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Experimental Study of Plate Freezer with the Ejector

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Abstract

This paper introduced a kind of fluid supply system on ejector throttling. Comparing with the fluid supply system of thermodynamic expansion valve，this paper studied two kinds of fluid supply system on the freezing time，overall energy consumption and uniformity temperature distribute. The results showed that, in this working condition, the fluid supply system of ejector is 14% shorter than the thermodynamic expansion valve in freezing time, which reducing the power consumption by shortening the working time of compressor, condenser and other equipment. Meanwhile, Ejector can act like isentropy and recycle some expansion work, which could increase the refrigerant capacity of evaporator to save about 6.3% power consumption compared with the isoenthalpy throttling of thermodynamic expansion valve. The system can reducing 10°C temperature difference by avoiding two-phase flow fluid supply of the evaporator and reduce the flow resistance of refrigerant in evaporator. Thus, the quality of the product is improved.

Keywords: Ejector, Thermal expansion valve, Freezing time, Energy consumption, Uniformity temperature distribute；

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1. Introduction

As the economy develops with speed, energy saving has become one of the significant topic among the field of refrigeration and air-condition. Throughout the researches at home and abroad, we can find that the main cooling energy saving researches focus on the design of refrigeration cycle, the improvement on compressor techniques, the enhancement on heat exchange performance of condenser and evaporator and the new refrigerant, rarely on the throttling. In order to reduce the loss of throttling, scholars around the world have conducted some researches, among which the replacement of expansion valve with ejector is one of the programs with the biggest research value and application prospect [1].

In 1910, Maurice Leblanc proposed ejector used for jet refrigeration system for the first time [2]. It had been used in cooling system driven by low-grade heat source, which is a good way to recycle the waste heat. Internally, the research on this field is comparatively mature [3-5]. But the real application of ejector into vapor compression refrigeration system began in the late 1980s. Lorentzen replaced the throttling valve with ejector, which drives the recycle of refrigerant to enhance the evaporator's performance [6]. Kornhauser had put forward that expansion throttling loss could be recycled by compression/ejection mixed compression refrigeration cycle which can improve the cooling efficiency of refrigeration system [7]. Dopazo and Seara used two ejection in the NH3/CO2 cascade plate freezing to achieve the goal of energy saving through increasing the fluid recirculation rate to more than 3 as evaporation temperature rises [8-9]. Minetto and other experts applied the double fluid supply by ejector into air conditioning system and studied the temperature distribution of evaporator. The results suggest that ejection could adapt itself to variable working condition [10].

At home, Fuzhou refrigration equipment company had put forward the idea of single-stage compression plate frezzer fed by ejector in 1992 [11]. And the plate freezer improves constantly based on experiments. The liquid in the single-stage compression refrigeration system is provied by ejection, which could enhance the cooling effects of evaporator and reduce freezing time by the increasement of mass flow rate of refrigerant in the plate evaporator caused by the advancement of ejecting coefficient and multiplication rate.

The research team authorized invention patent "a fluid supply system of ejector throttling" in 2015 [12], which could recycle some expansion work and raise the pressure of compressor. Thus, the system could make the evaporator supply double fluid without circulation liquid pump and its power consumption. The patent theoretically analysis the feasibility, but the energy-saving features of the ejector have not yet publish experimental data.

2. Description of the chiller system and data envelopment analysis

2.1. New system

Based on the features of ejector to reduce throttling losses and eject low pressure, patent proposes a new fluid supply system of ejector throttling by figure1. Vapor-liquid separator 1 could make the vapor in the refrigerant two-phase flow from ejector back into compressor through middle vapor suction mouth and the fluid in the refrigerant two-phase flow from ejector into evaporator.

The present invention patent has the following advantages: 1. It could make the vapor in the refrigerant two-phase flow back into compressor directly, which avoid the waste of refrigerant vapor obtained the expansion work. 2. It could achieve that the pure liquid refrigeration flow into the evaporator, which reduce the flow resistance of the two-phase refrigerant in the evaporator and improve the heat exchange efficiency. 3. The system could make the evaporator supply double fluid without circulation liquid pump and its power consumption. 4. Simple structure, easy application, which can be used in various forms of air conditioning, refrigeration and cryogenic systems to save energy.

