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# Research on Vapor-injected Rotary Compressor through End-plate Injection Structure with Check Valve

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## ABSTRACT

The refrigerant injection technology can improve the performance of heat pump in low ambient temperature. Traditional end-plate injection of rotary compressor controls the injection by the rotation of the piston, which leads to some drawbacks, such as small injection area and bad adaptability to variable working condition. By adopting a check valve system, a novel end-plate gas injection structure for rotary compressor had been put forward to increase injection port area and enhance the adaptability to variable working condition in previous research. In this paper, a vapor-injected rotary compressor prototype is manufactured and tested compared to single-stage and two-stage rotary compressor. The experimental results indicate that the vapor-injected compressor can enhance the heating capacity by 23.8~42.3% and COP by 4.0~11.8% compared to single-stage compressor. Furthermore, the influence of the parameters of the injection port are researched based on a numerical model verified by experimental results. The results show that the smaller injection port may decrease the power consumption obviously and increase COP, but has little effect on the heating capacity. So, there is an optimal injection port for the end-plate injection with check valve.

Keywords: rotary compressor, end-plate injection, heat pump, low ambient, large compression ratio

## 1. INTRODUCTION

Considerable technologies have been used to improve the performance of heat pump in low ambient temperature, such as two-stage compression, variable speed compressors, and economizer technology. For the cylinder rotary compressor, the single cylinder rotary compressor with the economizer has attracts much attention because of its low cost and high adaptability. There are three kinds of vapor injection technologies used in single cylinder rotary compressors depend on the location of injection port, which called end-plate injection technology, cylinder injection technology and blade injection technology.

For the end-plate injection, the injection port is opened on the end-plate. The start and end of the vapor injection is controlled by the motivation of the rolling piston. Previous research indicates that the limited injection port area, too early or too late closure of the injection port under different working conditions are the essential reasons to limit the performance improvement of the end-plate injection technology (Wang et al.,2018). For the cylinder injection technology, the injection port is settled on the cylinder near the discharge port. However, inevitable back flowing of injected refrigerant heavily weakens the improvement of gas injection (Liu et al., 2016). To avoid the refrigerant's back-flowing and enhance adaptability to working conditions, a novel end-plate injection with check valve is put forward in previous research (Wang et al., 2018). The simulated results indicate that the novel end-plate injection structure can increase the heating capacity and COP by 12.5~18.2% and 0.8~3.5%, respectively.

In this paper, a rotary compressor prototype with novel end-plate injection structure is manufactured based on the injection port design principles purposed in the previous research and its performance is studied by experiments. Furthermore, a preliminary optimal research on injection port are conducted by simulation.

# 2. COMPRESSOR PROTOTYPE AND TEST BENCH

## 2.1 Rotary Compressor Prototype

A rotary compressor prototype is designed and produced based on the injection port design principles which avoid the refrigerant's back-flowing completely and enlarge the area of injection port as soon as possible (Wang et al., 2018). But for the actual end-plate injection structure, the inner and outer injection boundaries reserve some margin for insurance. The injection port is closed by four arcs for the convenience of manufacture, which is shown as Fig.1. The total area of the injection port is 21.0 $mm^2$ and suction volume is 30.5 $cm^3$.

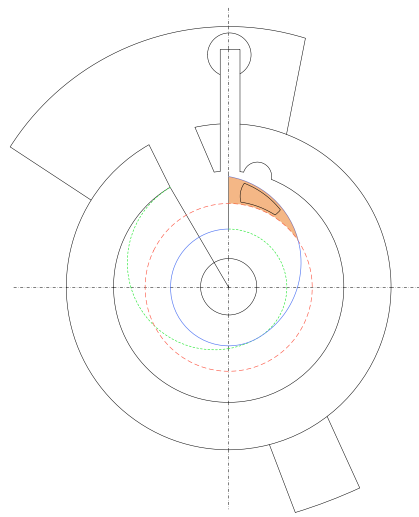

**Fig. 1:** Injection port on end-plate of compressor prototype

To avoid the refrigerant's back-flowing, a check valve is installed behind the injection port. A lift limiter milled on the end-plate in front of the check valve to control the valve's deformation. To ensure the rolling piston's safety, an intermediate smooth plate is installed between the end-plate and cylinder. When the injection pressure is higher than the pressure in the compression pocket plus spring force of the check valve and the injection port starts to appear, the check valve is open and the injected refrigerant flows into the cylinder. If the injection pressure is lower than the compression pressure plus the spring power of the valve, the check valve will rebound and the injection has to be stopped. So the new end-plate injection structure has a better adaptability to variable conditions.

