

Performance improvement of air source heat pump by using gas-injected rotary compressor

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Abstract. Rotary compressor is most widely used in small capacity refrigeration and heat pump systems. For the air source heat pump, the heating capacity and the COP will be obviously degraded when it is utilized in low temperature ambient. Gas injection is an effective method to enhance its performance under those situations, which has been well applied in air source heat pump with scroll compressor. However, the development of the gas injection technology in rotary compressor is relatively slow due to limited performance improvement. In this research, the essential reason constraining the improvement of the gas injection on the rotary compressor and its heat pump system is identified. Two new injection structures for rotary compressors has been put forward to overcome the drawback of traditional injection structures. Based on a verified numerical model, the thermodynamic performance of air source heat pumps with the new gas-injected rotary compressor are investigated. The results indicate that, compared to the air source heat pump with the traditional gas injected rotary compressor, the new injection structures both can enhance heating capacity and COP of the air source heat pump obviously.

1. Introduction

Rotary compressors have been widely applied in small capacity air conditioners and heat pumps due to its advantages such as high efficiency, low cost and high reliability. In 2014, more than 100 million rotary compressors have been produced in China. However, the rotary compressor will face the substantial performance degradation when it is adopted in air source heat pump (ASHP) working in low temperature ambient, just like the scroll compressor encountered in light commercial applications. The heating capacity and COP will quickly decrease with the descending of the outdoor temperature, which has become a main technical barrier restraining the further application for ASHP in cold region. Aiming at the problems, many solutions have been proposed for the scroll compressor and the screw compressor, such as cascade cycle, two-stage compression, vapor injection, and so on. Previous many investigations confirmed that the vapor injection technology can improve the heating capacity and COP in low ambient temperature by enhancing the refrigerant mass flowrate and decreasing the under compression loss [1-3]. Consequently, the vapor injection technology has been widely adopted in scroll compressor currently due to both its technical and economic effectiveness.

For rotary compressors, the two-stage compression has been used for years [4, 5]. But different from the traditional two-stage compression system using two separated compressors, the two compression cylinders of rotary compressor always are installed in one shell and through the same crankshaft, which is called twin-cylinder rotary compressor. The twin-cylinder structure solves a lot of critical operation problems two-stage compression system encountered when two separated single-cylinder rotary compressors are adopted, such as easier oil balance, lower noise and vibration due to



more balanced structure. However, it has been proved that the performance of the twin-cylinder rotary compressor is lower than the single-cylinder one under the temperate working conditions [6], such as low compression ratio air conditioning working condition, because of twice discharge loss and fixed volume ratio of two cylinders. As a result, the vapor injection in single cylinder, instead of the two-stage compression, was considered in rotary compressors to realize higher thermodynamic performance both in wild and mild ambient. Besides, compared to the twin-cylinder rotary compressor, the single-cylinder rotary compressor has lower cost, better reliability, and smaller size.

In this paper, the drawbacks of traditional injection structures of rotary compressor are analyzed, two kinds of new injection structures for rotary compressors are developed, and finally their thermodynamic performance are investigated.

2. Drawbacks of traditional injection structures of rotary compressor

According to the different position of the injection port, the single rotary compressor has two types of traditional injection structures, the cylinder injection, in which the injection port was opened on the cylinder, and the end-plate injection, in which the injection port was opened on the end-plate. Apparently, for the cylinder injection, when the rolling piston rotates after the injection port, the injection port will connect to the suction pocket, which results in the injected refrigerant gas was injected into the suction pocket and it will flow back into suction tube as Figure 1(a). The back-flowing refrigerant will largely decrease the mass flowrate of suction, and finally weakens the performance enhancement by gas injection. Previous research [7] showed that 23.3%~29.3% injected refrigerant flowed back into the suction tube and the heating capacity of single-cylinder rotary compressor with traditional cylinder injection is only 5.6%~14.4% higher than the common single-cylinder compressor, which is obviously lower than the 20%~25% improvement of twin-cylinder rotary compressor over the common single-cylinder one. That could be the main reason why the twin-cylinder rotary is more widely used than the gas-injected single-cylinder in low temperature ASHP.

For the end-plate injection, the location of the injection port are diverse. Figure 1(b) shows one of the typical location. It's easy to find that the back-flowing of the injected refrigerant still existing in that end-plate injection structure, and the negative effect is even more serious due to a longer back-flowing time span compared to the cylinder injection.