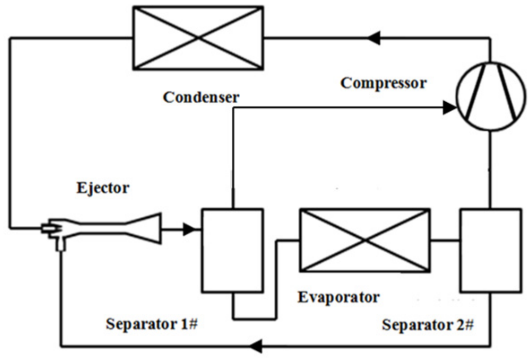


Fig. 1. schematic diagram of ejector system

However, due to the difficult compressor manufacturing process of the center suction mouth, it is hard to find this kind of compressor among the market. This experiment chooses the system of Figure 2 which has no center air suction mouth different form Figure 1. The refrigerant vapor from vapor-liquid separator 1 is decompressed by valve and sucked by the compressor when it mixed with the refrigerant from vapor-liquid separation 2. By this way, the expansion work from the vapor cannot be used, but it lowers the requirements on the compressor and cuts the cost.

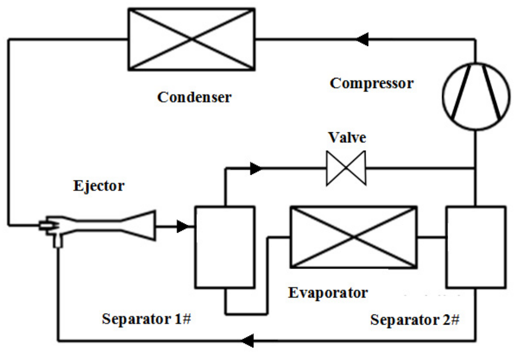
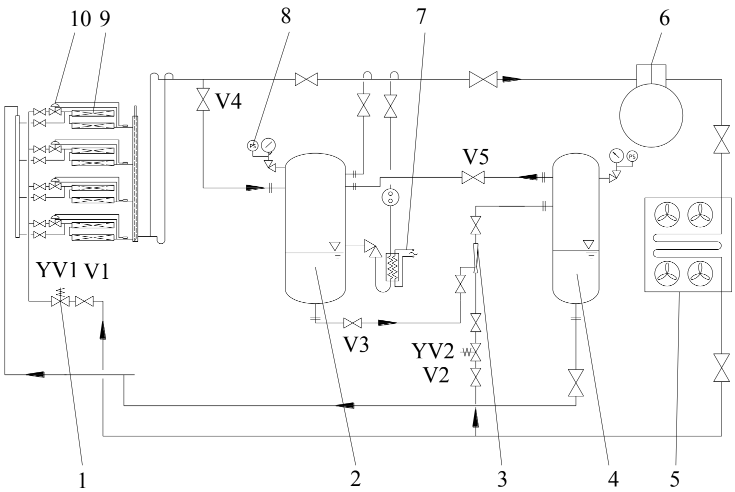


Fig. 2. schematic diagram of ejector system (compressor without centre suction mouth)

2.2. Experimental device

According to the design theory, this paper set up a experimental table for fluid supply system of ejector throttling. It will study the influence of two fluid supply systems namely thermodynamic expansion valve and ejector, on the energy consumption, uniform temperature distribution and freezing time. The experiment on ejector takes R22 as working medium, and the two fluid systems are in parallel illustrated by Figure 3.



