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Abstract

The antiwear properties of alkylbenzene (AB) lubes as refrigeration lubes for HFCs were evaluated. ABs showed better antiwear properties than polyol ester (POE) lubes in the lubrication between the vanes and rollers. ABs with n-pentane also showed very good antiwear properties.

By chemical modification of ABs, new chemistries which are miscible with HFCs were developed. In the durability tests, AB derivatives showed similar antiwear properties to the immiscible ABs.

Introduction

As refrigeration lubes are required to have miscibility with refrigerants generally, poly alkylene glycols (PAGs) and POEs have been applied to automotive air conditioners and household refrigerators, respectively.

In Japan, rotary compressors have been applied mainly for large size household refrigerators and HCFC-22 has been adopted instead of R502 in most cases. Although POEs were tried with rotary compressors for HFCs as with reciprocating compressors at the beginning of the development, only ABs have been applied to rotary compressors for household refrigerators regardless of their immiscibility with HFCs because of their very good antiwear properties at the vanes and rollers, which could not be obtained from the combination with POEs.

The uncertain point in the use of immiscible lubes with refrigerants will be the oil return property to the compressors from the systems. Recently a new system in which a few mass percent of n-pentane is added to the refrigerant has been developed and marketed.

On the other hand, refrigeration lubes should be well miscible with the refrigerants in package air conditioners with very long refrigerant pipelines in order to keep good oil return properties.

This paper presents rotary compressor durability test results with ABs and ABs plus pentane, and describes the development of AB derivatives which are miscible with HFCs.

Experimental Procedure

Compressor Durability Tests

Compressor durability tests were conducted using the circuit shown in Figure 1. Short-term durability tests with current commercially available rolling piston compressors (both horizontal and vertical, for CFC-12 and HCFC-22) were conducted. The discharge gas was extracted with a needle valve and returned to the compressor inlet. The test conditions are shown in Table 1.

In test condition 1, the compressor temperature was set at 110℃ and the discharge pressure was set at 2.94 MPa. The test period was 2000 hours. In test condition 2, the compressor temperature was set at 150℃ in order to observe the effect of the test temperature, and the frequency was accelerated in order to observe the effect of the rotating speed in conditions 3 and 4. In condition 5, the differences between AB and POE were examined under medium test conditions using vertical compressors.

ABs with a viscosity range from VG 5 to 68 were used in these durability tests. POEs with the viscosities of VG 32 and 68 were also evaluated as references. Mineral oils of VG 32 and 56 were used with CFC-12 or HCFC-22 to determine the standard levels. The compressors were torn down after the tests and the surface roughness of the sliding materials like the vanes, rollers, shafts, bearings, etc., was inspected.

Solubility of Refrigerant

Using the testing device shown in Figure 2, the solubility of HFC-134a into AB and mineral oil and the viscosity of the mixture were measured. The tested oils were AB with the viscosity of 8.1 mm^2/s at 40℃ and mineral oil with the viscosity of 9.6 mm^2/s at 40℃.

Physical Properties and Oil Return Properties of AB with Pentane

The kinematic viscosity of the mixture of AB and pentane was measured at 0℃ and -20℃. A Cannon-Fenske type viscometer was used for the measurement of kinematic viscosity at 0℃. At -20℃, the absolute viscosity was measured using a rotary viscometer, and it was converted to kinematic viscosity.

Using the testing device shown in Figure 3, the oil return properties of ABs with n-pentane were evaluated. A copper tube 1.5 m in length and 3.6×10^{-3} m in inner diameter was wrapped into a coil, and a specified amount of oil was kept inside the tube at a fixed temperature while HFC-134a was passed through the tube at the rate of 0.001 m^3/min. After the oil-refrigerant mixture was recovered, the weight of the remaining oil was measured.

