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EXPERIMENTAL STUDY OF REFRIGERANT-OIL BEHAVIOR INSIDE ROTARY COMPRESSOR

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ABSTRACT

A quality of a refrigeration cycle and a reliability of a compressor can be reduced if a refrigerant including excessive lubricating oil is exhausted from the compressor. Thus, the analysis of the oil behavior inside the compressor is required to prevent the problem. A tested rotary compressor with visualization windows has been manufactured in this study to investigate the oil behavior using developed visualization techniques. The oil behaviors at various operating conditions have been quantified to obtain the relationship with the outlet pressure inside the compressor. Also, the effect of the operating conditions on the quantity of the exhausted oil from the rotary compressor has been investigated using the visualization technique.

1. INTRODUCTION

The rotary compressor is widely used for refrigeration systems. However, reliability has not been studied intensively so far for the rotary compressor such as internal oil behaviors. Thus, the oil behavior has been investigated using the developed visualization technique in this study.

Heat transfer characteristics inside a condenser are influenced by oil which exists in the refrigerant vapor compressed by a compressor. Also, an expansion valve can be frozen if oil is exhausted too much from the compressor. This phenomenon results in reduced efficiency of the expansion valve and an evaporator because an evaporation temperature increases by oil membrane on a heat transfer surface. A total efficiency of the refrigeration cycle also decreases if the oil is discharged too much from the compressor because of reduced heat transfer characteristics, pressure drops, and oil deficiency in the compressor. Therefore, the oil behavior should be observed accurately inside the compressor. The oil behavior can be analyzed by the measurement of the oil circulation rate and visualization using optical methods.

In this study, the visualization window has been installed around the exit nozzle of the rotary compressor to analyze the oil distribution. Also, a test model has been made to capture the projection of the oil movements by controlling the amount of oil and refrigerants.

2. EXPERIMENTAL SETUP

2.1 Test Model for Visualization of Oil Behaviors

The test model has been manufactured to obtain projected data from a laser because it is difficult to capture the oil movements inside the real compressor at various conditions. Since the model has been made of acryl, the whole parts of the exit nozzle can be visualized to analyze average intensities of captured images as shown in Fig. 1. In the test model, the amounts of oil and refrigerant can be controlled by an oil generator and a regulator, respectively.
before inserting to the model so that the total amount of oil and refrigerant inside the test model can be known variables during the experiment. The inserted oil moves upward rapidly through the holes (Fig. 2) like the real compressor. The oil generator and the regulator have been connected to the test model and a heating circulator as shown by Fig. 3. The test model has been visualized by a 80mW Ar-Ion laser to analyze the oil behavior with known amounts of oil and refrigerant as shown by Fig. 4.

Figure 1: Photograph of test model

Figure 2: Layout of test model

Figure 3: Experimental setup for test model
2.2 Rotary Compressor with Visualizing Window

There are a motor and a cylinder inside the rotary compressor covered by opaque metals (Fig. 5). Thus, a special manufacture should be required to visualize inside the compressor using the laser. In this study, 3 visualizing windows have been installed to inspect the upper part of the compressor for visualization of the exhausted oil through the exit nozzle. The windows are made of quartz glass for one ring-shaped window to capture side view and two circular windows for cross-sectional views installed at top plate of the compressor as shown in Figs. 6 and 7. The quartz glasses have been tested for safety and confirmed to be hold until 60 bars that is 3 times of a real operating condition. Nevertheless, the window has been covered by polymer film of 0.2 mm to protect from an impact.

The refrigeration cycle has been composed using a package air-conditioning system. The images have been captured by a CCD camera with a resolution of 640×480 and an image-capture board to save the images simultaneously from 3 CCD cameras.
3. EXPERIMENTAL METHOD

For a test model, the experimental condition has been divided into 4 cases with two different inlet pressures and two different internal temperatures. That is, the condition 1 is 1 bar and 77°C, 2 is 2 bar and 77°C, 3 is 1 bar and 57°C, and 4 is 2 bar and 57°C in Table 1. The test model has been investigated by a vertical sheet and a horizontal sheet of the laser beam using a cylindrical lens.

For the real compressor model with installed visualization windows, the experimental setups for the visualization using the laser, a white light, and the CCD camera are shown in Figs. 8 and 9. The vertical sheet of the laser beam has been constructed by the cylindrical lens to capture the side view as shown in Fig. 8 while the top view has been captured by the horizontal sheet of the laser beam and two CCD cameras as shown in Fig. 9. The experiments have been performed for 5 conditions for Exp. I and 6 conditions for Exp. II.

Shapes of most of oil droplets inside the upper part of the compressor are spheres. Thus, the beam can be reflected and refracted for all of directions. Those reflected and refracted beams have been captured by the CCD camera as shown by Fig. 10. Because the parts of the oils give bright images on the screen, the intensity of the brightness for the image increases if the amount of the oil increases. By this technique, the average intensities of the captured images can be obtained and the amount of the oil inside the compressor can be calculated from the intensities. The average intensity can be derived as follows:

\[
I_{\text{avg}} = \frac{\sum_{i=0}^{M \times N} I(i)}{256 \times (M \times N)} \times 100\%
\]  

(1)

where \(M\) and \(N\) are numbers of pixels in \(x\) and \(y\) directions for an interrogation area as shown in Fig. 11. The maximum value of the CCD camera for the 8 bit system is 255 in Eq. (1).
4. RESULTS AND DISCUSSION

4.1 Test Model
The results of the experiment for the test model show that the amount of the oil inside the upper part of the model increases with increasing the internal temperature as shown in Fig. 12. It can be confirmed by the calculated average intensities in Table 1. Also, the exhausted oil increases if the inlet pressure increases as shown by Fig. 13 because more oil droplets can be found around the exit nozzle by measuring the intensity. The amount of the discharged oil and the inserted refrigerant also increase if the inlet pressure increases as shown in Table 1.