1-Electromagnetic valve 2-Seperator 2# 3-Ejector 4-Seperator 1# 5-Condenser 6-Compressor
7-Oil return heater 8-Pressure sensor 9-Plate freezer 10-Thermodynamic expansion valve

Fig. 3. schematic diagram of two fluid supply systems

Plate freezer adopts the PA/PF aluminum alloy plate freezer with the freezing capacity of 420~500kg per time, 25 m2 effective evaporation areas made by Nantong Sinrofreeze Equipment Ltd. Compressor uses S6F-30.2-40P Bitzer reciprocating double-stage compressor whose double-stage gas displacement is 101.4 m3/h. Condenser employs Bitzer FNH-1.2/4 air-cooled condenser. Throttling valve applies Danfoss TX2-068Z3209 thermodynamic expansion valve which could be used in low-temperature device for its evaporation temperature range is from -60°C to 50°C。

The core of this whole jet experiment is the ejector composed of nozzle, nozzle connecting pipe, suction chamber and diffusion chamber. Its main geometric sizes are shown in table 1 below.

Table 1. The main geometry of ejector

Minimum diameter of nozzle	5.06mm
Inlet diameter of nozzle	20mm
Diameter of suction chamber	40mm
Length of the mixing chamber	216mm
Diameter of mixing chamber	18mm
Length of the diffuser chamber	180mm
Angle of the diffuser chamber	16°

In the experiment device of measurement system, T-thermocouple is applied in temperature sensor achieving the ±0.5°C accuracy; the model of electric comprehensive analysis tester is DZFC-1 with the 1.0 Class power measurement accuracy. Temperature recorder is Agilent 34980A which can record date per ten seconds.

2.3. The starting and operation of the experimental table

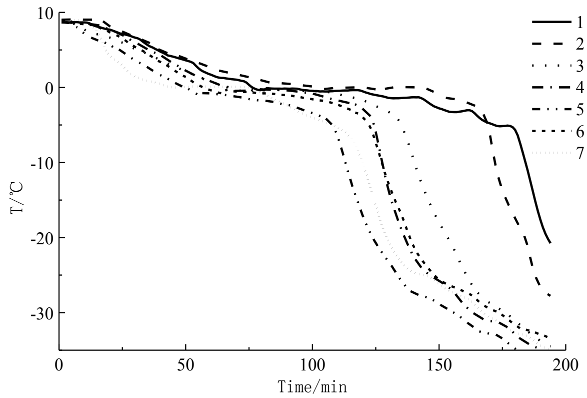
This experiment is conducted in Shanghai for two continual days when the outdoor temperature is stable at 8~12°C. The subject used for freezing simulation is the sponge fully absorbing water and the surface could perfectly touch the surface of the up and below panel, which could reflect the actual condition of heat transfer. 6 trays are placed on every layer of plate which holds about 12.5kg sponge containing water. There are 7 layers with 42 trays in total weight up to 500kg. The initial temperatures and the weight of the two experiments are almost kept in the same level. Besides, the test points to measure the temperature of the products are chosen in the center of the sponge on very layer, 7 layers in total from the top.

a. The fluid supply system of thermodynamic expansion valve including compressor, condenser, plate freezer and thermodynamic expansion valve is applied in this experiment. First, turn off V2, V3, V4 and V5 valve shown on Figure 3. Second, turn on V1 valve (the other valves without directions are kept on) and start the power supply keeping the machine works normally. The refrigerant from condenser will be supplied to the plate evaporator for the cooling capacity needed after being throttled by the thermodynamic expansion valve. Consequently, refrigerant vapor are sucked by the compressor for circulation. When the temperatures of al test points reach -18°C, the experiments is completed. Then turn off the power.

b. The fluid supply system of ejector throttling including compressor, ejector, plate freezer, vapor-liquid separation circulation barrel and vapor-liquid separation fluid supply barrel is applied in this experiment. First, turn off V1 valve. Second, turn on V2, V3, V4 and V5 valve (the other valves without directions are kept on) and start compressor to make the machine work normally. After a period of time, Vapor-liquid separator 2 liquid refrigerants will be sucked back by the ejector and be supplied in cycle to evaporator after the Vapor-liquid separator 1. When the temperatures of al test points reach -18°C, the experiments is completed. Then turn off the power.