## 2.2 Test Bench

Fig.2 presents schematics of the test bench, which chooses flash tank as the economizer because flash tank is confirmed to have better performance than intermediate heat exchanger (Nguyen et al., 2007). The tested vapor-injected rotary compressor works in the environment chamber shown as the blue box in the Fig 2. The temperature of the environment chamber is controlled by a cooling system and a resistance heater. The temperature of the condenser is controlled by a water loop which has the constant temperature. When the vapor-injected compressor or two-stage compressor is tested, the subcooling refrigerant flows into the first passage which has two expansion valves and a flash tank. The refrigerant is throttled twice on this passage and the injected vapor is generated in the flash tank. The other passage which only has an expansion valve is used to test single-stage compressor. The evaporator is installed in a secondary refrigerant calorimeter. In the test, the evaporating pressure, the condensing pressure and the superheated degree of suction gas are controlled. The working conditions shown in the Table 1.

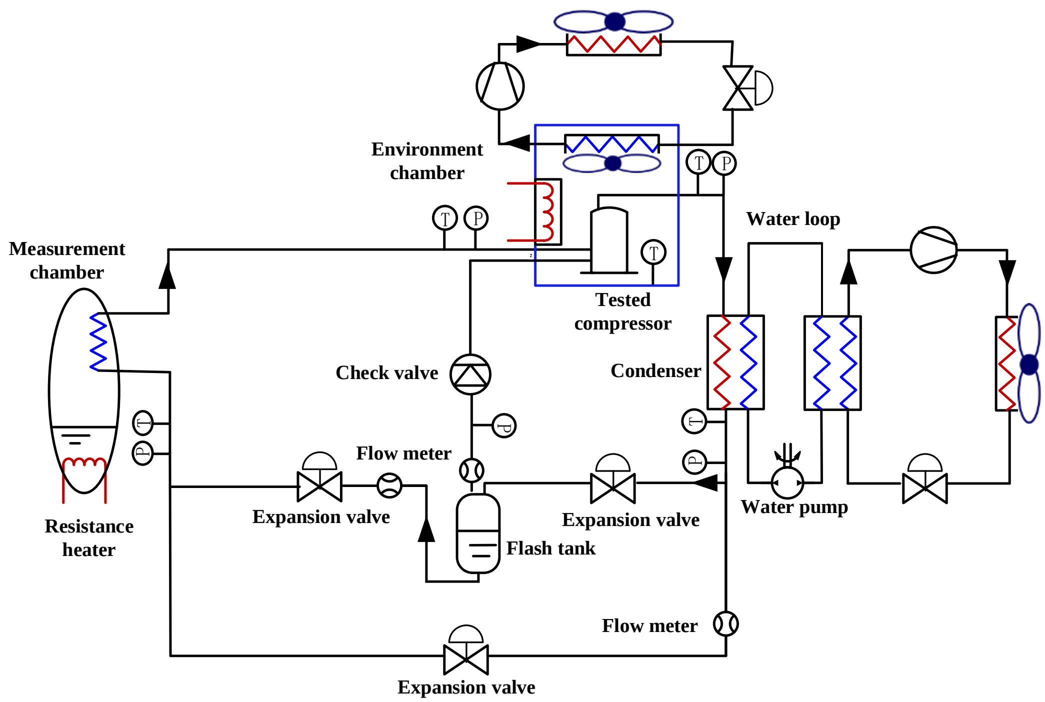


**Fig. 2:** Schematic of the air conditioner system experimental bench

**Table 1:** Test conditions

| Evaporating temperature (°C) | Condensing temperature (°C) | Suction gas temperature (°C) |
|---|---|---|
| -15, -10, -5, 0 | 45 | 15 |