Table 1: Average intensity with inserted refrigerant and discharged oil.

<table>
<thead>
<tr>
<th></th>
<th>Cond. 1</th>
<th>Cond. 2</th>
<th>Cond. 3</th>
<th>Cond. 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inserted Refrigerant</td>
<td>4.06kg</td>
<td>6.6kg</td>
<td>4.12kg</td>
<td>6.22kg</td>
</tr>
<tr>
<td>Discharged Oil</td>
<td>7ml</td>
<td>10ml</td>
<td>2ml</td>
<td>7ml</td>
</tr>
<tr>
<td>Average Intensity (ppm)</td>
<td>5501.7</td>
<td>8849.9</td>
<td>2864.5</td>
<td>6686.2</td>
</tr>
</tbody>
</table>

4.2 Rotary Compressor with Visualizing Window
The conditions 5 and 6 are shown in Fig. 14 for Exp. I with changing the inlet temperature. However, there is not much change for the intensities between those two conditions as shown in Fig. 15 and Table 2. The differences of the conditions 7, 8, and 9 for Exp. I are outlet pressures controlling the valve around the exit nozzle (Fig. 16). The average intensity increases if the outlet pressure increases as shown in Fig. 17. From the results, it is realized that the amount of the oil is influenced more by the outlet pressure than by the inlet temperature as shown by Table 2.

The effects of the outlet pressure have also been investigated by the average intensities using Exp. II as shown in Fig. 18 for 6 different pressures. The results have also been drawn in the graph for the relationship between the outlet pressure and the oil distribution in the upper part of the compressor.
Figure 15: Captured images of Exp. I;
(a) Top view of condition 5,
(b) Top view of condition 6,
(c) Side view of condition 5, and
(d) Side view of condition 6.

Figure 14: Cyclomatic chart of Exp. I for conditions 5 and 6.

Figure 13: Oil behaviors by inlet pressure;
(a) 1 bar and (b) 2 bar.

Figure 12: Captured images for test model;
(a) 2bar and 77°C for side view,
(b) 2bar and 77°C for top view,
(c) 2bar and 57°C for side view, and
(d) 2bar and 57°C for top view.

Figure 15: Captured images of Exp. I;
(a) 2bar and 77°C for side view,
(b) 2bar and 77°C for top view,
(c) 2bar and 57°C for side view, and
(d) 2bar and 57°C for top view.
Figure 16: Cyclomatic chart of Exp. I for conditions 7, 8, and 9.

Figure 17: Captured images of Exp. I:
(a) 13.1 bar, (b) 16.2 bar, and (c) 20.7 bar.

Figure 18: Captured images for Exp. II:
(a) 11.4 bar, (b) 12.0 bar, (c) 13.5 bar, (d) 17.2 bar, (e) 18.8 bar, (f) 22.8 bar.

Figure 19: Outlet pressure of rotary compressor intensity.
Table 2: Average intensities with various conditions.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Inlet Temperature (°C)</th>
<th>Outlet Temperature (°C)</th>
<th>Outlet Pressure (bar)</th>
<th>Average Intensity of Top View (%)</th>
<th>Average Intensity of Bottom View (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>26.3</td>
<td>89.3</td>
<td>11.8</td>
<td>53.09</td>
<td>60.10</td>
</tr>
<tr>
<td>6</td>
<td>30.0</td>
<td>90.6</td>
<td>11.9</td>
<td>53.20</td>
<td>60.48</td>
</tr>
<tr>
<td>7</td>
<td>29.6</td>
<td>95.6</td>
<td>13.1</td>
<td>56.43</td>
<td>60.78</td>
</tr>
<tr>
<td>8</td>
<td>30.0</td>
<td>106.1</td>
<td>16.2</td>
<td>60.78</td>
<td>64.86</td>
</tr>
<tr>
<td>9</td>
<td>30.1</td>
<td>123.6</td>
<td>20.7</td>
<td>75.32</td>
<td>76.32</td>
</tr>
</tbody>
</table>

5. CONCLUSION

For the case of the test-model experiment, it was found that the amount of the exhausted oil changed by the internal temperature. That is, the amount of discharged oil increased with increasing the internal temperature. The inlet pressure and the exhausted oil increased if the temperature of refrigerant increased.

The visualization technique was developed to analyze the oil behavior inside the rotary compressor with visualizing windows. The amount of the oil was not affected much by the inlet temperature. However, the oil behaviors in the upper side of the compressor were influenced much by the outlet pressure.

NOMENCLATURE

I  intensity
M  number of pixels in vertical direction
N  number of pixels in horizontal direction

REFERENCES


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