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Abstract

Immiscible alkylbenzene (AB) is currently used for household refrigerators with R134a. The applicability of immiscible AB was also studied for new air conditioners that will adopt HFCs, focusing on R407C and R410A. With regard to the antiwear property in rotary compressors, even AB with much lower viscosity compared with the current refrigeration lube performed satisfactorily. Good oil return property was observed in cycle evaluations of 19,000 Btu/hr room air conditioners with AB VG 10 and VG 22, and both R407C and R410A.

Introduction

Alkylbenzene (AB) that is poorly miscible with HFCs was first applied as a refrigeration lube for rotary household refrigerators with R134a at the beginning of 1994. Since then, its application has expanded to dehumidifiers with R134a and commercial refrigerators with HFC mixtures. In the past, it was generally thought that refrigeration lubes which are poorly miscible with refrigerants cannot be applied to air conditioners because they would have problems with oil return due to the long pipelines with the increased refrigerant. In Japan, new air conditioners with R407C and R410A have been on the market since 1997, and almost all manufacturers use miscible lubes with refrigerants like POE. However, as the introduction of polar bases like oxygen atoms into the lubricant molecular structure is necessary in order to create new lubes miscible with HFCs, new problems arose, such as big increases in hygroscopicity and cost. The superior properties of ABs were described in previous papers. Here, durability test results with vertical rotary compressors for air conditioners with R407C and oil return test results with split air conditioners with R407C and R410A are reported.

Experimental

Compressor durability tests

Compressor durability tests were conducted with simplified gas circuits using twenty current 1 HP vertical single piston R22 compressors. R407C was used as the refrigerant and AB ISO VG 10, 15, 22, and 32 with the same dosage of antiwear additive were tested as refrigeration lubes. The current mineral oil containing antiwear additive was tested as a control as well. Four compressors were used for each viscosity grade. They were used for durability tests for 500, 1000, 2000, and 4000 hours. The discharge pressure was set at 2.85 MPa and the suction pressure was controlled to 0.379 MPa. The discharge temperature was around 100 degrees C. The ambient temperature was room temperature, and the return gas temperature was between 6 and 17 degrees C. The discharged gas was cooled by water. After passing through the desiccant, XH11, the refrigerant was expanded by an expansion valve and the refrigerant gas was returned to a compressor. The compressors were disassembled after the durability tests and the wear condition at the bearing parts (i.e., vanes, rollers, shafts, bearings, etc.) was observed. The used lubes were recovered and their physical and chemical properties were examined. The combination of HCFC-22 and mineral oil (white oil with phosphates as antiwear additives) was tested as a control.

Table 1: Durability test conditions

Oil VG	Antiwear Additive	Refrigerant	Pd MPa	Ps MPa	Td deg. C	500 h	1000 h	2000 h	4000 h
AB 10	Yes	R407C	2.85	0.379	100	X	X	X	X
AB 15	Yes	R407C	2.85	0.379	100	X	X	X	X
AB 22	Yes	R407C	2.85	0.379	100	X	X	X	X
AB 32	Yes	R407C	2.85	0.379	100	X	X	X	X
MO 38	Yes	R22	2.85	0.379	100	-	X	X	X
POE 68 N	No	R407C	2.85	0.379	100	-	-	X	-
POE 68 Y	Yes	R407C	2.85	0.379	100	-	-	X	-