As a conclusion, developing gas injection system without back-flowing for rotary compressor is quite important for pursuing high heating performance.

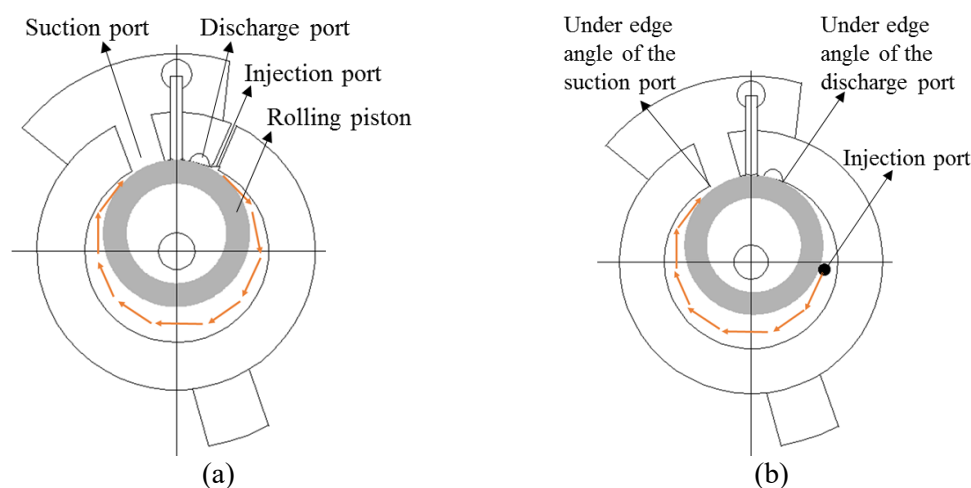


Figure 1. Traditional injection structures for single rotary compressors: (a) cylinder injection structure; (b) end-plate injection structure.

3. Blade injection structure and its performance

A novel injection structure is proposed in Figure 2, in which the injection passage is screwed in the middle of the blade and the injection port is opened oriented to the discharge port. The new injection structure also need to mill a platform on the blade where the spring valve plate and the lift limiter are installed.

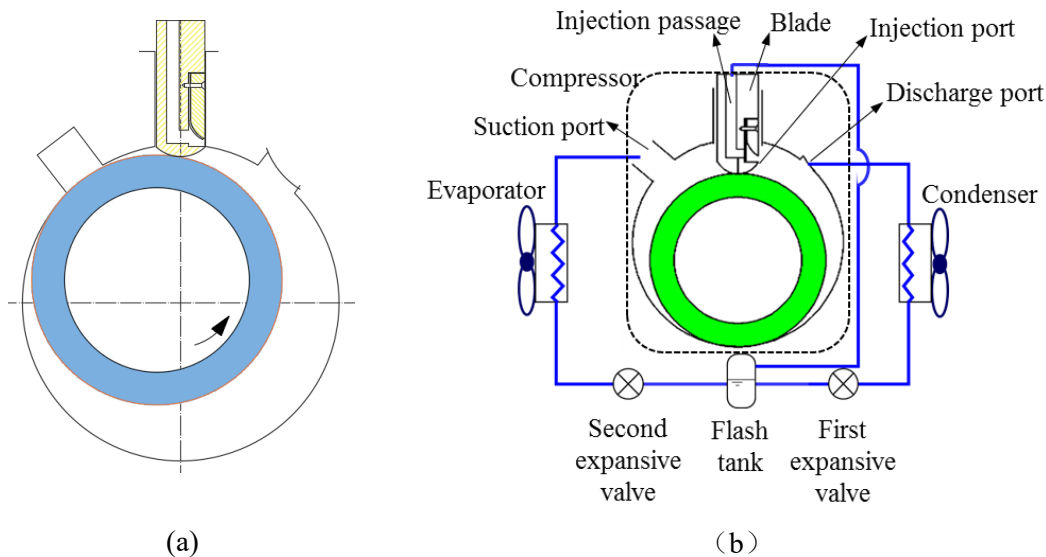


Figure 2. Rotary compressor and ASHP with blade gas injection: (a) compressor; (b) ASHP.

