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ALKYLBENZENES FOR SPLIT AIR-CONDITIONERS WITH R410A PART1; RELIABILITY EVALUATION OF COMPRESSORS

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ABSTRACT

Alkylbenzenes (AB), which are barely miscible with HFC refrigerants, are chemically stable and show better anti-wear properties than polyolesters (POE). The objective of this study is to examine the possibility of ABs with R410A used in residential split air conditioners. For R410A/AB, R22/mineral oil (MO) and R410A/POE, the wear at sliding parts (vane and rolling piston) and the flow decline in a capillary tube are evaluated in the case of rotary compressor after the durability test on overload condition. In addition, the bearing lubrication on flood-back and flooded-start conditions is evaluated. As the results, the system applying R410A/AB shows better properties than the one applying R22/MO as well as R410A/POE.

1. INTRODUCTION

From the viewpoint of the earth environment conservation, HCFC refrigerants are decided to be abolished by 2020. Switching from HCFC to HFC refrigerants, which do not destroy the ozone layer, are advanced rapidly. Now, as an alternative refrigerant for residential use R410A (R32/R125 =50/50wt%) is a powerful candidate.

As refrigerating oils for HFC refrigerant, three candidates, AB, POE and polyether, are mainly investigated. General characteristics of the refrigerating oils above when they are applied to HFC and MO to HCFC are shown in Table 1. POE has high miscibility with HFC refrigerants, but has weak points that hygroscopic property is high and easy to deteriorate by hydrolysis. Therefore it is required to control strictly the contamination in the manufacturing process of air conditioner when we use POE. Especially, the amount of moisture contained in the process should be extremely little. Polyether has high miscibility with HFC and does not hydrolyze, but has disadvantages, that is, oxidation stability, hygroscopic property and production cost are inferior to POE. AB is much superior to above two oils with every respect, except that miscibility with HFC refrigerant is extremely low[1],[2],[3]. For air-conditioners to be accompanied with installations, when we use AB as a refrigerating oil, high quality can be maintained due to its high chemical stability. In addition, for rotary compressors having sliding parts(vane and rolling piston), at which lubrication state is severe, high reliability can be obtained when we use AB, due to its good lubricity.

Table 1. General characteristics of refrigerating oils

Refrigerant	HCFC	HFC		
Refrigerating Oil	MO	AB	POE	polyether
Lubricity	○	○	○	△
Oxidation stability	○	○	○	△
Hydrolytic stability	○	○	△	○
Hygroscopicity	○	○	△	△
Miscibility	○	×	○	○
production cost	○	○	△	△

So, we paid our attention to AB and investigated the possibility of its use for room air-conditioner using R410A with a 2-cylinder rotary compressor. In this paper, as part I, we discuss reliability evaluation results of the compressor, for which AB is used as a refrigerating oil.

2. OUTLINE OF TESTED COMPRESSORS

2.1 Specification and structure

Major specifications of tested compressors are shown in Table 2 and the cross sectional view of them is shown in Figure 1. Both a new(R410A) and a current(R22) compressors have rated power of about 0.75 kW and are rotary type with two cylinders, driven by an inverter. The displacement of the new compressor is reduced to 70 % of that of the current compressor by shortening cylinder height in order that both compressors have almost the same cooling capacity. Furthermore, surface treatment is enforced on the vane that is the severest sliding part for the new compressor, in order to increase anti-wear characteristics. This is because the surface pressure on the tip of vane for the new compressor is higher than that for the current compressor and the lubricating ability of R410A is inferior to that of R22. As a refrigerating oil, either AB having viscosity grade of VG22 or POE having that of VG56 is used for the new compressor, and MO having viscosity grade of VG56 is used for the current compressor.

2.2 Viscosity characteristics of refrigerating oils with refrigerant

The viscosity of R410A/AB, R410A/POE and R22/MO in an oil reservoir of compressor is shown in Figure 2. Horizontal axis is oil temperature and condensation temperature(CT), implies saturation pressure in the oil reservoir, is 50°C. The viscosity of these three oils is almost equal in the range of high oil temperature. But in the range of low oil temperature, the viscosity of R22/MO and R410A/POE falls sharply so that the refrigerant is easy to dissolve into oil. On the other hand, even in the range of low oil temperature R410A/AB can keep high viscosity so that the refrigerant hardly dissolves into oil.

