The Effect of Water Contents of POE on Scuffing Characteristics

H. Nakao  
*Mitsubishi Electric Corp.*

K. Matsukawa  
*Mitsubishi Electric Corp.*

Y. Shirafuji  
*Mitsubishi Electric Corp.*

S. Sekiya  
*Mitsubishi Electric Corp.*

Follow this and additional works at: https://docs.lib.purdue.edu/icec

https://docs.lib.purdue.edu/icec/1387
The Effect of Water Contents of POE on Scuffing Characteristics
Hideto Nakao, Koei Matsukawa, Yoshinori Shirafuji, Shin Sekiya
Mitsubishi Electric Corporation
8-1-1 Tsukaguchi-Honmachi, Amagasaki, Hyogo 661-8661, Japan

Abstract

The conditions, required for applying POE to refrigerating oil of rotary compressor using HFCs, were examined. It became clear that the vanes and pistons are more likely to scuff when the water content is high, however, the scuffing pressure of the sliding bearings is less likely to be affected by the water content. The use of POE with optimized extreme pressure additives and controlled water content ensures more excellent scuffing characteristics than that when a conventional refrigerating atmosphere or other refrigerating oils are used, and contributes to the reduction of sludge.

Therefore, rotary compressors using POE with optimized EPAs and controlled water content are reliably manufactured.

1. Introduction

HFCs (hydrofluorocarbons) have come to be increasingly used as the refrigerant in air-conditioning equipment in order to protect the ozone layer. HFCs, unlike the conventional refrigerant HCFCs (hydrochlorofluorocarbons), do not contain chlorine atoms in their molecular structure, and hence are likely to cause defective boundary lubrication.

Further more, polyolester (POE), one of the refrigerating oils for HFCs, is degraded when it coexists with contaminants such as water and chlorine, and is likely to deteriorate the lubrication performance and increase the quantity of sludge.

Hence, in order to clarify the conditions required for using POE as a refrigerating oil, scuffing experiments were conducted using both the materials used in sliding bearings and crankshafts and the materials used in vanes and pistons in rotary compressors. The quantity of sludge processed was also evaluated using rotary compressors. The results of the tests are reported below.

2. Experimental Method

2.1 Scuffing experiments

2.1.1 Common conditions in scuffing experiments

The scuffing apparatus equipped with a disc-on-disc type test piece shown in Figure 1 was used. The sliding area of the test piece was 0.16 cm² and the surface roughness was 1.0 µmRz. The temperature at the start of the test was 298 K, the atmospheric pressure was 1.1 MPa and the sliding speed was 2.6 m/s. A step loading system was employed, adding 98 N every 60 seconds starting from the no-load state. Scuffing was defined as taking place when the friction coefficient exceeded 0.6 during the test.

2.1.2 Scuffing experiments of the sliding bearings

(1) Selection of refrigerating oil

First of all, the refrigerating oil selection experiments were carried out. Two major refrigerating oils for HFCs, POE and polyvinylether (PVE), were selected and two lubricants, a mixture of R407C and POE (R407C/POE) and a mixture of R407C and PVE (R407C/PVE), were used for the experiments. The viscosity grade of POE was VG56 and that of PVE was VG68. Two types of the oils, one with an extreme pressure additive (EPA) and the other without any EPAs were also used. The concentration of refrigerating oil against the refrigerant was set to 5 wt.%. The sliding
bearing material (cast iron) was used on the fixed side and the crankshaft material (cast iron) was used on the rotating side.

(2) Optimization of EPAs to POE

Two types of EPAs, Type A and Type B, were added and the quantity of EPAs to the POE was optimized regarding the scuffing performance.

(3) Consumption of EPAs

The experiments were conducted using a similar test machine to the one shown in Figure 1 to clarify the relation between the sliding time and the consumption of the EPAs in POE. The sliding area of the test piece was 0.96 cm² and the surface roughness was 1.0 μmRz. The test was carried out at the temperature of 328 K and in atmospheric air. The sliding speed and the load were set to 0.96 m/s and 13.3 MPa, respectively. The maximum sliding time was 14000 hours. The sliding bearing material (cast iron) was used on the fixed side and the crankshaft material (cast iron) was used on the rotating side.

(4) Effect of water contents

The scuffing experiments with the water content as the parameter were conducted using both sliding bearing and crankshaft materials, under the test conditions shown in Table 1.