Results and Discussion

Compressor Durability Tests

The durability test results are shown in Table 2 for test condition 1. Low viscosity ABs showed better antiwear properties than mineral oil with CFC-12 regardless of the addition of antiwear additives. In the test of AB-L, a slight touchdown was found at the shaft and bearing part. This problem seemed to happen because of the lack of the viscosity at which the hydrodynamic film can be maintained at the bearing part. In the evaluation of POE (VG 32), only POE without antiwear additives showed mild wear in a test for about 1000 hours.

In test condition 2, the antiwear properties were evaluated in different oils at 150℃ as the compressor temperature. In this condition, no abnormal wear was observed clearly in either AB or POE. (Table 3)

In test condition 3, durability tests with accelerated frequency were conducted at 150℃ of compressor temperature. In the evaluation of POE (VG 68), medium wear was found in the case without antiwear additives, and slight wear was found in the case with phosphate additive (PA). The wear was modified in the case with activated phosphorus compounds (PB, PC), and the best antiwear property was shown in the case of AB with PA additive. A durability test with the current mineral oil (VG 56) and CFC-12 combination was conducted as a reference, and the antiwear properties were the same as with POE plus PB or PC. (Table 4)

In test condition 4, the difference of the antiwear properties among the ABs of different viscosity from VG 5 to VG 15 was tested under the same conditions as test condition 3. In regard to the test with POE as a reference, VG 32, the lower viscosity one, was evaluated. Although ABs without antiwear additives showed a larger wear width at the vane tip, the surface of the vane and roller was not very rough. Among them, AB VG 8 showed the best results in this test condition. It is suggested that refrigeration lubes with higher viscosities do not always maintain better antiwear properties between the vanes and rollers in rotary compressors. On the hand, although the wear width of the vane tip was not very large in the case of POE, the surface roughness was very severe at both the vane tip and roller. Not only the selection of the type but also the optimization of the viscosity of refrigeration lubes seems one of the important issues for the HFC systems. The combination of the current mineral oil (VG 32) and HCFC-22 was also tested as a reference, and almost the same results as those for ABs without antiwear additives were found. (Table 5)

In test condition 5, vertical rotary compressors were used for the durability evaluations at 130℃ with highly accelerated frequency. Though POE with PC additive, which showed comparatively good results in test condition 3, showed only slight wear, POE with PB produced very severe wear. AB with PA was evaluated and the vane tip remained very smooth; very slight wear was found at the surface of the roller, though. (Table 6)

Summarizing these results, it was confirmed that the wear between the vane tips and rollers in the HFC systems was accelerated at very high temperatures like 130℃ or 150℃ and high frequency. In regard to the difference of the antiwear properties among the different oils, the combination of AB and HFC showed the best results. Mineral oil with CFC or HCFC showed better results than the combination of POE and HFC. Antiwear additives improved the wear between the vane and roller. In the case of POE, more active additives are required.

Solubility and Viscosity of the Mixture of AB and HFC

The solubility of HFC-134a into AB VG 8 and mineral oil VG 9, and the viscosities of the mixtures were measured. The test results are shown in Table 7. AB dissolved twice as much HFC-134a as mineral oil, the viscosity of the mixture became much lower than that of mineral oil. As shown in Figure 4, AB can be expected to have better oil return property.

Viscosity Characteristics of the Mixture of AB and n-Pentane

The viscosity characteristics of the mixture of AB and n-pentane were evaluated and the results are shown in Table 8. In this case, 5, 10, 20, 30 mass % of n-pentane was mixed with AB VG 32. In the measurement at -20℃, the obtained absolute viscosity was converted into kinematic viscosity.

In the measurement of the 5 mass % mixture of n-pentane to AB, the viscosity at 0℃ seemed similar to the viscosity of AB VG 15 at 0℃. The viscosity of the 10 % mixture of n-pentane at 0℃ was similar to that of AB VG 8, and the viscosity at -20℃ was similar to that of AB VG 15. The viscosity of the 20 % mixture was similar to that of AB VG 5.

