A study on the oil flow characteristics in the inverter rotary compressor

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Abstract. In order to secure the reliability of the oil in the inverter rotary compressor used in the system multi-air conditioners in heating and cooling modes, it is necessary to study the oil flow characteristics which affect to the compressor efficiency. In this study, sight glasses were installed at the compressor and accumulator for oil flow measurements, and various experiments were performed to measure the amount of discharged oil for different refrigerant pipe lengths. On the basis of the experimental measurements, we compared the OCR (Oil Circulation Rate) results of the system multi-air conditioner for various operating conditions. The results are graphically depicted.

1. Introduction
With higher standards of living, the air conditioner has become a home appliance necessity, although its use has raised concerns about the residential environment. In particular, the system multi-air conditioner has become the solution to energy conservation and environmental issues, etc. It consists of an outdoor unit with an inverter rotary compressor, refrigerant pipes connected to the outdoor unit, and several indoor units. The indoor units are controlled through the variable inverter rotary compressor according to the thermal load of each room. The installed refrigerant pipe length reflecting the different distances between each room and the outdoor unit influences the compressor performance.

Many studies have been carried out about the indoor and outdoor units of the system multi-air conditioner. However, only a few studies have been performed on the influence of the incremental pipe length of an installed system multi-air conditioner [1, 2]. The oil discharged from the compressor influences the system performance and the reliability of the compressor. Excessive discharged oil can deteriorate the reliability of the compressor by reducing the efficiency of the compressor with rising temperature and by over pressurizing the compressed oil [3, 4]. Cremaschi et al. [5] investigated oil retention in air conditioning systems by experiments. They found that the oil retention volume is proportional to the oil mass fraction and the ratio of the liquid film viscosity to the refrigerant vapor viscosity.

In this study, the discharged oil from the inverter rotary compressor was measured for different lengths of the refrigerant pipe. We compared the OCR (Oil Circulation Rate) results of the system multi-air conditioner for various conditions, such as normal, overload and low temperature conditions, in cooling and heating modes.

2. Experiments
2.1. Experimental devices
Experiments were performed with a commercial system multi-air conditioner. The experimental devices were configured to measure the amount of discharged oil from the inverter rotary compressor. The Discharged Oil Measurement Device (DOMD) was installed to measure the amount of the separated oil before the experiment. In particular, we investigated the effects of the refrigerant pipe lengths of a short-line pipe (SLP: 5m) and a long-line pipe (LLP: 75m), which were installed between the indoor unit and the outdoor unit. The schematic diagrams of the experimental devices are given in Figs. 1 and 2. The major components of the experimental devices for the measurement of discharged oil are shown in Fig. 3. The valves (v1, v2, v3, v4) change the path of discharged flow from the compressor to the DOMD. As shown in Fig. 4, sight glasses were installed at compressor, accumulator and DOMD to visualize oil flow behaviours. The experiments were performed in a chamber in the calorimeter laboratory, which could set up the environmental conditions.

![Figure 1](image1.png)  
**Figure 1.** Schematic diagram of the commercial system multi-air conditioner.

![Figure 2](image2.png)  
**Figure 2.** Revised schematic diagram for experiments.

![Figure 3](image3.png)  
**Figure 3.** Photos of the discharged oil measurement devices.

![Figure 4](image4.png)  
**Figure 4.** Installed sight glasses at the compressor, accumulator and discharged oil measurement devices.
### Table 1. The experimental conditions (using the calorimeter laboratory).

| Mode       | Working condition | Temperature [°C] |
|------------|-------------------|------------------|
|            |                   | Indoor / Outdoor | Indoor / Outdoor |
|            |                   | Dry bulb / Wet bulb | Dry bulb / Wet bulb |
| Heating [30°C] | Normal          | 20 / 15          | 7 / 6             |
|            | Overload         | 27 / 15          | 24 / 18           |
|            | Low temp.        | 20 / 15          | 2 / 0             |
| Cooling [18°C] | Normal          | 27 / 19.5        | 35 / 24           |
|            | Overload         | 32 / 27.5        | 43 / 33           |
|            | Low temp.        | 21 / 15          | 21 / 15           |
| Compressor | Frequency        | 58Hz             |                   |

### Table 2. The amount of discharged oil at various operating conditions.

| Operating mode | SLP [5m] | LLP [75m] |
|----------------|----------|-----------|
| Average level of discharged oil [cm] | Heating | 3.5 | 4.5 |
|                 | Cooling  | 2.6 | 4.6 |
| Average the amount of discharged oil [kg/h] | Heating | 6.0 | 3.6 |
|                 | Cooling  | 4.7 | 3.2 |
| Max. the amount of discharged oil [kg/h] | Heating | 9.2 (Overload) | 5.2 (Low temp.) |
|                 | Cooling  | 8.1 (Normal) | 3.9 (Overload) |
| Min. the amount of discharged oil [kg/h] | Heating | 4.1 (Normal) | 1.0 (Low temp.) |
|                 | Cooling  | 2.1 (Low temp.) | 0.9 (Low temp.) |

#### 2.2. Experimental methods

In this study, SLP and LLP experiments were carried out to investigate the influence of oil flow on the performance of an inverter rotary compressor according to pipe length. The fixed frequency of 58Hz was used for experimental reliability of the compressor. Also, the amount of discharged oil was measured for various temperature conditions as given in Table 1 [6]. The operating fluids were R-410a refrigerant and polyol ester oil.

