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Comparative Research on Air Conditioner with Gas-injected Rotary Compressor through Injection Port on Blade

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ABSTRACT

Economizer technology has become a critical method to improve the performance of air conditioners with rotary compressor in low ambient temperature. A novel vapor injection structure on the blade of the rotary compressor has been proposed in previous research to overcome the drawback of the traditional cylinder injection structure. Based on a verified numerical system model, the performance of an air conditioner adopting different economized rotary compressors has been investigated. The results indicate that: compared to the single cylinder rotary compressor with traditional injection structure, the rotary compressor with blade injection structure can enhance the heating capacity and COP by 12.9%~15.7% and 1.5%~4.1% in low ambient temperature, respectively. And compared to the twin-cylinder rotary compressor, the rotary compressor with blade injection structure has a competitive performance.

1. INTRODUCTION

Economizer technology has previously been used in centrifugal compressors, screw compressors and scroll compressors. Many investigations indicated the economizer technology could effectively improve the compressor performance in low ambient temperature [1-3]. However, the application of economizer in single-cylinder rotary compressors, which is also called vapor injection into the rotary compressor, is not as wide as twin-cylinder rotary compressors and scroll compressors [4-5]. The main barrier constraining the application of economizer in single-cylinder rotary compressors is its inherent compressor structure. For the single-cylinder rotary compressor with conventional injection structure, whose injection port is opened in the cylinder and close to the discharge port, considerable injected refrigerant gas directly flows back into the suction tube. The back-flowing will reduce the practical suction refrigerant from the suction tube and decrease the volumetric efficiency of the compressor. On the other side, constrained by the limited space for injection port and considering to avoid a larger back-flowing, the area of the injection port could not be enlarged. Finally, back-flowing of the injected refrigerant and limited injection port area leads to the constricted injection mass flow-rate and constricted enhancement on the performance. That is the main reason why the economizer technology is not well developed in single-cylinder rotary compressor, not like in twin-cylinder rotary compressors and scroll compressors.

However, compared to twin-cylinder rotary compressors, the single-cylinder rotary compressor has some advantages, such as simpler structure, lower cost and better reliability. So if the gas injection performance of the single-cylinder rotary compressor can be greatly improved, it will produce great value. According to above, a novel vapor injection structure on the blade for the single-cylinder rotary compressor has been proposed [6]. Preliminary research indicated that the proposed vapor injection structure can eliminate the back-flowing of the injected refrigerant completely. Meanwhile, the novel blade injection structure can enhance the heating capacity and COP of the compressor under the constant evaporating temperature and the constant condensing temperature by 23.1~48.9% and 3.2~8.0%, respectively, compared to the traditional injection structure.

To evaluate the system performance of single-cylinder rotary compressor with the new blade injection structure, a numerical study on an air conditioner equipped with rotary compressor is conducted in this research. Three kinds of rotary compressors with same suction volume, including a twin-cylinder rotary compressor, a single rotary compressor with traditional injection structure, and a single rotary compressor with the blade injection structure, are respectively adopted in the air conditioner for comparison.

2. AIR CONDITIONERS WITH DIFFERENT ECONOMIZED ROTARY COMPRESSORS

Figure 1 shows system schematics of air conditioners with different rotary compressors. Figure 1(a) present an air conditioner with twin-cylinder rotary compressor. Figure 1(b) present an air conditioner with single-cylinder rotary compressor using traditional injection structure. Figure 1(c) shows the air conditioner with a rotary compressor adopting the new blade injection structure. The high pressure refrigerant gas coming from discharge port of compressor is condensed in the condenser into high pressure liquid, then throttled by the first expansive valve and flows into the flash tank. In the flash tank, the saturated refrigerant gas at the top of tank goes through the injection pipe, the injection passage and the injection port on the blade and finally is injected into the compression pocket. The other refrigerant in the flash tank, saturated liquid refrigerant, is throttled by the second expansive valve and flows into the evaporator. The refrigerant is sucked by the compressor into the suction pocket after heated in the evaporator into a superheated gas.

