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# Heating Performance with a Volume Ratio on 2-Stage Compressor

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## ABSTRACT

Generally, the lower outdoor air temperature gets, the more heating capacity is needed. But the heating capacity of heat pump decreases, when the outdoor air temperature becomes low. As one way to prevent the performance degradation, in this study the heat pump with 2-stage rotary compressor has been investigated with variable volume ratios. The volume ratio is one of the major factors which are influenced to the heat pump performance. The computer simulation and experimental test have shown that the optimal volume ratio is 63% and 59%, respectively. Finally, the heating capacity and COP of the gas injection system are enhanced by 18 % and 10% at the outdoor air temperature of -15℃, respectively. This improvement is resulted from the increase of refrigerant mass flow rate and efficiency of the evaporator.

## 1. INTRODUCTION

The demands of people about the efficient energy consumption are increasing continuously by reason of the exhaustion of fossil fuel and global warming. To meet these demands, most governments are strengthening the regulation of the $CO_2$ emission and standard about certification of products and each company is spurred to the development of new technology for the high efficiency. Also, the demand for high efficiency in heating and cooling system is increasing by a growing customer's recognition about the energy conservation. The demand of the heat pump also is increasing continuously, because it has the high efficiency comparing with the existing heating and cool system by the different way, even though the heat pump has a disadvantage that the structure is complicated and the performance of product and change of building load have an opposing trend. Moreover, the heat pump is standing out by a technology development like inverter in order to respond effectively to the building load. In this paper, I analyze 2-stage injection that is the high effective technique and the affection of the volume ratio and intermediate pressure change to 2-stage compressor that is the core component.

# 2. EXPERIMENTAL SETUP AND TEST PROCEDURE

## 2.1 Experimental apparatus

In this study, the performance test is running at Psychrometric Calorimeter as Korea Standard (KS C-9306). Psychrometric Calorimeter is consisted of two constant temperature and humidity chambers. It controls the temperature and humidity in chamber as each experiment condition. The temperature and humidity are controlled by the chiller, heater and humidifying device. Dry/Wet bulbs in chamber operate within error range of Korea Standard (Dry bulb ± 1.0℃, Wet bulb ± 0.5℃). The practical error of experimental device is ± 0.1℃. The capability is measured as atmosphere-enthalpy method, de-humidity performance measuring humidity and flow rate through the Indoor unit. In order to estimate the performance, the temperature of inlet/outlet air is measured by the Dry/Wet bulbs. Flow rate throughout indoor unit is measured by Cord-tester composed with the nozzle and assistant blower. The error of flow rate limited under ±0.05% is very small and the experimental device has the reliability within ± 3% error.

## 2.2 Test condition

Fig. 1 is the heat pump system diagram used in this experiment. As appearing in the picture, this system is composed with 2-stage vapor injection compressor, indoor heat exchanger unit, EEV, phase separator and etc. The condition of cooling performance test is the ASHRE standard condition (35/24℃), and the condition of heating performance test is 7/6℃ that is the standard condition and various conditions in low temperature. In the case of cold climate, the capacity of heat pump is very important at the low temperature condition especially and the investigation is necessary. The VR is changed in the 55 ~ 63% scope. The test condition is table 1. In order to analyze the cycle characteristics, T-type thermocouples are attached in the main cycle part and measure the temperature. In order to evaluate the effect for the change of intermediate pressure, the pressure sensor is affixed to the injection line former/after and the suction/discharge parts of compressor