The amount of discharged oil was measured by a 4-step procedure, which consists of discharge, separation after sampling, measurement and return to accumulator. Ma and Seok [7] analyzed the dynamic response behaviors of the valve system of the rotary compressor. At the discharge step, after opening the valve 2, we operated the system multi-air conditioner until the surface of the oil stabilized, which was observed by the naked eye through the sight glasses of the compressor and accumulator [8]. At the separation – after – sampling step, if the oil surface had stabilized, valve 2 was closed, and both valve 1 and valve 3 were opened simultaneously. Hence, the mixture of refrigerant and oil was circulated through the system via the DOMD. At the measurement step, valve 2 was opened at a specified time, and then DOMD was isolated from the system after both valve 1 and valve 3 were closed to measure the oil level. Finally, at the return – to – accumulator step, the valve 4 was opened...
so that the compressor could recover the oil. The OCR that can be calculated by using the measured amount of discharged oil can be expressed as follows:

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OCR (\%) = \frac{\text{System oil circulation rate (g)}}{\text{System [oil + refrigerant] circulation rate (g)}}
\]  

(1)

3. Results and discussion

3.1. Pressure-enthalpy diagram

Experimental data of the SLP and LLP conditions were measured such as the temperatures and pressures of the inlets and outlets of the compressor and condenser at the steady state condition. The results are depicted in the p-h diagram for various operating modes of the SLP (see Fig. 5(a, b)) and the LLP conditions (see Fig. 5(c, d)). And we confirmed the stable cycles of the systems with different pipe lengths for all operating conditions.

3.2. The amount of discharged oil

The levels of discharged oil for various external conditions are plotted in Figs. 6 and 7 for the heating and cooling modes, and the measured values are given in Table 2. It is noted that for the SLP experiment, the amount of discharged oil was measured in a short time, less than 150 s. However, for the LLP experiment, the measurement required 600 s. Results showed that the average discharge rate of oil was 6 kg/h in the heating mode of the SLP, and 4.7 kg/h in the cooling mode of the SLP.

Results also confirmed that the average discharge rate of oil was 3.6 kg/h in heating mode of the LLP, and 3.2 kg/h in cooling mode of the LLP. The discharge rate of oil was 0.9 kg/h at the low temperature condition in the cooling mode of the LLP condition, which had the smallest thermal loading. And the highest discharge rate of oil was 9.2 kg/h at the overload condition in the heating mode of the SLP condition, which had the largest thermal load. In the cooling mode at the low temperature LLP condition, the amount of discharged oil was 3.5 times less than the average amount of discharged oil.

Figure 5. P-h diagram at the steady state.
However, in the heating mode of the overload SLP condition, it was twice the average value. The amount of discharged oil increased as the thermal load of the system increased in the SLP condition.

![Figure 6](image6.png)  
(a) short-line pipe  
(b) long-line pipe  

**Figure 6.** The level of discharged oil in the heating mode.

![Figure 7](image7.png)  
(a) short-line pipe  
(b) long-line pipe  

**Figure 7.** The level of discharged oil in the cooling mode.

![Figure 8](image8.png)  

**Figure 8.** Comparison of OCR results in the heating mode.

![Figure 9](image9.png)  

**Figure 9.** Comparison of the OCR results in the cooling mode.
3.3. Compressor oil reliability
Based on the calculated OCR results, the reliability of a compressor was evaluated for various external conditions. Min and Hwang [9] reported that the OCR influences the reliability of a rotary compressor. The comparison of the OCR results between the SLP and LLP conditions is shown in Figs. 8 and 9 for various operating conditions, such as normal, overload and low temperature conditions, in heating and cooling modes. The OCR of the SLP condition was higher than that of the LLP condition in both heating and cooling modes. If the OCR is high, the amount of oil discharged from the compressor is increased, creating an oil shortage that can decrease the reliability of a rotary compressor. In particular, the OCR results of the SLP and LLP conditions showed the greatest difference up to 1.06% at the low temperature condition in the heating mode, and a difference of 0.94% at the normal condition in the cooling mode.

4. Conclusions
In order to secure the reliability of the inverter rotary compressor used in system multi-air conditioners, the oil flow characteristics were experimentally investigated. In particular, the amount of discharged oil from the compressor was measured. Also, p-h diagrams were prepared and the cycle was found to have a stable formation at all specified geometrical and operational conditions. Therefore, the operating reliability of the inverter rotary compressor can be secured in the system multi-air conditioner. In the SLP condition, the average value of the OCR in the heating mode was 0.19% higher than that in the cooling mode. However, in the LLP condition, the average value of the OCR in the cooling mode is slightly higher than that in the heating mode. Based on OCR comparison, we may conclude that the reliability of oil in the compressor is low at the low temperature condition in the heating mode because of the big difference of OCR between SLP and LLP conditions.

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