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NUMERICAL ANALYSIS ON THE PERFORMANCE OF A COMPACT SCROLL COMPRESSOR WITH VAPOR INJECTION

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ABSTRACT

Applying vapor injection to refrigeration compressors may improve the heating capacity and COP. However, a small scroll compressor may not be commercialized due to the increase of the internal leakage and the production costs. In this study, a compact scroll compressor was considered to apply vapor injection for the improvement of the cycle efficiency. To this end, the performance of the compressor was numerically analysed with vapor injection. The results show that vapor injection is still applicable to relatively small refrigerant compressors resulting in increased cooling capacity and COP.

Keywords: scroll compressor, vapor injection, economizer, numerical analysis, CFD.

1. INTRODUCTION

A scroll compressor shows higher compression efficiency compared to a reciprocating compressor. It is also widely used in air-conditioning industry because of less noise and vibration. In recent years, various studies have been actively done in order to further improve the performance of the scroll compressor. Among those studies, vapor injection (VI) that injects the refrigerant into the compressor during a compression process for the economizer cycle [1]. A typical economizer cycle is shown in Figure-1. In an economizer cycle, a portion of the refrigerant past the condenser expands (4'→ 4) and, a heat is transferred through heat exchanger(HXC) (4'→ 2'), entering the compressor during a compression process. When the refrigerant at the injection pressure flows into the compressor, the compressor pressure changes to the intermediate pressure (2 + 2'→ 3), as in Figure-2. As a result, the compression work of an economizer cycle becomes less than that of a one-stage cycle (2 → 3').

Navarr, *et al.* [2] increased the heating capacity and COP of the scroll compressor using VI to 10 to 20 %. They also showed that the COP decreases with reducing pressure ratio.

Shuxue, *et al.* [3] improved the heating capacity of the scroll compressor more than 4% by applying VI to the ejector cycle.

Cho *et al.* [4] showed that a multi-hole injection of the scroll compressor shortens the injection time and improves the performance of the compressor. Despite the significant benefits of scroll compressor with VI in terms of energy saving, VI is not used in small-size scroll compressors. This is because scroll-wrap angle in a scroll compressor decreases with decreasing scroll-wrap shape resulting in difficulties in production.

In addition, since the scroll-wrap thickness is thinner, the VI port diameter connected to two compression chambers causing adverse effects to increase the internal leakage [5-7].Because of these problems, applying VI to the scroll compressor has been done primarily only in the large-capacity heat pump cycle whose energy savings are big. However, existing problems are being improved through continuous research. For instance, various scroll wrap shapes are developed and the algebraic spiral scroll among those showed an increase in the stroke volume while decreasing the overall size compared to the previous in volute scroll [8].

Thus, in this study, we numerically evaluated the performance changes by applying VI to a small scroll compressor to find out the feasibility of VI for a relatively small-size scroll compressor.

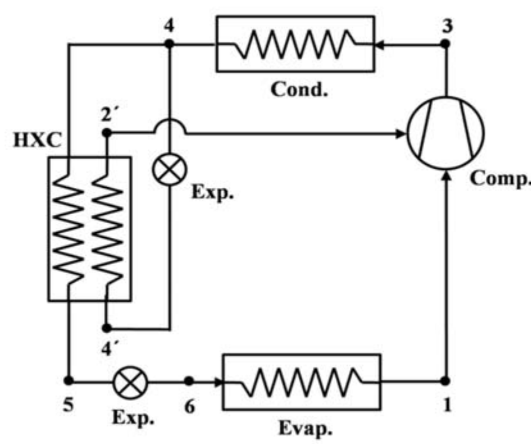

Figure-1. Schematic of economizer cycle.