The detailed working process of the rotary compressor with the new injection structure can be explained as following. Before the suction pocket is isolated from the suction tube, the blade don't protrude enough and the injection port is still sealed by the wall of the blade house. Under the press of the spring valve, the injection port is closed, and the injection process does not start. When the suction pocket is isolated from the suction tube, the suction process finishes. At the same time, the blade moves down where the lower edge of the injection port exactly reveals, the injection port connects to the compression pocket and then the spring valve plate opens as the injection pressure is greater than the compression pocket pressure, starting injection. With increase of the rotation angle and increase of the compression pocket pressure, as the compression pocket pressure equals the injection pressure, the spring valve plate closes and the injection process ends. Hereafter, the rolling piston rotates to the bottom center, the initial discharge and the end of discharge, respectively. The injection spring valve plate keeps close.

Therefore, the rotary compressor with the blade injection structure can totally avoid the back-flowing of the injection refrigerant into the suction tube. At the same time, it can achieve injection at the first time when the suction process finishes, and so it can achieve the maximum of injection mass flow. Moreover, the volume between the injection port and the spring valve plate at the injection structure has no influence upon the volumetric efficiency. Because the volume does not connect to the suction tube, it has no influence on the compressor suction mass flow-rate from the suction tube.

Based on a validated model [8], the performance of the ASHP with blade gas injected is compared with the traditional cylinder injection structure.

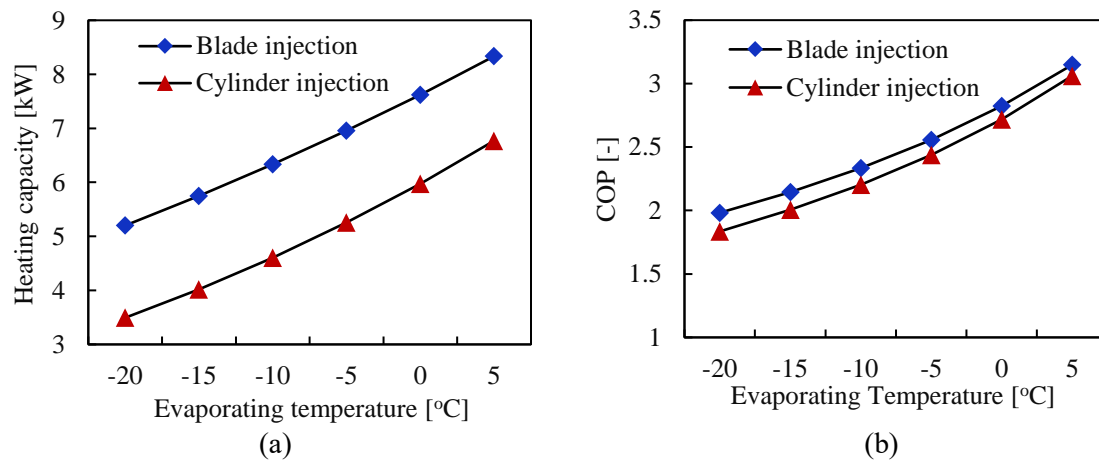


Figure 3. Performance improvement of ASHP by blade gas injection compared to the traditional cylinder injection: (a) heating capacity; (b) COP.

Figure 3 shows the heating capacity and COP of a rotary compressor different working conditions. Comparing to the rotary compressor with traditional cylinder injection structure, the heating capacity and COP of the rotary compressor with the blade injection structure are enhanced by 23.1~48.9% and 3.2~8.0%, respectively. That means the rotary compressor with the new injection structure can solve the degradation of the heating capacity and COP in low ambient temperature to a large extent.

4. No-back-flowing End-plate injection structure and its performance

Apparently, the back-flowing of injected refrigerant is inevitable for the cylinder injection structure because the gas injection port must lower than the discharge port. But for the end-plate injection, the conclusion is not so sure. Firstly, the research attempts to analyze the possible location without back-flowing and the size of the injection port for the end-plate injection.

According to the rotation mechanism of the rolling piston, the necessary and sufficient conditions for the end-plate injection structure avoiding the refrigerant gas back-flowing the suction tube completely are: (1) the injection port cannot connect with the inner circle of the rolling piston at any time to avoid large influence on the compression work and lubricant performance, which mathematically means the injection port should NOT be set in the union set of inner circle of the rolling piston at all rotating angle; (2) the injection port cannot connect with the suction pocket at any time, which mathematically means the injection port should NOT be set in the union set of the suction pocket at all rotating angle; (3) the injection port connects with compression pocket at some time, which mathematically means the injection port must be set in the union set of the compression pocket at all rotating angle.

Obviously, to avoid the back-flowing of the injected refrigerant, the eligible injection area equals to the intersection of the area which is confirmed by the above three conditions.