Oil Return Property of the Mixture of AB and n-Pentane

The oil return test results of the mixture of AB (VG 32) and 5 mass % and 10 mass % of n-pentane are shown in Table 9 and Figures 3, 4. The oil return ratio at 0℃ and 30 min. (30.5 % for the 5 % mixture, and 33.8 % for the 10 % mixture) was inferior to that of AB VG 8 (42.4 %). On the other hand, the oil return ratio of the 5 % mixture at -20℃ (16.6 %) was much better than that of AB VG 22 (2.4 %), although their viscosities at -20℃ were almost the same. Thus it was confirmed that n-pentane plays the role of an oil carrier, especially at low temperature.

Compressor Durability Tests with the Mixture of AB and n-Pentane

Compressor durability tests with horizontal rotary compressors were conducted with the mixture of AB and n-pentane in test condition 3. Antiwear additive, PA, was added to the mixture of AB (VG 8 and VG 32), and 5 % of pentane. The test results are shown in Table 10.

The vane tips and rollers were very smooth in both cases, and no touchdown was found between the shafts and bearings, the parts of the hydrodynamic lubrication, even with the low viscosity lube, the mixture of AB VG 5 and n-pentane.

The Chemistry of the Derivatives of AB

The distinctive feature of AB refrigeration lube for HFCs is immiscibility with the refrigerant, and it is considered to be the sole problem in the use of ABs with HFCs. In order to give good miscibility to ABs while maintaining good antiwear property, polar bases, which are expected to have good miscibility with HFC, were introduced to ABs, and AB-X's were synthesized. The physical properties are shown in Table 11. Miscibility with HFCs was freely controlled by the chemical structure of polar base X's.

Compressor Durability Test with AB Derivatives

Compressor durability tests with horizontal rotary compressors were conducted with AB derivatives in test condition 3. AB-X2 (VG 68) was evaluated as base stock with and without antiwear additive PA. The test results are shown in Table 12.

In the test without PA, the wear width at the vane tip was comparatively large and the roughness of the vane tip and roller did not seem good. On the other hand, AB-X2 with PA showed very good results, the wear was quite narrow and the sliding surface was very smooth. Durability tests are also being conducted for AB-X1, which is completely miscible with HFCs.

Summary

In the antiwear tests of the lubes with rotary compressors, the results were good in the order of ABs with HFCs, current mineral oils with CFC-12 or HCFC-22, and POEs with HFCs. Although the current phosphate type antiwear additive, having the same polarity as POEs, did not work with POEs, it was very effective with ABs. It was suggested that the determination of the viscosity of lubes would be one of the important issues for HFC systems.

The addition of n-pentane was found to be effective for the oil return property in the systems where immiscible ABs were used, especially at low temperature. It was confirmed that the mixture of n-pentane did not affect the antiwear property.

Miscible ABs to which polar base X's were chemically introduced were developed. AB-X2, which has a wider miscible zone than ABs, showed the same antiwear property in the compressor test as ABs. In regard to AB-X1, which is completely miscible with HFCs, durability tests are being conducted.

References

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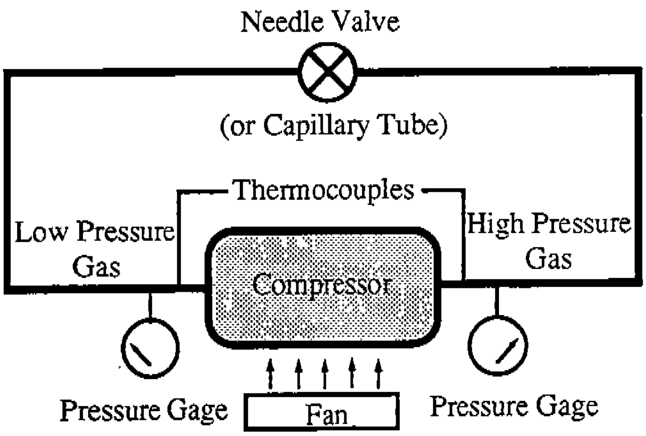