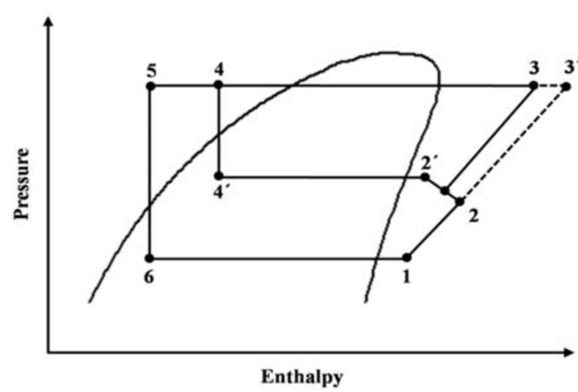

Figure-2. P-h diagram.

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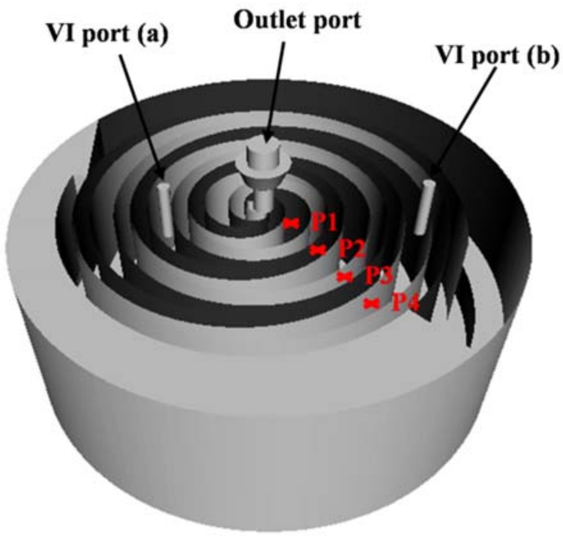


Figure-3. Schematic of the numerical analysis model.

2. NUMERICAL ANALYSIS METHOD

In this study, a numerical analysis for the 2HP scroll compressor was carried out. VI port diameter is smaller than the thickness of the scroll wrap not to connect the two compression chambers. The location of VI ports is shown in Figure-3. Model 1 is a baseline model that does not have VI, model 2 has VI at a center point of the stator radius (VI port (a)). In addition, model 3 has VI located on the 3/4 point of the radius (port VI (b)). Monitoring points were set at the location (P1 ~ P4) as in Figure-3to determine the pressure change in each compression chamber. The considered refrigerant is R134a, suction pressure is 350 kPa and the discharge pressure 2,100 kPa. The injection pressure is 660 kPa and suction gas temperatures 25 °C, based on the ISO condition.

3. RESULTS AND DISCUSSIONS

3.1 Variation of discharge mass flow with vapor injection

Figure-4 shows the overall discharge gas mass flow per cycle. The discharge gas mass flow of model 3 is 13% greater than that of model 1. The discharge gas mass flow of model 2 is 18% less than that of model 1 despite of VI. Therefore, the optimal VI port position is the location where the compression starts as model 3. VI location also affects the variation of the discharge gas mass flow. Therefore, VI port location should be carefully determined because it is the main variable in determining the discharge gas mass flow when designing a small scroll compressor.

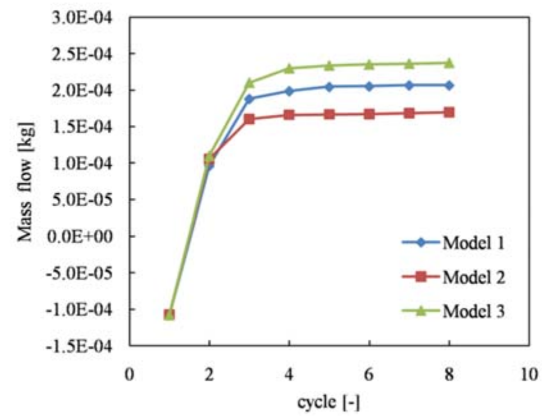


Figure-4. Variation of overall discharge gas mass flow per cycle.

