lower 34%, and the exhaust pressure is reduced by 8.01%. A thermoelectric subcooling system proposed by Sánchez et al. [57] was carried out at two ambient temperatures of 25 °C and 30 °C, and the evaporation temperature was maintained at -10 °C, and the power supply voltage and heat dissipation pressure were changed. The experiment confirmed that there was an optimal voltage to maximize COP.

3.4.2. Mechanical subcooling. For mechanical refrigeration, that is, the subcooling at the outlet of the air cooler is especially responsible by another refrigeration cycle, which absorbs the heat from the air cooler in the main cycle to achieve the subcooling. Liu et al. [61] comprehensively analysed four kinds of two-stage compression systems. Taking the common single-stage compression with mechanical subcooling as the reference object, after evaluating the energy performance, evaporation temperature, ambient temperature, exhaust pressure and other parameters, it is considered that the performance of the two-stage compression system with R290 as the working fluid is the best. Dai et al. [62] also proposed a trans-critical CO2 refrigeration cycle combining the mechanical subcooling of the azeotropic mixture with the main cycle, and established the energy model. It was proposed that higher subcooling degree was needed to achieve its optimal operating conditions, so it was applied in hot and warm areas or low evaporating temperature environment. From the perspective of energy performance of refrigeration system, Llopis et al. [63] analysed and discussed the modification of mechanical subcooling to the best working condition of trans-critical CO2 refrigeration cycle, and evaluated the efficiency of improving cycle. Finally, it was found that mechanical subcooling cycle was more powerful for the ambient temperature above 25 °C, and its increment was higher for the ambient temperature at medium temperature.

3.5. Internal Heat Exchanger cycle

The IHX is frequently used in other refrigeration systems, which makes the refrigerant before throttling subcooled and the refrigerant entering the compressor overheated. Although this will lead to the increase of the discharge pressure of the compressor, it is good for some of the refrigerant operating systems. In order to clarify the influence of IHX on CO2 system, Zhang et al. [64, 65] studied the performance influence of the IHX in trans-critical CO2 system and subcritical CO2 system, and proposed that using the IHX in trans-critical CO2 system is beneficial to improve cycle performance, while COP in subcritical CO2 system is slightly reduced. In the study of the IHX, it is found that the change of the flow form of the refrigerant has different effects on the cycle. Specifically, when the exhaust pressure is lower than the exhaust limit temperature of the compressor, the larger the IHX size is, the better, the performance of the countercurrent form is better than that of the downstream form, and the arrangement of the countercurrent form is more convenient [66].

In the traditional trans-critical CO2 reciprocating compression cycle, Rigola et al. [67] used numerical simulation method to study the effect of the IHX on cycle performance. The results show that the COP and cooling capacity of the system are improved after adding the IHX, and it is found that when the temperature rises, the COP of the system increases more: at 35 ° the COP of the system increases by 20%, while at 43 ° the COP of the system increases by 20% The increment of the total cost is between 25% and 30%. This shows that in hot or mild areas, the use of IHX in trans-critical CO2 refrigeration cycle system can provide greater practicability. In the trans-critical CO2 refrigeration system with ejector, the use of IHX also has a positive impact on the system. Nakagawa [68, 69]
compared the performance of ejector refrigeration system with that of traditional expansion refrigeration system with IHX. The results also showed that the performance of the system was significantly improved with the addition of IHX. After using the 60 cm IHX, the COP increment of the system reached 27%.

In the research of Zhang [69], from the perspective of energy efficiency, it is considered that the use of IHX is more suitable for the situation of low isentropic efficiency of ejector, high outlet or evaporation temperature of gas cooler, and there is an optimal entrainment rate of ejector, and the use of IHX can improve the optimal entrainment rate. Purohit [70] conducted data research on the performance of transcritical CO2 refrigeration system with or without IHX from the perspective of energy and exergy. The results show that under different ambient temperature conditions (32℃, 35℃, 40℃ and 45℃), the IHX has more advantages at high ambient temperature. Different from the above, when the evaporation temperature increases, the IHX leads to the decrease of exergy and exergy efficiency down.

4. Conclusion
This paper reviews the latest development of transcritical CO2 refrigeration system technology in recent years and the application of CO2 trans-critical refrigeration system in food refrigeration. It is found that these technologies have broad prospects for the performance and refrigeration capacity of the system. Especially in food refrigeration, more and more companies prefer to use natural refrigerants as working fluids in actual operation, and a large number of practical cases of CO2 system control and sales have emerged. It is believed that the cost of the promoted CO2 system will be reduced to an acceptable level, so that more supermarkets do not need to consider the initial investment of equipment. For the improvement of transcritical CO2 refrigeration system, the research in this paper can provide suitable ideas for transcritical CO2 system in different directions. The main conclusions and future prospects are as follows:

- Flash steam bypass and parallel compression are the same, but parallel compression is an improvement of flash steam bypass. The in-depth study of parallel compression also reflects the importance of flash steam bypass. In the future, it is also considered in the complexity of the system. Due to the increase of initial investment of auxiliary compressor generated by parallel compression, the low cost of its actual operation the measurement between the two is a problem to be considered;
- Ejector is a hot research topic nowadays, but there are many problems, such as its geometry and operating conditions. In addition, simulation software is needed to visualize the internal flow of two-phase flow, especially when there is a lack of research on the nozzle at the refrigerant inlet;
- For the two main ways of subcooling, there have been a large number of research directions, and now the main research direction is to combine with other methods to improve system performance;
- As a method to improve the efficiency of the system, the research of IHX has been very comprehensive. It is also very common to use in transcritical CO2 refrigeration system, and it can be used in this system without doubt. However, it can be seen that IHX is more suitable for use at higher ambient temperature.

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