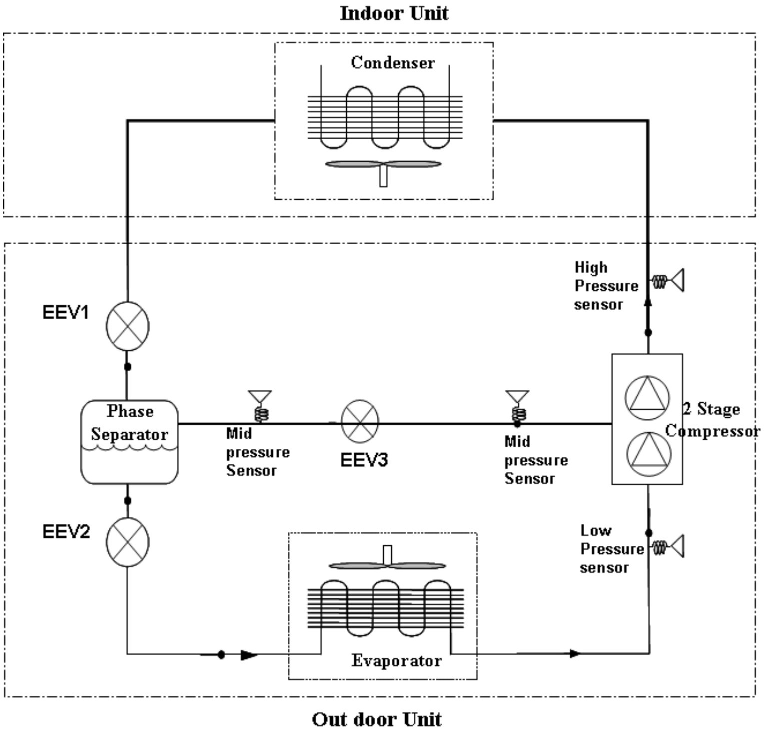

Figure 1 Experimental setup

Table 1 Test conditions

| Item | | Outdoor temperature | Indoor temperature | Volume ratio |
|---|---|---|---|---|
| Operating mode | Cooling | 35/24℃ | 27/19℃ | 55% / 59% / 63% |
| | Heating | 7/8℃ | 20/15℃ | |
| | | -10/-11℃ | 20/15℃ | |
| | | -15/-16℃ | 20/15℃ | |

## 3. RESULTS AND ANALYSIS

The volume ratio is the core design factor in the 2-Stage injection compressor. We can optimize the capacity and COP according to the volume ratio. For the optimum volume ratio decision, we have to evaluate the best outdoor temperature, target capacity and performance of compressor component, preferentially. In addition, we have to examine a side effect according to the variation of VR. For example, the imbalance of upper and lower cylinder's torque gives rise to vibrate and change the torque according to the various angle of rotation. So the side effect has to be changed under the permit range through the computer simulation or experiment

### 3.1 Heating capacity

The volume ratio of the rotary compressor being used in this study shows the ration of whole cylinder's internal volume to under cylinder's internal volume. The ratio of volume (Equation1) is defined as below in this paper. The more upper compressor volume increases, the less heating capacity decreases in the same condition of 2-stage cycle, because if the volume ratio increases, upper cylinder's volume decreases. The results give rise to increase the intermediate pressure, because the injection vapor's quality decreases at the condition of the same condensing pressure and condensing outlet temperature.

$$VR = \frac{V_1}{V_1 + V_2} = \frac{1}{1 + \frac{V_2}{V_1}} = \frac{1}{1 + VR_o} \qquad (1)$$

Fig.1 shows the results of the heating capacity according to variation of volume ratio. As you can see the simulation data, the more compressor volume increases, the less heating capacity decreases. The lower outdoor temperature is, the less variation of capacity decreases. In 7℃ temperature condition, the capacity change is 109W per VR. On the other hand, in -15℃ temperature condition, the capacity change is 26W per VR. Fig. 2 shows that the more outdoor temperature decreases, the more specific volume and change rate of refrigerant increase. So the width of change to the intermediate pressure decreases according to variation of VR. Because the slope of the saturated liquid line grows toward low temperature, the increase rate of the quality is slow down according to the middle pressure decrease by the variation of VR. Therefore, the range of capacity's variation decreases. Fig. 3 shows the improvement of the injection capacity for the non injection capacity. In the outdoor temperature of -15℃, the 52~53% range of VR is the range of the best improvement capacity. In the outdoor temperature of 7℃, it shows the lower VR is, the higher improvement rate is. When showing the trend of capacity, the capacity improvement ratio is under 0 in over 67% of VR. Therefore, there is no improvement of the injection cycle in over 67% of VR.