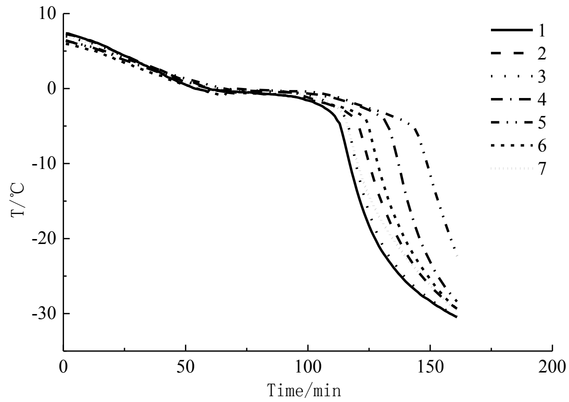
3. Results and discussion

Figure 4 and Figure 5 shows that the freezing curve graphs of the products by applying thermodynamic expansion valve and ejector fluid supply modes respectively. The initial temperatures of freezing products are about 8 °C, when the center temperature dropped to 18 °C, the experiment is over.



1 ~7 indicate temperature measuring point of each plate

Fig. 4. the freezing curve graphs of thermodynamic expansion valve



1 ~7 indicate temperature measuring point of each plate

Fig. 5. the freezing curve graphs of ejector system

By comparing two different ways for freezing curve, this paper analyses the freezing time, the total energy consumption, maximum temperature difference when frozen products is complete and unit power consumption in table 2.

Table 2. The freezing performance of two fluid supply system

Project / Fluid supply	Freezing time (min)	Energy consumption (kW·h)	Max temperature difference (°C)	unit power consumption (kW·h)
Thermodynamic expansion valve	190	63.2	20	0.126
Ejector	163	59.2	10	0.118

In terms of freezing time, the fluid supply system of ejector is 14% shorter than the thermodynamic expansion valve. This is because in the fluid supply system of ejector, the supply flow of refrigerant is much larger than the amount of evaporation and the inner surface of the plate is fully wetted, which enhancing the convective heat transfer of the refrigerant side, thereby increasing the heat transfer efficiency and shorten freezing time. At the same time, the freezing curve graph of Figure 5 is more centralized than that of Figure 4, which shorted the maximum temperature difference between freezing products and be more advantageous to the improvement of the product's quality.

In addition, the results shows that the fluid supply system of ejector saves about 6.3％ total energy consumption compared with thermodynamic expansion valve and its unit power consumption is minimal. The fluid supply system of ejector could provide evaporator with double fluid, as a result, heat transfer coefficient rises significantly and heat transfer temperature difference drops substantially, which could cut the irreversible loss and save the freezing time. In addition, it reduces the power consumption by shortening the working time of compressor, condenser and other equipment. Meanwhile, the ejector can recover part of the expansion work, thereby further improving the cooling capacity of the evaporator.

4. Conclusions

Under the same operating conditions, the fluid supply of ejector systems has large refrigerant flow and high flow rate, which prompting the refrigerant pipe wall with a fuller contact and enhancing heat transfer, thus freezing time is 14% shorter than the thermodynamic expansion valve.

Ejector can act like isentropy and recycle some expansion work. Meanwhile, it reduces the power consumption by shortening the working time of compressor, condenser and other equipment, which could increase the refrigerant capacity of evaporator to save about 6.3% power consumption compared with the isoenthalpy throttling of thermodynamic expansion valve.

The system can make full use of heat exchange area of the evaporator, lower the product temperature in a close pace reducing 10°C temperature difference by avoiding two-phase flow fluid supply of the evaporator and reduce the flow resistance of refrigerant in evaporator. Thus, the quality of the product is improved.

Ejector shares many advantages, such as simple structure, no moving parts, low cost, safe operation and convenient installation and maintenance. It could be applied in any flow pattern including two-phase flow, and there is no increment on the system complexity but the improvement on system performance when it is used in refrigeration cycle.

The results of the experiment suggest that it is feasible to adopt the fluid supply system of ejector into the refrigeration system of plat freezer. It would have a brighter future if there is an improvement and enhancement on its system design, mating auxiliary machinery, ejector serialization and automation.

Acknowledgements

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