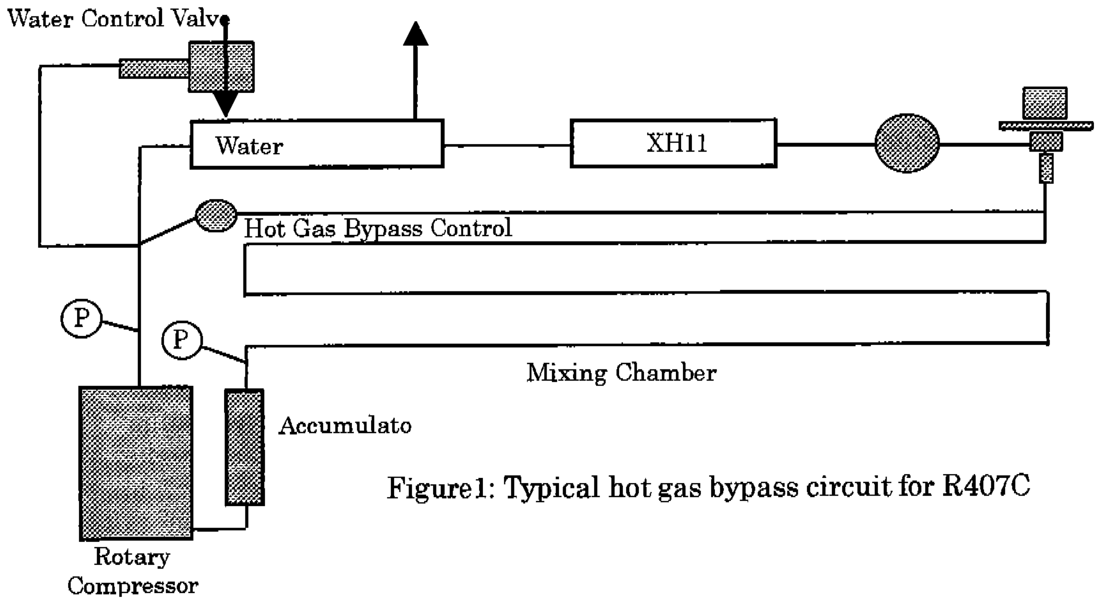

Figure1: Typical hot gas bypass circuit for R407C

Oil return tests

The oil return property of AB was observed with a 19,000 Btu/hr split air conditioner. R407C and R410A were used as the refrigerants, and AB ISO VG 10 and 22 were tested. The current combination of mineral oil and R22 was also evaluated as a control. Two sight glasses were attached to the modified compressor in order to observe the oil level in the compressor. Thermocouples were set at the bottom of the compressor, the discharge port, the middle of the condenser, the middle of the evaporator, and the inlet of the accumulator. A flow meter was set between the evaporator and the compressor, and the oil flow rate was observed for each test condition. The indoor unit was set about five meters above or below the outdoor unit.

Table 2: Oil return test conditions

No	Ground level	5m above	Refrigerant	Oil	Conditions
1	Indoor (Evaporator)	Outdoor (Condenser)	R407C: 1400 g	AB VG 10: 600 ml	3
2	Indoor (Evaporator)	Outdoor (Condenser)	R407C: 1400 g	AB VG 22: 600 ml	3
3	Indoor (Evaporator)	Outdoor (Condenser)	R410A: 1540 g	AB VG 10: 600 ml	3
4	Indoor (Evaporator)	Outdoor (Condenser)	R410A: 1540 g	AB VG 22: 600 ml	3
5	Outdoor (Condenser)	Indoor (Evaporator)	R410A: 1540 g	AB VG 10: 600 ml	2
6	Outdoor (Condenser)	Indoor (Evaporator)	R410A: 1540 g	AB VG 22: 600 ml	3
7	Indoor (Evaporator)	Outdoor (Condenser)	R22: 1400 g	MO VG 56: 600 ml	3

Results and discussion

Compressor durability test

It was reported that the application of antiwear additives is very effective for ABs with HFCs [1], so a certain amount of phosphate type antiwear additive was used for the serial evaluation. The surface roughness of each sliding part was measured. The results are shown in the tables. Among the ABs, ISO VG 10 produced a slightly larger amount of wear compared with the higher viscosity grades, but all of them showed better antiwear properties than did the current combination of mineral oil and R22. This is thought to be due to a lack of viscosity for maintaining a lubrication film. The viscosity of the lubricant and refrigerant solution is important at the hydrodynamic lubrication parts, i.e., the shafts and bearings, but no significant differences were observed between the tests with ISO VG 10 and those with ISO VG 32.