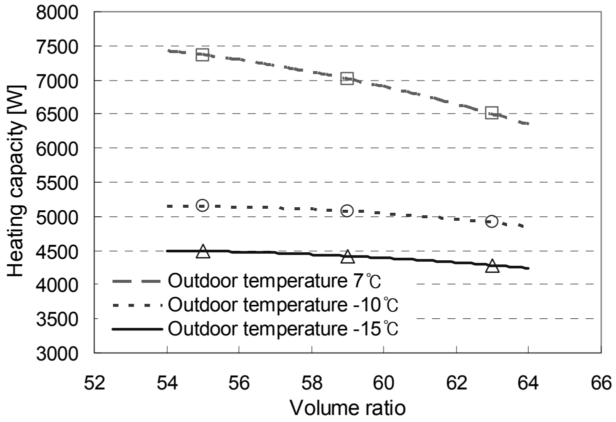

Figure 2 Variation of heating capacity with volume ratio

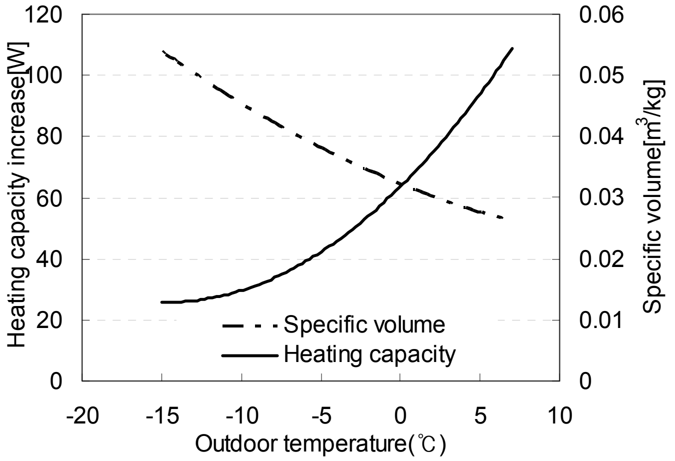

Figure 3 Variation of heating capacity with outdoor temperature and volume ratio

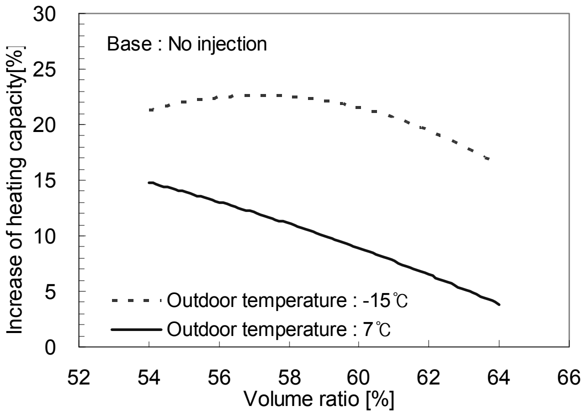

Figure 4 Increase of heating capacity with volume ratio

### 3.2 Cooling capacity & COP

Differently to the heating operation, in case of cooling operation the mass flow rate does not increase but the evaporate enthalpy increases for the injection effect. By separating the injection to vapor and liquid, the evaporating heat flux increases by reducing the quality of refrigerant in evaporator. As the intermediate pressure is low, the effect of injection becomes large. However the optimal point exists, because the input power of compressor increases. As VR increases like the heating mode, the increase rate of capacity reduces. The COP has the minus effect in the VR range of 55% ~ 61% and the COP has the 1.4% plus effect in 63% of VR.

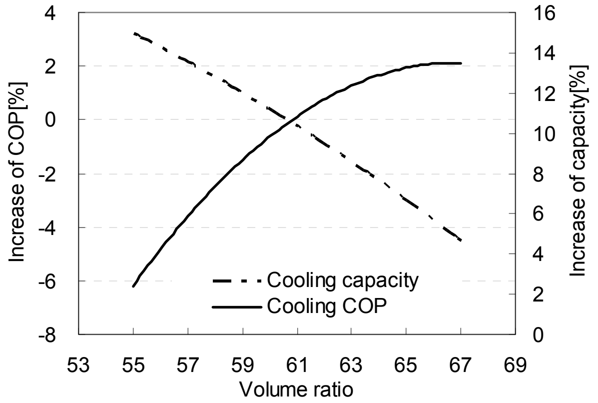

Figure 5 Increase of cooling capacity and COP with volume ratio

### 3.3 COP variation

Fig. 4 is the variation of COP which is measured by experiment Through VR. This experiment was tested by the VR condition of 55%, 59% and 63%. The COP is the highest in 59% of VR. Although considering heating capacity and COP, the condition of 59% is the best condition of the other cases. According to the paper about the variation of VR, the lower VR of injection is, the higher increase rate of COP is than non injection. And even though, in the outdoor air temperature which is -15℃ and the VR condition of 63%, COP of this system is the highest to compare to the single compression system, the variation of COP was not almost changed by VR. Fig. 6 shows the increase of COP to compare the outdoor air temperature with VR. As you can see, The increase of COP is steady with VR in the outdoor air temperature of -15℃ condition. In 7℃ of the air temperature, the increase of heating capacity decreases with VR and increases 2% point than the based performance of no injection in the 63% condition. As a result of this, in order to make the performance maximize, 55% of VR is the optimum condition in -15℃ of air temperature aspect heating capacity and COP and 59% of VR is the optimum condition in 7℃ of air temperature aspect heating capacity and COP.