Table 2. Specifications of tested compressor

Items	New		Current
Refrigerant	R410A		R22
Refrigeranting oil	AB	POE	MO
Displacement(cc)	9.2		13.0
Rated power(kW)	0.75		0.75
Surface treatment on vane	done		not done

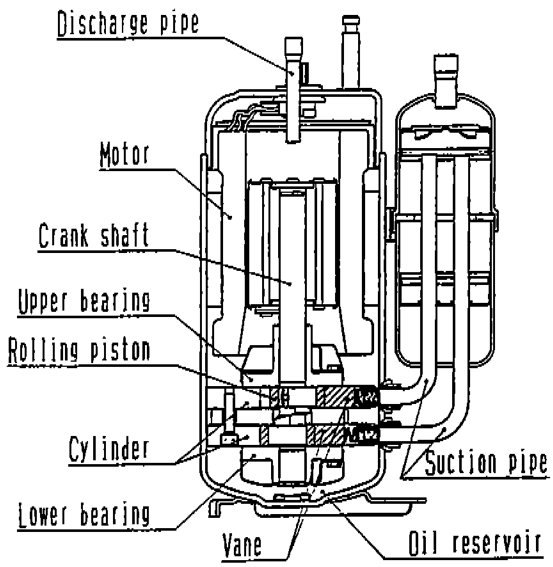


Figure 1. Cross sectional view of tested compressor

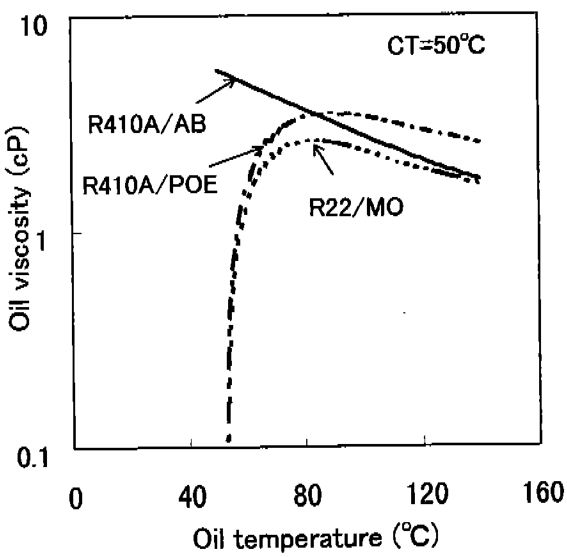


Figure 2. Oil viscosity in oil reservoir

3. RELIABILITY IN OVERLOAD CONDITION

Durability tests with units on an overload condition were enforced. Test conditions are shown in Table 3.

3.1 Clogging of capillary tube

Section photographs of capillary tubes after durability tests are shown in Figure 3. Operating time is 1000 hours. The quantity of sludge adhered to the inner wall side of the capillary tube is extremely little for R410A/AB, in comparison with that for R410A/POE and R22/MO. The main component of sludge for R410A/POE is metallic soap caused by deterioration of oil at sliding parts of the compressor. And that for R22/MO is inorganic substances caused by a reaction between metal and chlorine atoms which are contained in R22. On the other hand, that for R410A/AB is also inorganic substances, but not a chloride and the quantity of sludge is less than that for R22/MO and R410A/POE. Because R410A has not chlorine atoms and AB barely deteriorates at sliding parts of compressors.

Table3. Test condition in durability test

Discharge pressure(MPa)	4.0～4.5
Suction pressure(MPa)	0.7～1.0
Discharge temperature(°C)	100～120
Rotational speed(s^{-1})	120

The ratio of mass flow rate in capillary tubes is shown in Figure 4. Horizontal axis is operating time. The ratio of mass flow rate represents the ratio of air mass flow rate after the above test to that before the test. The ratio after 4,000 hours exceeds 95% for R410A/AB, and it is larger than that for R22/MO and R410A/POE.