## 3. EXPERIMENTAL RESULTS

### 3.1 Heating Capacity

In order to identify the effects of the new end-plate injection, a common single cylinder compressor and a two-stage dual cylinder compressor with same (first-stage) suction volume are also been tested. Fig. 3 shows the heating capacity $Q_c$ of the three rotary compressors. As the evaporating temperature increases, heating capacity of all of three kinds of compressors increase. For the three kinds of compressors, two-stage compressor has highest heating capacity and single-stage compressor has the lowest one. The two-stage compressor and new vapor-injected compressor can enhance the heating capacity of the air conditioner for 27.6~50.9% and 23.8~42.3% compared to the regular single-stage compressor, respectively. The heating capacity enhancement compared to single-stage compressor decreases with the increase of evaporating temperature of the two kinds of compressors. The results show that the vapor-injected has a competitive potential for the application in cold regions.

### 3.2 Power Consumption

The comparison of power consumption $W_c$ of three kinds of compressors is shown in the Fig.4. It is obvious that, with the increase of the evaporating temperature, the power consumption of the three kinds of compressors increase. The increasing refrigerant mass flow rate results in the energy consumption's increase. Moreover, the power consumption of single-stage compressor is smallest because it has the smallest refrigerant mass flow rate. The vapor-injected compressor and two-stage compressor increase the power consumption compared to single-stage compressor by 19.0~27.3% and 23.6~29.4%, respectively. The power consumption of rotary compressor with novel end-plate injection structure is close to that of two-stage compressor.