Fig 1 Circuit of Compressor Durability Tests

Table 1 Compressor Test Conditions

Test Method	Comp.	Td. °C	Pd. MPa	Ps. MPa	Frequency	Period hrs	Refrigerant
A	Horizontal	110	2.94	0.157	Stand.	2000 (1000)	HFC-134a
B	Horizontal	150	1.67	0.098	Stand.	720	HFC-134a
C	Horizontal	150	1.67	0.098	Accel.	720	HFC-134a
D	Horizontal	150	1.67	0.098	Accel.	1000	HFC-134a
E	Vertical	130	2.06	0.294	Accel.	1000	HFC-134a

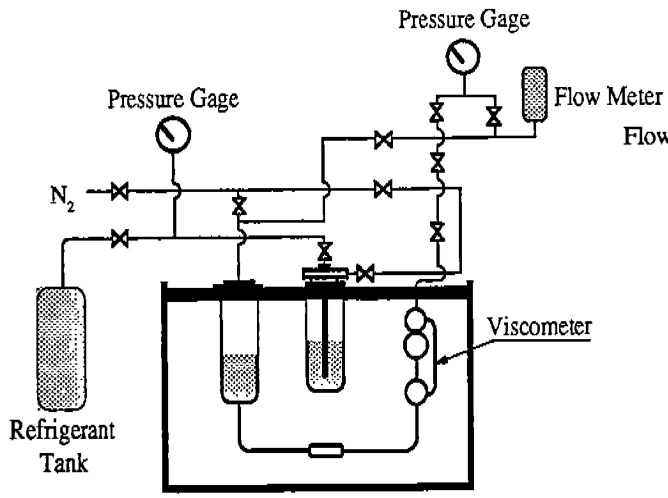

Fig 2 Testing Device for Solubility of Refrigerants into Oils

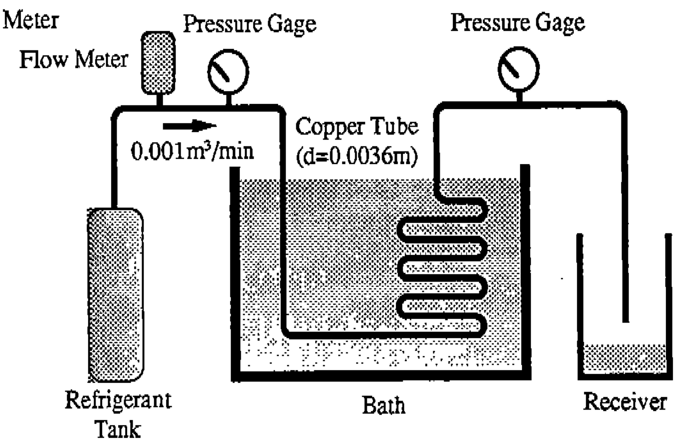

Fig 3 Testing Device for Oil Return Property

Table 2 Compressor Durability Test, Condition 1

Base Oil	VG	Add.	Refrigerant	Period hrs	Roughness, Ra Vane / Roller	(Appearance)
AB-B	8	None	HFC-134a	2000	0.06 / 0.12	(A / B)
	8	PA	HFC-134a	2000	0.06 / 0.12	(A / B)
AB-L	5	PA	HFC-134a	2000	0.08 / 0.19	(A / B)
POE	32	None	HFC-134a	1000	0.20 / 0.29	(C / C)
	32	PA	HFC-134a	1000	0.05 / 0.11	(A / B)
Mineral	32	None	CFC-12	1000	0.06 / 0.10	(A / B)

Appearance: A: Very Smooth, B: Smooth, C: Medium, D: Rough, E: Very Rough

Table 3 Compressor Durability Test, Condition 2

Base Oil	VG	Add.	Refrigerant	Wear Width Vane, mm	Roughness, Ra Vane / Roller	(Appearance)
AB-B	8	PA	HFC-134a	1.22	0.05 / 0.10	(A / B)
POE	68	None	HFC-134a	1.20	0.04 / 0.17	(A / B)
	68	PA	HFC-134a	1.25	0.05 / 0.10	(A / B)
Mineral	56	None	CFC-12	1.23	0.05 / 0.16	(A / B)