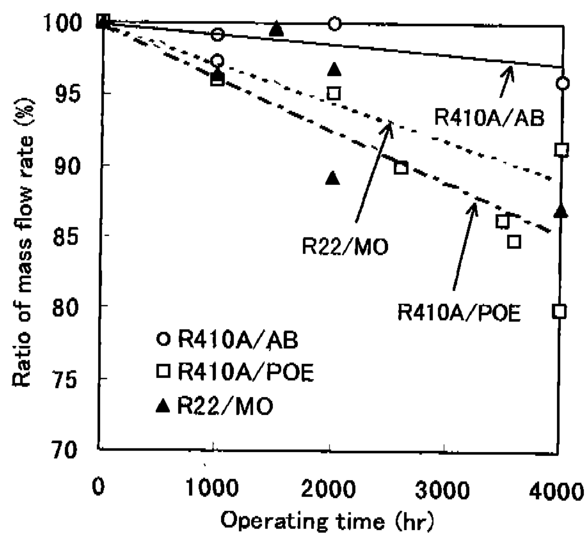
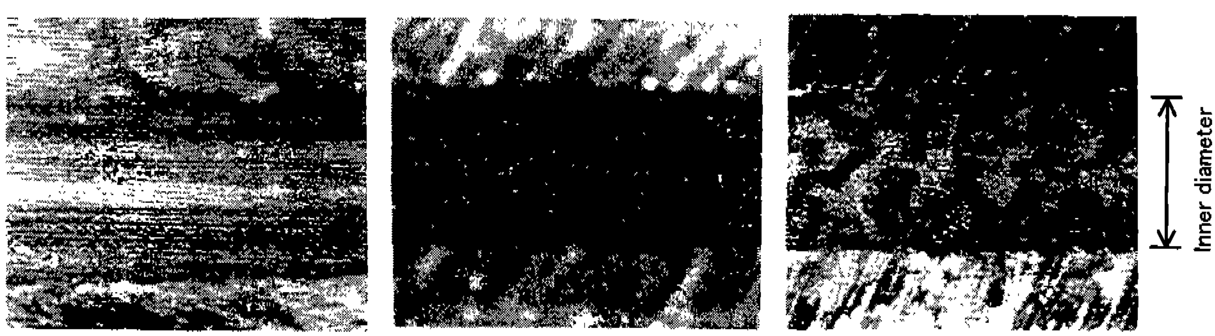


Figure 4. Clogging of capillary tube after durability test

3.2 Wear characteristics of sliding parts

The wear volume of vane and rolling piston after the above tests is shown in Figure 5. Horizontal axis is operating time. The wear volumes for both



(a) R410A/AB (b) R410A/POE (c)R22/MO

Figure 3. Section photograph of capillary tube after durability test

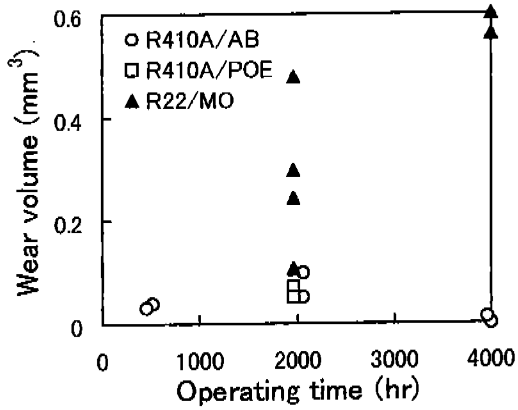
R410A/AB and R410A/POE are less than that for R22/MO by the effect of surface treatment on vane.

4. LUBRICATING CHARACTERISTICS OF JOURNAL BEARINGS

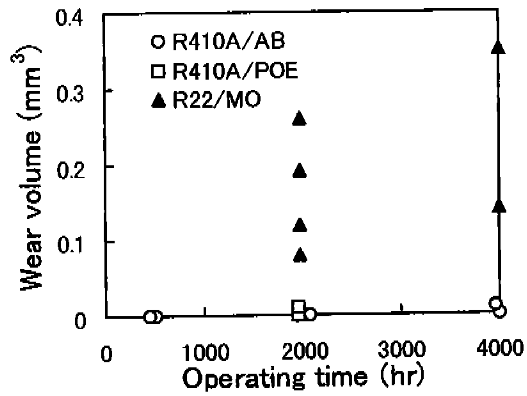
4.1 Evaluation of bearings on flooded-start condition

Because AB hardly dissolves with R410A, oil and liquid refrigerant are divided into two layers in the oil reservoir when liquid refrigerant accumulates in the compressor. Because specific gravity of AB is smaller than that of liquid refrigerant, oil forms the upper layer. Therefore on a severe flooded-start condition, which much liquid refrigerant accumulates in the compressor, the insufficiency of lubrication in journal bearings is anxious about. The worst case assumed here is that much liquid refrigerant is supplied to the bearings and oil is hardly supplied to those.