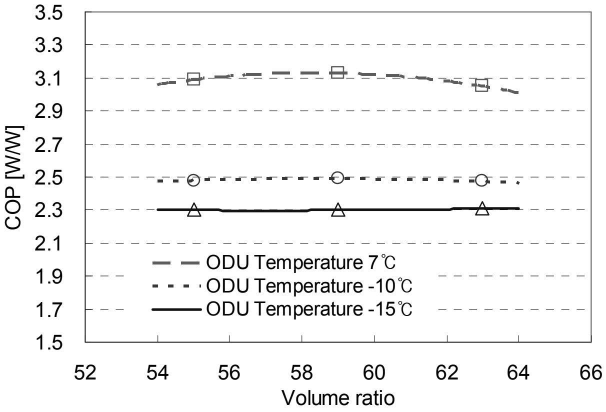

Figure 6 Variation of COP with volume ratio

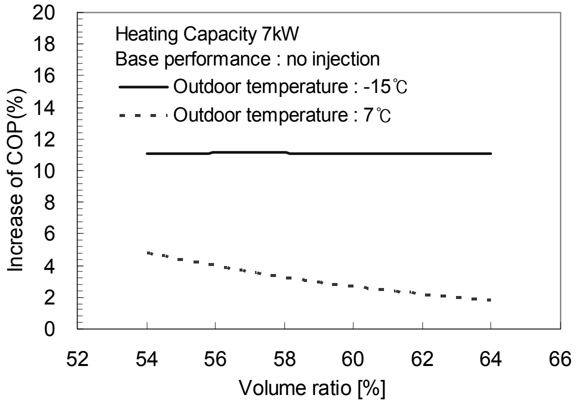

Figure 7 Effect of vapor injection in COP(heating mode)

Fig. 8 is the graph to compare EER by the experiment of compressor with COP by the experiment of heat pump. The results are conflicted. When VR increases, EER increases at the results of ARI in the experiment of compressor's performance. This result means that the consumption power decreases in the same frequency, because the identical cooling capacity is the same (The performance experiment of compressor in no injection condition). And there are several causes of this result like over-compression of 1st and 2nd compression, energy loss by expansion and friction of mechanical system. On the other hand, in this result the COP of heat pump decreases by increasing of VR because of two reasons. First, the effect of injection increases when VR is small. Second, the capability of injection decreases by the increase of middle pressure, when VR increases.

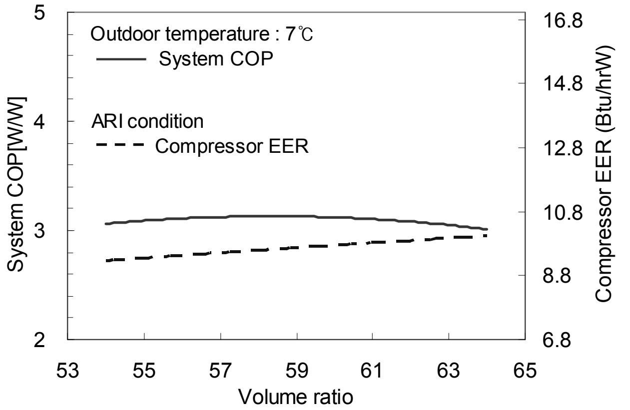

Figure 8 Comparison between the result of compressor performance test and experimental result

### 3.3 Torque variation with rotational angle

The change of compressor torque is considered with the heating capacity and optimal COP significantly. Contrary to the twin compressor, 2-stage compressor has different torque characteristics according to the change of rotational angle, because the upper and lower cylinder volume is different. Fig. 9 is the variation of torque according to the rotational angle of twin and 2-stage compressors during non injection. Twin and 2-stage compressors present two peaks for 360 degree revolution. The twin compressor has the constant interval each 180 degree because it compresses from evaporation pressure to condensation pressure by one cylinder. On the other hand, 2-stage compressor has 2 patterns. It has generally the gradual change of torque change and low peak value by using injection between two different cylinders. In torque side, 2-stage compressor has an advantage, but has larger vibration than twin compressor. Fig. 9 is the change of torque according to the rotation angle of injection, non injection and twin compressor in -15℃. The torque peak of 2-stage compressor is higher than twin compressor in ARI condition. In the low outdoor temperature, unbalance of 1st and 2nd compression increases when compared to ARI condition, because the compression load of upper cylinder is larger than the low load. By using injection, the compression ratio is lower than non injection ratio and the torque peak decreases by the increase of middle pressure. So, the compressor has to be designed by considering the operation condition and volume ratio.