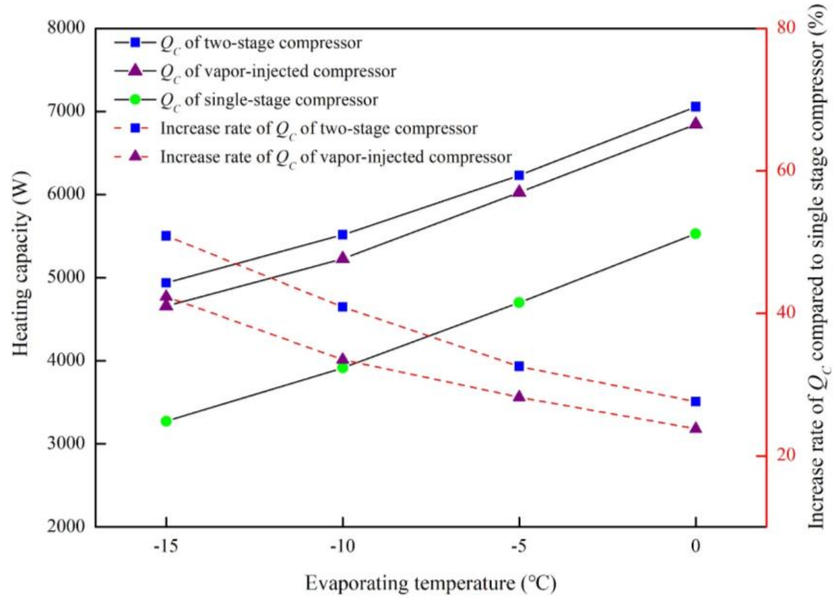


**Fig. 3:** Heating capacity of different compressors under different working conditions

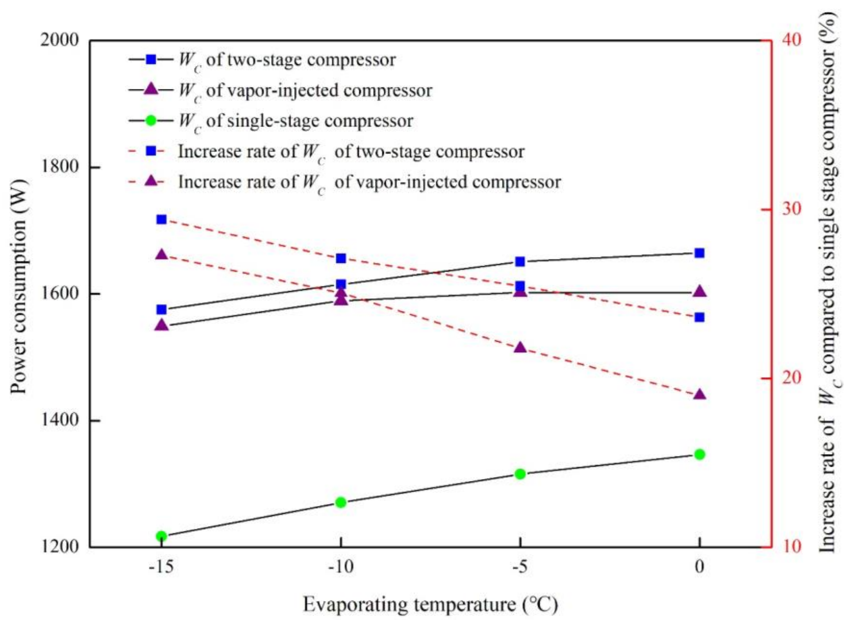


**Fig. 4:** Power consumption of different compressors under different working conditions

## 3.3 COP

Fig 5 shows the variations of the COP of three kinds of compressors. In the low temperature conditions, especially when the evaporating temperature is lower than -5℃, the two-stage compressor has the highest COP and the single cylinder compressor has the lowest COP. Two-stage compressor and rotary compressor with novel end-plate injection structure have 3.2~16.6% and 4.0~11.8% higher COP compared to the single-stage compressor. The lower the evaporating temperature, the greater the COP superiority. With the increase of evaporating temperature, the COP gap between two-stage compressor and single cylinder compressor with novel end-plate injection structure is getting smaller and smaller. When the evaporating temperature is higher than -5℃, the COP of the vapor-injected rotary compressor is higher than the two-stage rotary compressor. That indicates that the new vapor injected rotary compressor has greater potential for large range variable working conditions.

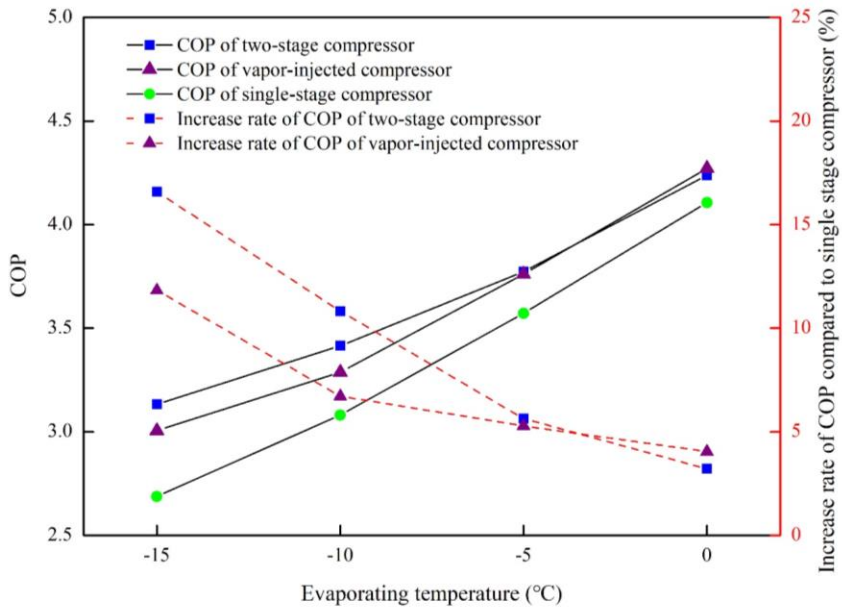


**Fig. 5:** COP of different compressors under different working conditions

## 4. PRELIMINARY OPTIMIZATION OF INJECTION PORT

According to the experimental results, the vapor-injected compressor can enhance the heating capacity significantly but the power consumption also increases obviously. The injection port and installation platform which undertakes the lift limiter and check valve increase the back-pressure volume, which explains the increased power consumption of the vapor-injected compressor. The back-pressure volume can be decreased by the optimization of the injection port and check valve. In order to investigate the influence of injection port and back-pressure volume on the performance of compressor, a validated distributed-parameter rotary compressor model is used (Wang et al., 2017).