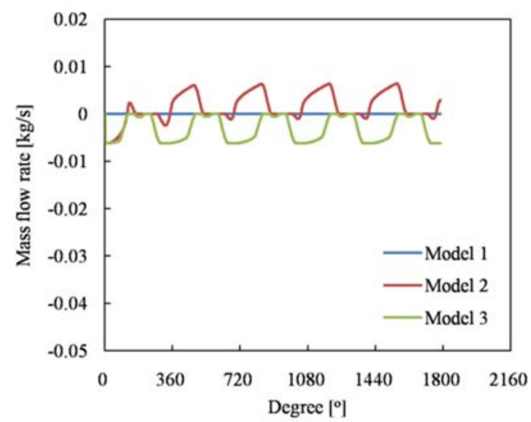
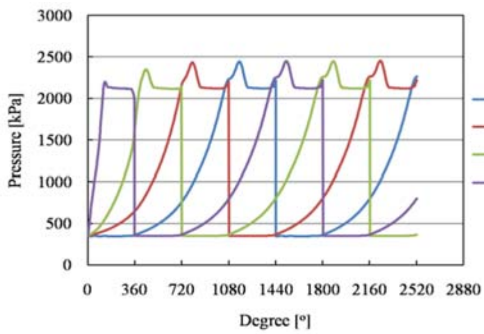


Figure-5. Variation of injection gas mass flow rate with orbiting angle.

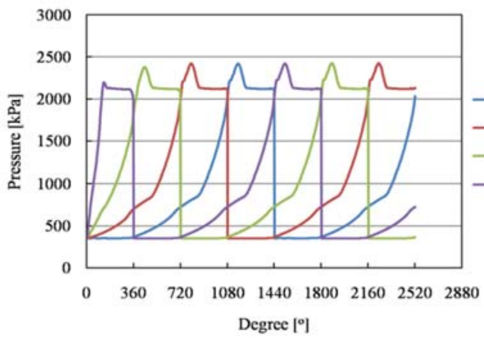
Figure-5 shows the mass flow rate of the injection gas according to the orbiting angle. The mass flow rate flowing into the compression chamber from the port VI is a negative value, and the reverse mass flow is a positive value. The injection gas of model 2 flows back to the VI port as the pressure of the compression chamber rises. Through this, it can be seen that model 2 has the lowest discharge gas mass flow even though it has VI.

3.2 Variation of compression chamber pressure and temperature with vapor injection

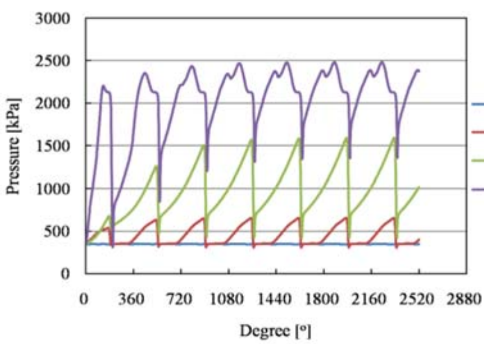
Figure-6 shows the pressure variation of the compression chamber with the orbiting angle. Figure-6 (a) and Figure-6 (b) indicated the pressure change at a point that moves with the compression chamber for model 1 and 2, respectively and Figure-6 (c) represents the pressure change at a fixed point that does not move with the compression chamber for model 3.



(a) Model 1



(b) Model 2



(c) Model 3

Figure-6. Variation of compression chamber pressure with orbiting angle.

Model 2 as in Figure-6(b) shows the increase in the pressure rise rate due to the inflow of gas injection in the initial compression. When the pressure inside the compression chamber becomes higher than the injection gas pressure, gas flows into the compression chamber flows back to the port VI. Thus, pressure rise is decreased due to the reverse flow of the injection gas. The internal compression chamber pressure of model 3 at P2, as in Figure-6 (c), is smaller than the gas injection pressure. Therefore, as shown in Figure-5, the injection gas of model 3 regularly flows intothe compression chamber without any reverse flows. As a result, the discharge pressure of model 3 is the highest compared to model 1 and model 2. When the pressure difference between the compression chamber and the pressure of the injection gas is large, the gas inflow rate is increased.