Appearance: A: Very Smooth, B: Smooth, C: Medium, D: Rough, E: Very Rough

Table 4 Compressor Durability Test, Condition 3

Base Oil	VG	Add.	Refrigerant	Wear Width Vane, mm	Roughness, Ra Vane / Roller	(Appearance)
AB-B	8	PA	HFC-134a	1.12	0.04 / 0.06	(A / A)
POE	68	None	HFC-134a	1.71	0.23 / 0.24	(C / C)
	68	PA	HFC-134a	1.82	0.19 / 0.19	(B / B)
	68	PB	HFC-134a	1.26	0.08 / 0.09	(A / A)
	68	PC	HFC-134a	1.23	0.06 / 0.08	(A / A)
Mineral	56	None	CFC-12	1.16	0.08 / 0.11	(A / B)

Appearance: A: Very Smooth, B: Smooth, C: Medium, D: Rough, E: Very Rough

Table 5 Compressor Durability Test, Condition 4

Base Oil	VG	Add.	Refrigerant	Wear Width Vane, mm	Roughness, Ra Vane / Roller	(Appearance)
AB-L	5	None	HFC-134a	2.04	0.17 / 0.19	(B / B)
AB-B	8	None	HFC-134a	1.65	0.19 / 0.19	(B / B)
	8	PA	HFC-134a	1.10	0.06 / 0.08	(A / A)
	10	None	HFC-134a	1.88	0.10 / 0.11	(B / B)
	15	None	HFC-134a	2.01	0.19 / 0.19	(B / B)
POE	32	None	HFC-134a	1.67	1.00 / 1.00	(E / E)
Mineral	32	None	HCFC-22	1.93	0.27 / 0.20	(C / B)

Appearance: A: Very Smooth, B: Smooth, C: Medium, D: Rough, E: Very Rough

Table 6 Compressor Durability Test, Condition 5

Base Oil	VG	Add.	Refrigerant	Roughness, Ra Vane / Roller	(Appearance)
AB-B	8	PA	HFC-134a	0.07 / 0.16	(A / B)
POE	68	PA	HFC-134a	1.09 / 1.09	(E / E)
	68	PB	HFC-134a	0.98 / 0.99	(E / E)
	68	PC	HFC-134a	0.11 / 0.11	(B / B)

Appearance: A: Very Smooth, B: Smooth, C: Medium, D: Rough, E: Very Rough

Table 7 Solubility of HFCs into AB and Mineral Oil

Temp. °C	Pressure MPa	AB-B1 (8.2) Solubility mass %	AB-B1 (8.2) Viscosity mm²/s	Mineral (9.6) Solubility mass %	Mineral (9.6) Viscosity mm²/s
-20	0.098	6.1	124	4.8	210
	0.110	12.0	73	5.3	190
0	0.147	4.9	32	2.8	50
	0.196	6.8	24	3.4	48
	0.245	9.9	18	3.9	44

Table 8 Viscosity of the Mixture of AB VG 32 and n-Pentane

n-Pentane mass %	Kinematic Viscosity mm^2/s @ 0°C	Kinematic Viscosity mm^2/s @ -20°C
0	650	8600 (7650)
5	154	2420 (2130)
10	49	1440 (1250)
20	13	
30	5	
AB VG 8	51	240
VG 15	145	1000
VG 22	294	2690

( ) = Absolute Viscosity, mPa s

Table 9 Oil Return Rate of AB / n-Pentane Mixture, mass%

Temp. °C	AB (VG 32) + n-Pentane 0 %	5 %	10 %	AB VG 8	VG 22
-20	0.0	16.6	17.9	31.2	2.4
0	25.2	30.5	33.8	42.4	21.0