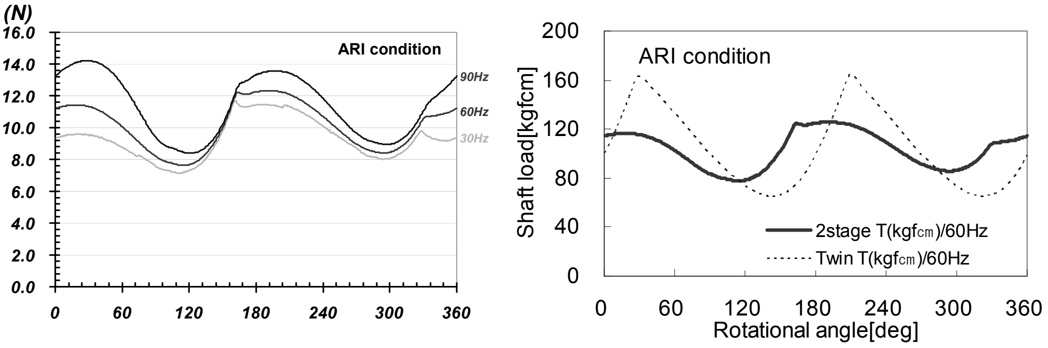

Figure 9 Torque variations with rotational angle of twin and 2 stage compressors during non injection

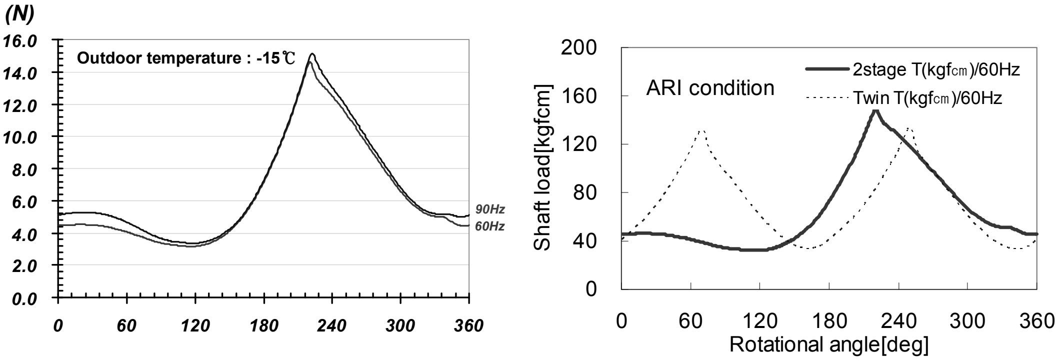

Figure 10 Torque variations with rotational angle of twin and 2 stage compressor during injection

## 4. CONCLUSIONS

The performance of 2-stage compressor is changed by the volume ratio and we investigated by changing the VR of compressor. The capacity of system increases as reducing volume ratio, that is, smaller volume ratio shows more big capacity. If the system will be demanded as the big capacity, small volume ratio will have to be selected. At this time, the performance enhances by the increase of condenser's heat flux and compressor's input power as the increase of flow rate by injection. The optimal volume ratio has to be selected by estimating only the increase of capacity by injection. Among the volume ratios used in this study, the 55% of VR has the best improvement at the capacity side. There is the optimal volume ratio that shows the highest COP according to the intermediate pressure. In the existing paper, 63% is the best performance effect, but this study result is the most effective at 59%. Along with selecting the volume ratio and considering the affects in operation range, the VR has to be designed for the maximization of injection effect and security of compressor reliability

## NOMENCLATURE

The nomenclature should be located at the end of the text using the following format:

| | | |
|---|---|---|
| COP | coefficient of performance | (W/W) |
| EER | energy efficiency ratio | (Btu/hrW) |
| N | newton | (kgm/s$^2$) |
| VR | volume ratio | (-) |
| V | volume | (cc) |

**Subscripts**

| | |
|---|---|
| 1 | 1st cylinder |
| 2 | 2nd cylider |
| o | conventional |

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