Different location and shape of the injection port results in different back-pressure volume and different injection area, which effects the performance of compressor. As the rolling piston rotates around center of the cylinder, the area close to the outer boundary appears firstly. The earlier the injection area appears, the bigger the pressure difference between the injection pressure and pressure of compression chamber, which is good for the increase of injected refrigerant. The different injection ports for research are shown as Fig.6. The radius of inner boundaries and injection area are presented in Table 2.

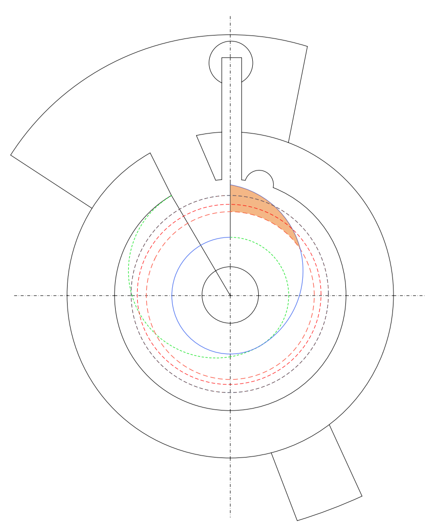

**Fig. 6:** Different inner boundaries of injection ports

**Table 2:** Areas of different injection ports

| No. | Radius of inner boundary (mm) | Injection Area ($mm^2$) |
|---|---|---|
| 1 | 20 | 111.4 |
| 2 | 22 | 61.8 |
| 3 | 23.5 | 20.1 |
| 4 | 24 | 5.8 |

## 4.1 Heating Capacity

The heating capacity of compressors with different injection port are shown in Fig.7. With the increase of evaporating temperature, the heating capacity goes up as usual. Except compressor 4, the difference of heating capacity of compressors with different injection port is quite small. Compressor 4 has the smallest heating capacity because it has the smallest injected refrigerant mass flow rate. When the injection port area is bigger than 20.1mm$^2$, the mass flow rate will not increase significantly.

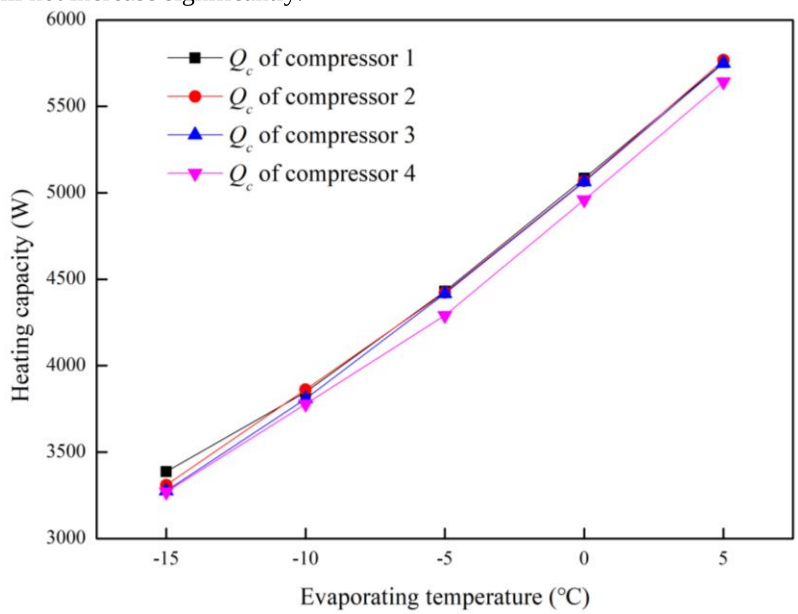


**Fig. 7:** Heating capacity of different vapor-injected compressors

## 4.2 Power Consumption

The power consumption of compressors with different injection port are shown as Fig.8. The power consumption of compressor 4 with injection area 5.8 mm$^2$ decreases by 8.6~18.26% compared to the compressor 1 and 4.38~7.48% compared to compressor 3.