Figure-7 shows the variation of the discharge gas temperature with the orbiting angle. In the case of model 2, the discharge gas temperature was found to be highest. The increase in the discharge gas temperature reduces the isentropic efficiency and the compression efficiency is thus reduced causing an adverse effect on the cycle performance. On the other hand, the discharge gas temperature of model 3 was the lowest compared to model 1 and model 2.

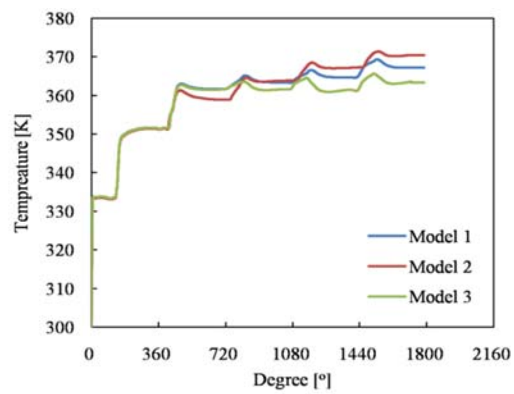


Figure-7. Variation of discharge gas temperature with orbiting angle.

3.3 Variation of the scroll compressor performance with vapor injection

Figure-8 shows the variation of the cooling capacity and the compressor power with applying VI or not. Cooling capacity increases by approximately 24% applying VI. This is because the discharge gas mass flow rate increases as the injection gas flows into the compression chamber. Compressor power increases by about 6% with VI applied. This is because the enthalpy of the discharge gas is reduced due to the decreased discharge gas temperature despite of the increased mass flow rate. Thus, as in Figure-9, COP has risen by 16% by applying VI, which means that VI may be successfully applied to a relatively small scroll compressor, such as 2HP-class scroll compressors.

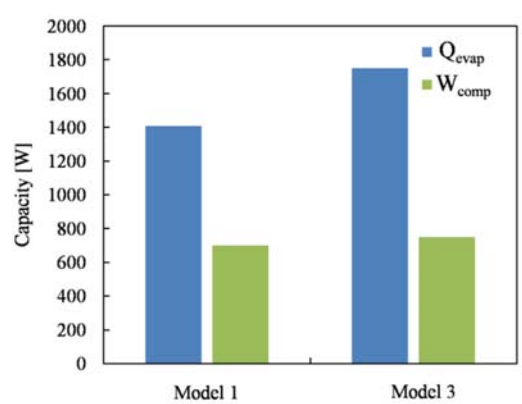


Figure-8. Variation of cooling capacity and compressor power with vapor injection.

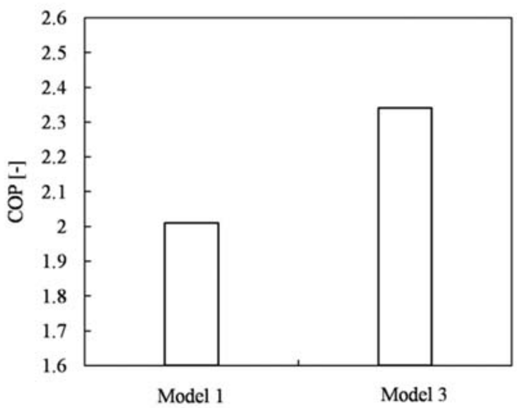


Figure-9. Variation of COP with vapor injection.

4. CONCLUSIONS

In this paper, we evaluate the performance characteristics of the 2HP-class scroll compressor with VI applied. The conclusions drawn from this study are as follows:

a) It is desirable that VI port locates in the area where th e early compression process occurs. VI also affects th e discharge gas mass flow rate.
b) The greater the pressure difference between the injecti on gas and compression chamber is, the higher the gas mass flow rate is. In addition, the discharge gas temp erature can be reduced by applying VI.
c) The 2HP-class scroll compressor with VI shows highe r COP by 16% compared to the compressor without V I. Therefore, VI is still effective for a relatively compa ct scroll compressor.

In the future, performance verification will be done with the prototype of a 2HP scroll compressor with VI.

ACKNOWLEDGEMENT

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