As a conclusion, the no-back-flowing injection port area does exist. It is close related to the parameters of the compressor and can be expressed by mathematic equations. The area is a half crescent close to the discharge port as Figure 4.

Based on the validated model of previous research [8], the performance of the ASHP with No-back-flowing end-plate injection is also compared with the traditional injection structure.

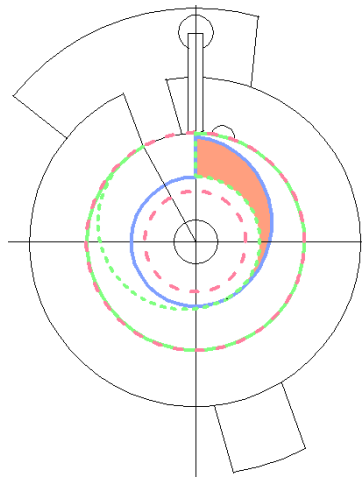


Figure 4. No-back-flowing end-plate injection port area

Figure 5 show the heating capacity and COP of the new no-back-flowing end-plate injection rotary compressor compared to the traditional end-plate injection. The heating capacity for the novel injection system has a greater improvement over 7.8%~11.6% compared to the traditional end-plate injection system as Figure 5(a). The COPs of two end-plate injection system is shown as Figure 5(b). The air conditioner employing the no-back-flowing end-plate injection rotary compressor has a higher COP compared to the system with the traditional end-plate injection rotary compressor over 0.6%~2.9%.

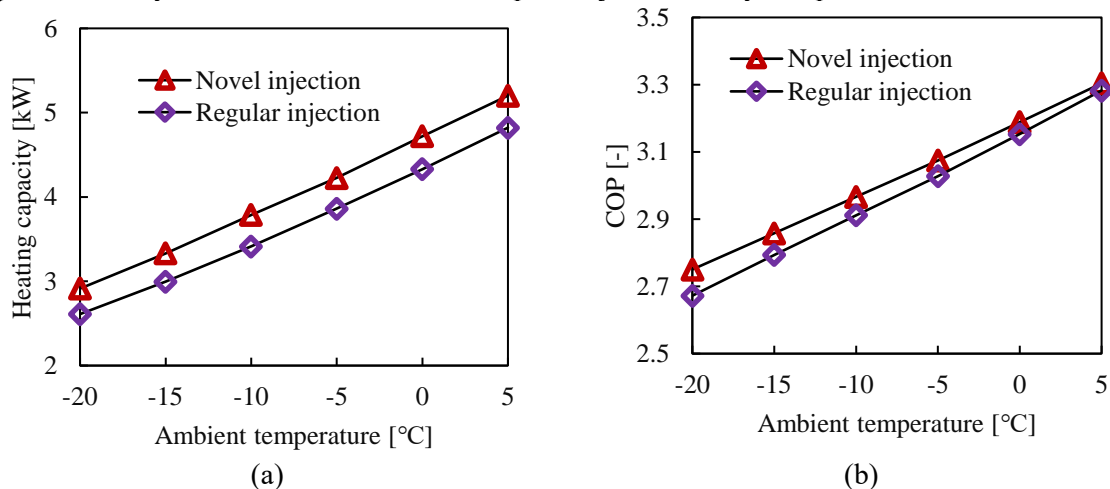


Figure 5. Performance improvement of ASHP by No-back-flowing end-plate (novel) injection compared to the traditional end-plate (regular) injection: (a) heating capacity; (b) COP.

5. Conclusions

Gas injection has been a crucial technology to avoid the serious degradation of air source heat pumps in low ambient temperature. The gas injection technologies of rotary compressor are investigated in this paper. The following conclusions can be gotten from this research.

- 1) The backflowing of the injected gas to the suction pocket largely limits the performance enhancement through gas injection for rotary compressor;
- 2) A blade injection structure and a new end-plate injection structure, which both can avoid backflowing of injected gas, are proposed and researched;
- 3) Compared to the traditional cylinder injection structure, the heating capacity and COP of rotary compressor with the blade injection structure is enhanced by 23.1~48.9% and 3.2~8.0%, respectively;
- 4) Compared to the air conditioner with the regular end-plate rotary compressor, the air conditioner with the no-back-flowing rotary compressor can enhance the heating capacity and COP by 7.8%~11.6% and

0.6%~2.9%, respectively.

6. References

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Acknowledgments

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