On this account we enforced an examination indicated as follows. The ambient air temperature in both outdoor and indoor unit was fixed to 2℃ at first. After 12 hours, the ambient air temperature in only the outdoor unit was risen to 7℃. The compressor was almost filled with liquid refrigerant and oil by this operation. The oil density in the oil reservoir was investigated in order to evaluate the supplying ability of oil to journal bearings after a flooded-start. Furthermore, the behaviors of oil and liquid refrigerant in the oil reservoir were observed through a sight glass mounted on the lower side of the compressor. A pipe was inserted into the oil reservoir and oil was able to be taken out into a container through this pipe in order to measure the oil density in the oil reservoir, as shown in Figure 6. The weight of the container was measured. And



(a) Rolling piston



(b) Vane

Figure 5. Wear characteristics of sliding part after durability test

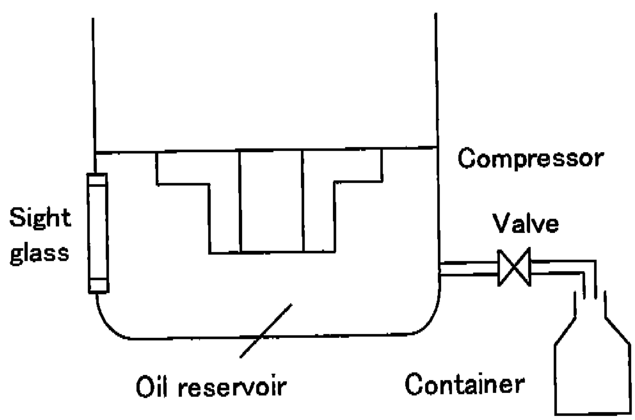


Figure 6. Schematic view of compressor lower side

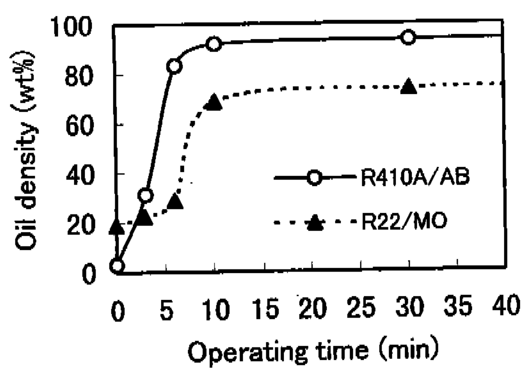


Figure 7. Oil density in oil reservoir on flooded-start

after liquid refrigerant in the container was evaporated, the weight of the container was measured again. The oil density was calculated by this operation.

The oil density after a flooded-start is shown in Figure 7 for R410A/AB and R22/MO. A solid line represents R410A/AB and a dashed line represents R22/MO. For R410A/AB the oil density is only a few percent before starting so that oil and liquid refrigerant are divided into two layers in the oil reservoir, but it rises rapidly and exceed that of R22/MO in about a few minutes. There are two reasons why recovery of the oil density is fast. One is that oil is never diluted, even oil temperature is low and there is a large quantity of flood-back. The other is that the oil density becomes almost uniform in an oil reservoir so that oil and refrigerant are stirred by the rotation of crank shaft. The above situation was observed through a sight glass. On the other hand for R22/MO, the oil density is about 20% before starting, but the increase of that is slow for several minutes after starting. After that, the oil density rises sharply. The reason why recovery of the oil density is slow is probably that much amount of liquid refrigerant continues to dissolve into oil for a while so that oil temperature rises slowly against the rapid increase of pressure inside the compressor. The same results as that for R22/MO was obtained for R410A/POE.

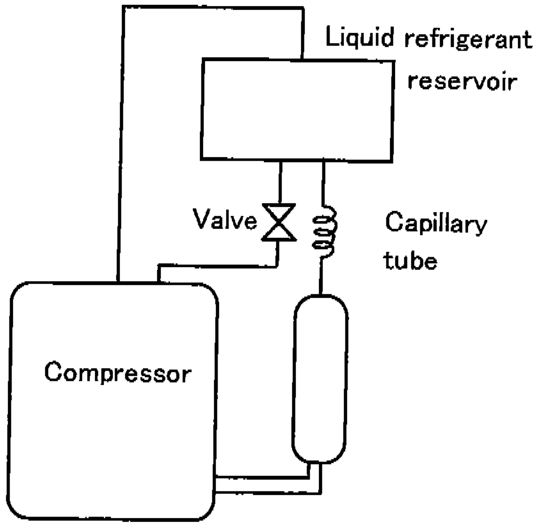


Figure 8. Test apparatus for durability test on flooded-start condition

Subsequently, we prepared a test apparatus shown in Figure 8 in order to evaluate durability of journal bearings on flooded-start conditions. A procedure of the test is shown in Figure 9. The compressor is almost filled with liquid refrigerant and oil before starting. After operating for 3 minutes, the compressor is stopped and valve is opened and liquid refrigerant is returned from a liquid refrigerant reservoir to the compressor. After this procedure was repeated 3, 000 times, wear characteristics of two journal bearings(upper and lower) was investigated. Results are shown in