Fig. 1 Air conditioners with different rotary compressors

The difference between Figure 1(b) and Figure 1(c) is the position of injection port. The injection port of the rotary compressor with traditional injection structure is opened in the cylinder as Figure 1(b), in which the back-flowing of the injected refrigerant gas into the suction tube is inevitable.

3. MODELLING

In order to investigate the performance of the air conditioner with different economized rotary compressors, the detailed distributed-parameter models of three kinds of rotary compressors and systems are built as follows.

3.1 Compressor

Except for the injection model, the models of the gas-injected rotary compressors, including the rotary compressor with traditional cylinder injection structure and the rotary compressor with blade injection structure, are completely same. The models of these two kinds of gas-injected rotary compressor have been established in previous research [6]. For the twin-cylinder rotary compressor, the working principle actually is two-stage compression process. It should be noted that, because the flash tank is used as economizer, the injected gas refrigerant mass flow-rate must equal to the gas generated in the flash tank, which is one of the important convergence index.

3.2 Heat exchanger, flash tank and expansive valve

A distributed-parameter model is developed to describe the characteristics of the condenser and the evaporator. Gnielinsk [7] correlations is adopted to calculate the in-tube convective heat transfer coefficient of refrigerant at the single-phase region. Gungor-Winterton [8] correlations are used to calculate the in-tube convective heat transfer coefficient of refrigerant at two-phase zone of the evaporator. Dobson-Chato [9] model is used to calculate the in-tube convective heat transfer coefficient of refrigerant at two-phase zone of the condenser. Friede [10] model is applied to calculate the pressure drop of refrigerant in tube.

For the flash tank, the inlet refrigerant enthalpy and the total outlet enthalpy both are equal to the refrigerant enthalpy at the outlet of the condenser. And the outlet gas and the outlet liquid both are saturated.

3.3 System model

C++ was used to solve equations because the solution procedure includes many submodules. And the method of variable step size was applied during calculating to reduce the calculation time. The method of 4th Order Runge-Kutta was used to improve calculation accuracy and accelerate the convergence process. Besides, the REFPROP, which is an international common software, was called to calculate refrigerant properties.

3.4 System model verification

To verify the accuracy of the model, the experimental data from a public papers [11] are collected to compare with simulation results. Figure 2 illuminates the simulation results of the air source heat pump with cylinder gas-injected rotary compressor compared to experimental results, which indicates that the heating capacity error is within 6% and the power consumption error is within 7%. Figure 3 presents the simulation results of air source heat pump with a two-stage rotary compressor compared to experimental results, which indicates the heating capacity error is within 7% and the power consumption error is within 6%. Generally speaking, the model have relative high accuracy and can be used in the further research.

Fig. 2. Rotary compressor with traditional injection structure

Fig. 3. Twin-cylinder rotary compressor

4. RESEARCH SCENARIO

Just as aforementioned, the gas injection will enhance the system heating performance under low ambient temperature conditions. So the heating performance of the air conditioners under low ambient temperature conditions are investigated in this paper. The suction volumes of single-cylinder rotary compressors and the low-pressure cylinder of the twin-cylinder rotary compressor keep same. The suction volume ratio of the high-pressure cylinder to the low-pressure one of the twin-cylinder is selected as 0.7 according to previous optimal research [4].

5. RESULTS AND DISCUSSION

Figure 4 shows the refrigerant flowrate in the evaporator and condenser. According to Figure 4(a), the refrigerant mass flowrate of twin-cylinder system in evaporator is greater than the air conditioner with single rotary compressor as same suction volume and close evaporating temperature for three kinds of compressors and the refrigerant injection has a clear negative effect on the suction of the rotary compressor, which can be attributed to the increase of the inner leakage of blade injection compressor[6]. The mass flowrate for the air conditioner with the blade injection is greater than the cylinder injection system as the heavy back-flowing of injected refrigerant in cylinder injection compressor [6].

As an addition of refrigerant flowrate in evaporator and injected refrigerant flowrate, the condenser mass flowrate of the two-stage rotary compressor is greater than the single-cylinder rotary compressor with the blade injection structure and the formers both are greater than the rotary compressor with traditional injection structure as Figure 4(b).