2.1.3 Scuffing experiments of vanes and pistons

A mixture of the conventional refrigerant HCFC22 (R22) and mineral oil (MO) (R22/MO), and a mixture of R407C and POE were used as lubricants. Water was added from 40 to 1000ppm to the refrigerating oil before conducting the scuffing experiments. The concentration of the refrigerating oil against the refrigerant was set to 20 wt.%. As for the materials, vane materials (high speed steel for R22/MO and nitride high speed steel for R407C/POE) were used on the fixed side and piston material (cast iron) was used on the rotating side for all the lubricants.

2.2 Oil deterioration experiments

(1) Sludge generation

In order to examine the oil deterioration, the quantity of sludge was measured using rotary compressors. It should be noted here that the sludge is hardly generated when using oil with a normally controlled quantity of contaminants. In this test, manufacturing contaminants, air and water were added to speed up the evaluations. The operating time was set to 2000 hours and the two lubricants, R407C/POE and R407C/PVE, were used.

(2) Sealed gas tube test

The sealed gas tube test (SGT) of POE was conducted under the test conditions given in Table 2.

3. Results and discussions

3.1 Scuffing experiments of the sliding bearings

(1) Selection of refrigerating oil

The results of the scuffing experiments are shown in Figure 2. The figure indicates that the scuffing pressure of R407C/POE was as high as that of R407C/PVE in the case of oil without EPAs. In the case of the oil with EPA, however, the scuffing pressure of R407C/POE was higher than that of R407C/PVE. This is attributed to the fact that the adsorption of PVE to the surface is higher than
that of the EPA, causing the adsorption of the EPA to the surface blocked by PVE. The adsorption of POE to the surface, on the other hand, is equivalent to or lower than that of the EPA, causing no blockage of the adsorption of the EPA to the surface. From the above results POE with the EPA was selected as the refrigerating oil.

(2) Optimization of EPAs to POE

Figure 3 shows the relationship between the quantity of the EPAs and the scuffing pressure when either Type A or Type B was added to POE. It can be seen from Figure 3 that there is an optimum quantity of the EPAs when either Type A or Type B is added at the quantity between a1 to a2. Figure 4 shows the relationship between the quantity of the EPAs added and the scuffing pressure when both Type A and Type B are added to POE. The scuffing pressure has also the maximum value when the quantity of Type A and Type B is from a1 to a2 as shown in Figure 4. This is considered that excessive formation of the extreme pressure film causes corrosion, resulting in the deterioration of the scuffing pressure. From the above results, it can be deduced that there is an optimum level of the quantity of the EPAs, which should be added to POE, indicating that the highest scuffing pressure can be maintained by adding the optimum quantity of EPAs.

(3) Consumption of EPAs

Figure 5 shows the relationship between the sliding time and the consumption of EPAs, and Figure 6 shows the EPMA analytical results of the test pieces. Figure 5 indicates that the consumption of either of the two EPAs, Type A or Type B, has the tendency to become saturated as time elapses. The analytical results in Figure 6 show that the quantities of both C and D, the extreme pressure elements, detected tend to become saturated with the elapse of time, indicating that a certain quantity of the extreme pressure film is formed immediately after the operation starts. After this the quantities consumed are limited to the amount of EPAs supplied to the newly formed surface due to boundary lubrication.

In order to confirm the reliability of POE regarding scuffing pressure after the EPAs were consumed in sliding, the scuffing experiments were carried out by adding quantities of EPAs equivalent to the residue after the operation lasting for 14000 hours shown in Figure 5 to the new POE oil. The test conditions were the same as in section 2.1.1. The test results are given in Figure 7. For comparison, the results of POE with the optimum quantity level (a1) of Type A and Type B and PVE (additive) are also shown in the figure.

From Figure 7, at the residual EPAs after 14000 hours operation, we can see that the scuffing pressure is lower than that of the new POE but higher than that of the new PVE. Therefore, there is no problem in the scuffing performance of the rotary compressor during actual operation.

(4) Effect of water contents

Figure 8 shows the relationship between the water contents and the scuffing pressure. We can see from Figure 8 that the scuffing pressure of the sliding bearing and crankshaft materials hardly shows any change.

3.2 Scuffing experiments of vanes and pistons

Figure 9 shows the results of scuffing experiments with both the vanes and pistons materials. From Figure 9, the scuffing pressure of R22/MO is hardly affected by the water content, but that of R407C/POE is decreased as the water content increases. This may be attributed to the fact that it is difficult for MO to be degraded due to hydrolysis whereas POE is easily degraded. Further, the
surfaces of both the vanes and piston materials have a higher local temperature than that of the sliding bearing and crankshaft materials due to friction, causing degradation to take place when the water content is high. The following test was conducted to verify this phenomenon experimentally.