Table 10 Compressor Tests of AB / n-Pentane Mixture

Base Oil	n-P %	Add.	Refrigerant	Wear Width Vane, mm	Roughness, Ra Vane / Roller	(Appearance)
AB 8	5	PA	HFC-134a	1.19	0.05 / 0.07	(A / A)
AB 32	5	PA	HFC-134a	1.16	0.04 / 0.04	(A / A)

Appearance: A: Very Smooth, B: Smooth, C: Medium, D: Rough, E: Very Rough

Table 11 Properties of AB Derivatives

Physical Properties	AB-X1	AB-X2	AB-X3	AB 8
Viscosity, mm^2/s				
@40 ℃	22.1	36.7	25.9	8.1
@100 ℃	4.2	5.2	4.6	2.0
Miscibility, ℃				
HFC-134a	LT -50	HT +30	+20	HT+30
R410A	LT -50	HT +30	HT +30	HT+30

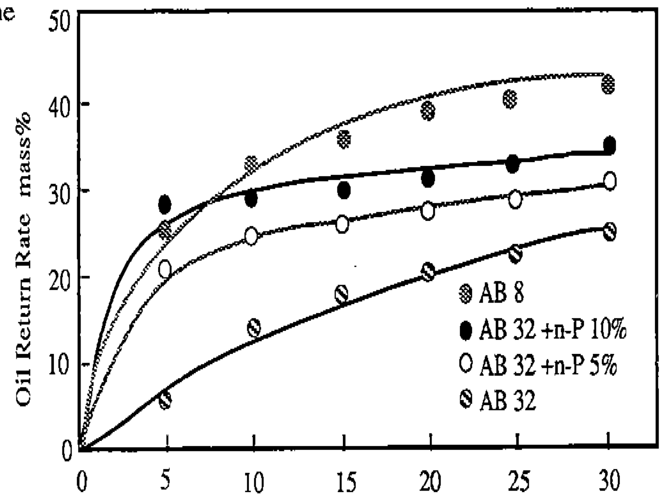

Figure 3 Oil Return Rate of AB / n-P Mixture @0℃

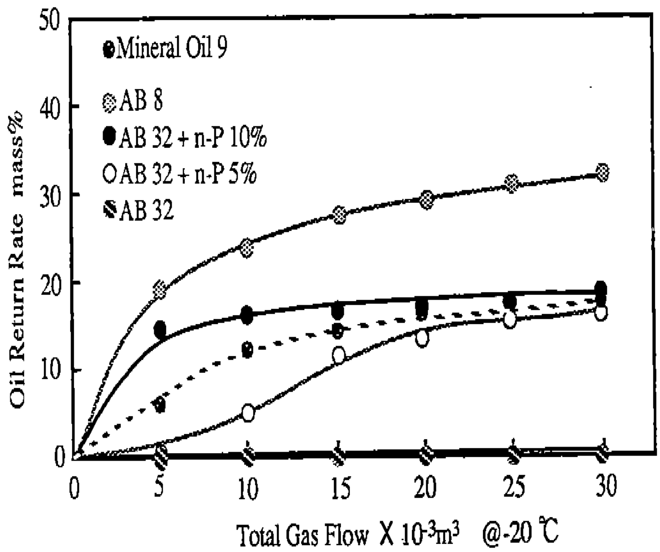

Figure 4 Oil Return Rate of AB / n-P Mixture @-20℃

Table 12 Compressor Tests of AB Derivatives

Base Oil	Add.	Refrigerant	Wear Width Vane, mm	Roughness, Ra Vane / Roller	(Appearance)
AB-X2	None	HFC-134a	1.70	0.43 / 0.42	(D / D)
AB-X2	PA	HFC-134a	1.18	0.03 / 0.03	(A / A)

Appearance: A: Very Smooth, B: Smooth, C: Medium, D: Rough, E: Very Rough