Fig. 4 comparison of system refrigerant mass flowrates

Fig. 5 System performances of different air conditioners with different economizer

Figure 5(a) and Figure 5(b) show the heating capacity and COP of air conditioner with different economizer. The heating capacity of the rotary compressor with the novel injection structure is slightly smaller than the one with the two-stage rotary compressor under all the working conditions. The blade injection system shows a slight improvement in COP relative to the twin-cylinder rotary compressor when the ambient temperature is higher than -10°C . But generally, the air conditioner with blade injected rotary compressor has a competitive performance with the air conditioner with twin-cylinder rotary compressor. On the other side, compared to the rotary compressor with cylinder injection structure, the heating capacity and COP with the new blade injection structure is enhanced by 12.9%~15.7% and 1.5%~4.1%, respectively.

6. CONCLUSIONS

Based on a verified numerical model, air conditioners with different rotary compressors, including a two-stage rotary compressor, a single rotary compressor with traditional injection structure and a single rotary compressor with the novel injection structure, are investigated and the results indicate:

- (1) The air conditioner with blade injected rotary compressor has a competitive performance with the air conditioner with twin-cylinder rotary compressor, and the rotary compressor with the blade injection structure could be considered to replace the two-stage rotary compressor.
- (2) Compared to the air conditioner with cylinder injection, the blade injection structure can enhance heating capacity and COP by 12.9%~15.7% and 1.5%~4.1%, respectively.
- (3) The heating capacity of the rotary compressor with the blade injection structure is slightly smaller than the one with the two-stage rotary compressor under all the working conditions. The blade injection system shows a slight improvement in COP relative to the twin-cylinder rotary compressor when the ambient temperature is higher than -10°C .

REFERENCES

- [1] B. L. Wang, W. X. Shi, X. T. Li, Numerical analysis on the effects of refrigerant injection on the scroll compressor. *Applied Thermal Engineering* 29 (2009) 37–46.
- [2] G. Y. Ma, Q. Chai, Characteristics of an improved heat-pump cycle for cold regions. *International Journal of Refrigeration* 26 (2003) 12–18.
- [3] J. Heo, M. W. Jeong, C. Baek, Comparison of the heating performance of air-source heat pumps using various types of refrigerant injection. *International Journal of Refrigeration* 34 (2011) 444–453.
- [4] S. X. Xu, G. Y. Ma, Experiment study on two-stage compression refrigerant/heat pump system with dual-cylinder rolling piston compressor. *Applied Thermal Engineering*, 62 (2014) 803–808.
- [5] Y. Ko, S. Park, S. Jin, The selection of volume ratio of two-stage rotary compressor and its effects on air-to-water heat pump with flash tank cycle. *Applied Energy*, 104 (2013) 187–196.
- [6] X. R. Liu, B. L. Wang, W. X. Shi, P. L. Zhang, A novel vapor injection structure on the blade of a rotary compressor, *Applied Thermal Engineering* (2016), <http://dx.doi.org/doi: 10.1016/j.applthermaleng.2016.02.098>.

- [7] Gnielinski V. New equations for heat mass transfer in turbulent pipe and channel flows. *International Chemical Engineering*, 1976, 16: 359-368.
- [8] Gungor K E, Winterton R H S. Simplified general correlation for saturated flow boiling and comparison of correlations with data. *Chemical Engineering Research & Design*, 1987, 65: 148-156
- [9] Dobson M K, Chato J C. Condensation in Smooth Horizontal Tubes. *ASME Journal of Heat Transfer* 1998, 120: 193–213
- [10] Didi M B O, Kattan N, Thome J R. Prediction of two-phase pressure gradients of refrigerants in horizontal tubes. *International Journal of Refrigeration*, 2002, 25: 935–947
- [11] Q. L. Jia, L. W. Feng, G. Yan, Experimental Research on Heating Performance of Rotary Compression System with Vapor Injection. *Journal of Refrigeration* 36 (2015) 65–70. (In Chinese)

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