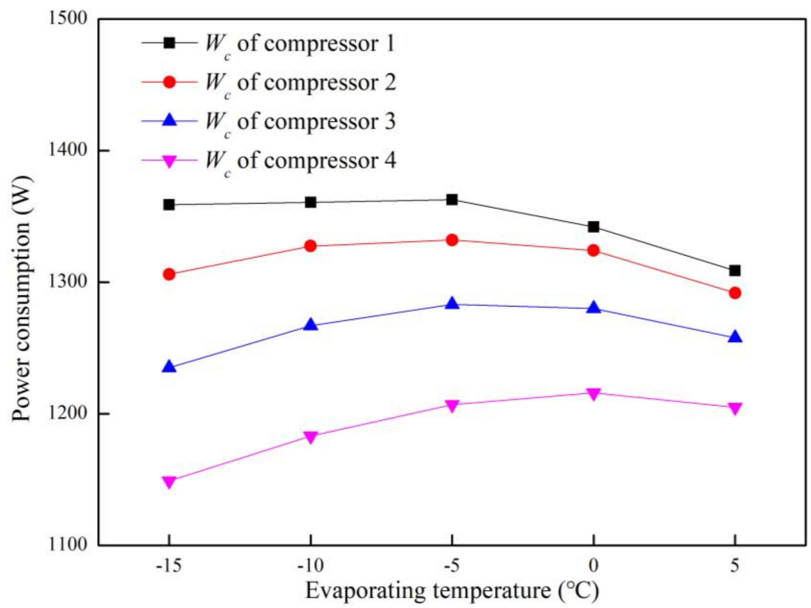


**Fig. 8:** Power consumption of different vapor-injected compressors

## 4.3 COP

Fig.9 represents the COP of different compressors. The tendency shows that a smaller injection port area can increase the COP. The compressor has the biggest injection port has the lowest COP. Compared to compressor 1, compressor 4 which has the smallest injection port area and back-pressure volume can enhance the COP by 6.6~14.1%. That means the maximum capacity and maximum COP could not be obtained at the same time. The optimization of the injection port should be conducted for the specific application.

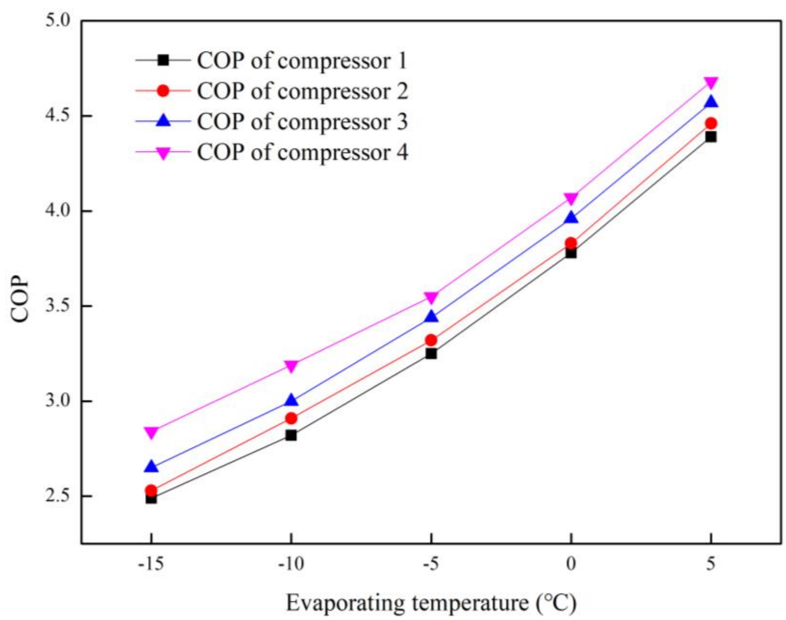


**Fig. 9:** COP of different vapor-injected compressors

## 5. CONCLUSIONS

A vapor-injected rotary compressor prototype with new end-plate injection structure is manufactured and tested. Then influence of the injection port on the compressor's performance is further studied by a numerical model. The experimental and simulation results indicate:

(1) The vapor-injected rotary compressor with new end-plate injection structure has the competitive performance with two-stage rotary compressor under heating conditions.

(2) Compared to the single-stage compressor, the new vapor-injected compressor can enhance the heating capacity and COP by 23.8~42.3% and 4.0~11.8%, respectively.

(3) The maximum capacity and maximum COP could not be obtained at a fixed injection port. The optimization of the injection port should be conducted for the specific application.

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