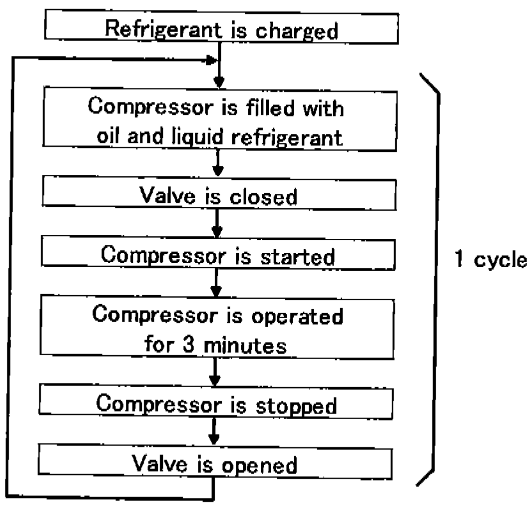


Figure 9. Flow of flooded-start durability test

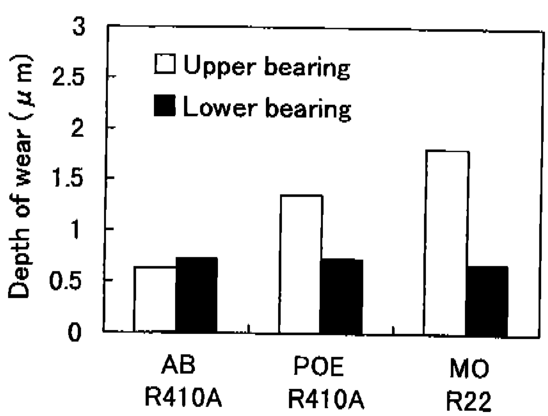


Figure 10. Wear depth of journal bearing after flooded-start durability test

Figure 10. The wear depth for R410A/AB is less than that for R410A/POE and for R22/MO.

4.2 Evaluation of bearings on continuous flood-back condition

We investigated the supplying ability of oil to journal bearings on the condition of the severest continuous flood-back for R410A/AB by using a compressor shown in Figure 6. The oil density was measured and the behavior of oil and liquid refrigerant in the oil reservoir was observed through a sight glass. And we confirmed that the oil density was sufficiently high so that oil and refrigerant were stirred acutely, and a separation between oil and liquid refrigerant did not occur. Finally, the accelerated durability tests on the above condition were executed for R410A/AB, R410A/POE and R22/MO and it was confirmed that wear rate of bearings after that test for R410A/AB was less than those for the other two oils.

As the results, the lubricating characteristics for R410A/AB is much superior to those for the other two oils, even on the severest flooded-start condition as well as on the severest continuous flood-back condition.

5. CONCLUSIONS

We investigated a possibility of adopting AB for an air conditioner with R410A, in comparison with R410A/POE and R22/MO. Clogging of a capillary tube and wear characteristics of sliding parts after durability tests on an overload condition were evaluated. And then the oil density in an oil reservoir and wear characteristics of journal bearings on a flooded-start condition were evaluated. Finally, wear characteristics of journal bearings on a continuous flood-back condition were also evaluated.

The evaluation results for R410A/AB are as follows in comparison with those for R410A/POE and R22/MO.

(1) A capillary tube after a durability test is extremely pure and drop of flow rate in that is least.

(2) Wear rate of sliding parts(vane and rolling piston) after the above test is least by the effect of surface-treatment on vane.

(3)The recovery of the oil density after a flooded-start is fastest so that oil and liquid refrigerant are stirred by a shaft's rotation and liquid refrigerant hardly dissolves into oil.

(4) Wear rates of journal bearings after durability tests on both the severest flooded-start and the severest continuous flood-back condition are least.

Consequently, it became clear that a higher reliability could be attained than a current system(R22/MO) as well as R410A/POE system by adopting AB for an air conditioner with R410A.

6. REFERENCES

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