The friction coefficients between the vane and piston materials, and between the sliding bearing and crankshaft materials were measured, under the conditions in Table 3. Table 4 shows the ratio of the friction coefficient of the sliding bearing and crankshaft as 1. Table 4 shows that the friction coefficients between the vane and piston materials are higher than that between the sliding bearing and crankshaft materials. It is considered, therefore, that the friction coefficient between the vane and piston materials is higher than that between the sliding bearing and crankshaft materials, causing the calorific power to increase. This in turn brings about the degradation of POE when the water content is high, causing the scuffing pressure to decrease.

3.3 Oil deterioration experiments

(1) Sludge generation

Figure 10 shows the total sludge quantities of rotary compressors after 2000 hours as the ratio of the total sludge quantity for R22/MO as 1. From Figure 10, the sludge generated by the rotary compressor using R407C/POE is approximately two-thirds of that for R407C/PVE, and is almost equivalent to that for R22/MO. Therefore, it is evident that POE is also the most suitable as refrigerating oil for rotary compressors using R407C from the standpoint of the amount of sludge generated.

(2) Sealed gas tube test

The degradations of refrigerating oils are non-dimensionally expressed in the Figure 11. It is evident from Figure 11 that the degradation level of POE is the same as MO degradation when the water content in the POE is less than 100ppm, but it increases when the water content is more than 500ppm.

4. Conclusions

The following conclusions were obtained from the results.

(1) The vane and piston are more likely to scuff when the water content is high.
(2) The vane and piston are less likely to scuff in R407C/POE than in R22/MO, irrespective of the water content.
(3) The scuffing pressure of the sliding bearings is less likely to be affected by the water content.
(4) The use of POE with optimized EPAs and controlled water content in rotary compressors using HFCs ensures more excellent scuffing characteristics than that when a conventional refrigerating atmosphere or other refrigerating oils are used, and contributes to the reduction of sludge.
(5) The EPAs in POE, which is consumed during operation of the compressor, tend to become saturated with the elapse of operation time. The residual EPAs after saturation, however, ensure high scuffing performance.
(6) Rotary compressors using POE with optimized EPAs and controlled water content are reliably manufactured.

References

156-161.

2) Shinsuke Miki et al., The Effects of Tribo-Conditions and Antiwear Additive on the Degradation of an Ester Oil and Analyses of Degradation Products, 1998 International Compressor Engineering Conference at Purdue, pp. 147-152.


Table 1 Conditions of scuffing experiments

<table>
<thead>
<tr>
<th>Refrigerating Oil</th>
<th>POE (VG-56, No Additive)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil Density [wt.%]</td>
<td>5</td>
</tr>
<tr>
<td>Water Contents [ppm]</td>
<td>50, 80, 250, 500, 1000</td>
</tr>
</tbody>
</table>

Table 2 Conditions of SGT

<table>
<thead>
<tr>
<th>Refrigerant/Oil</th>
<th>R22/POE</th>
<th>R407C/POE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature [K]</td>
<td>448</td>
<td></td>
</tr>
<tr>
<td>Water Contents [ppm]</td>
<td>50, 100, 500, 1000</td>
<td></td>
</tr>
<tr>
<td>Time Length [days]</td>
<td>0 – 56</td>
<td></td>
</tr>
</tbody>
</table>

Table 3 Conditions of measurement of friction coefficients

<table>
<thead>
<tr>
<th>Atmosphere</th>
<th>In atmospheric air</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refrigerating Oil</td>
<td>POE (VG56, No Additive)</td>
</tr>
<tr>
<td>Sliding Pressure [MPa]</td>
<td>44</td>
</tr>
</tbody>
</table>

Table 4 Ratio of friction coefficients

<table>
<thead>
<tr>
<th>Materials</th>
<th>Ratio of Friction Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vanes and Pistons</td>
<td>2</td>
</tr>
<tr>
<td>Sliding Bearings and Crank shafts</td>
<td>1</td>
</tr>
</tbody>
</table>

Fig. 1 Scuffing apparatus
Fig. 2 Results of refrigerating oil selection

Fig. 3 Relationship between quantity of EPAs and scuffing pressure

Fig. 4 Relationship between quantity of EPAs and scuffing pressure

Fig. 5 Relationship between sliding time and consumption of EPAs

Fig. 6 EPMA analytical results

Fig. 7 Results of scuffing experiments

Fig. 8 Relationship between water contents and pressure

Fig. 9 Results of scuffing experiments with both vanes and pistons materials

Fig. 10 Total sludge quantities of rotary compressors

Fig. 11 Degradations of refrigerating oils