In these tests, the surface roughness of the vanes and rollers decreased from 500 hours to 1,000 hours and increased afterward gradually. It is generally said that the wear between the vanes and rollers occurs at the beginning of operation, then smoothing occurs, and the wear increases gradually afterward. The same phenomena were observed with HFC in these test results. The surface roughness for the current combination of HCFC-22 and mineral oil was worse at every test period compared with the combination of R407C and ABs. The values of the surface roughness for the combination of mineral oil and HCFC-22 were twice as large as those for the combination of R407C and ABs. The values of the surface roughness at 500 and 1000 hours were extremely large, but those were assumed to be due to experimental errors. However, such abnormal wear was not found with ABs and R407C.

POE ISO VG 68, H8B9B[2], with or without the phosphate type antiwear additive that is used in ABs was tested as a reference. Only POE with antiwear additive created abrasive wear between the vane and roller. It created wear between the surface of the bearings and vane ends as well. Phosphate type additives sometimes increase the friction coefficient, and it is thought that stick slip phenomena occurred due to an increase of friction. Significant wear was not found at the hydrodynamic lubrication parts.

With regard to the recovered oil samples, no deterioration in color or increase in total acid number was found. The color of some AB samples changed to slight orange. The cause was thought to be the extraction of color from materials in the system or coloration due to partial degradation of oxidation inhibitor by the residue of process fluids or cleaning agents. POEs did not show significant deterioration in the physical properties even though POE with antiwear additive created wear. This means that the test conditions were severe for compressor lubrication but were not very severe for the acceleration of the degradation of the lubricants.

Table 3: Surface roughness Ra (μm), vane nose

Period h Oil VG	New	500	1000	2000	4000
AB 10	0.15	0.49	0.38	0.55	1.09
AB 15	0.15	0.29	0.17	0.32	0.45
AB 22	0.15	0.35	0.35	0.57	0.71
AB 32	0.15	0.23	0.34	0.22	1.02
MO 38	0.15	-	2.12	0.94	1.56
POE 68 N	0.15	-	-	0.48	-
POE 68 Y	0.15	-	-	1.04	-

POE 68 N=H8B9B without antiwear additive
POE 68 Y= H8B9B with antiwear additive

Table 4: Ra (μm), vane side

Period h Oil VG	New	500 h	1000	2000	4000
AB 10	0.11	-	0.10	0.13	0.07
AB 15	0.11	0.09	0.11	0.07	0.06
AB 22	0.11	0.09	0.09	0.09	0.10
AB 32	0.11	0.10	0.14	0.11	0.08
MO 38	0.11	-	0.07	0.07	0.19
POE 68 N	0.11	-	-	0.07	-
POE 68 Y	0.11	-	-	0.07	-

Table 5: Ra (μm), roller outside

Period h Oil VG	New	500	1000	2000	4000
AB10	0.22	0.50	0.37	0.52	0.88
AB15	0.22	0.37	0.20	0.31	0.46
AB22	0.22	0.33	0.34	0.53	0.53
AB32	0.22	0.28	0.32	0.22	0.96
MO38	0.22	-	2.08	0.97	1.52
POE68 N	0.22	-	-	0.48	-
POE68 Y	0.22	-	-	1.88	-

Table 6: Ra (μm), shaft eccentric outside

Period h Oil VG	New	500	1000	2000	4000
AB 10	0.20	0.12	0.16	0.15	0.15
AB 15	0.20	0.11	0.08	0.13	0.13
AB 22	0.20	0.10	0.16	0.14	0.16
AB 32	0.20	0.24	0.14	0.20	0.13
MO 38	0.20	-	0.16	0.15	0.21
POE 68 N	0.20	-	-	0.15	-
POE 68 Y	0.20	-	-	0.17	-

Table 7: Ra (μm), main bearing (roller side)

Period h Oil VG	New	500	1000	2000	4000
AB 10	0.21	0.15	0.17	0.16	0.16
AB 15	0.21	0.21	0.17	0.17	0.16
AB 22	0.21	0.20	0.17	0.17	0.13
AB 32	0.21	0.29	0.19	0.13	0.22
MO 38	0.21	-	0.16	0.14	0.09
POE 68 N	0.21	-	-	0.30	-
POE 68 Y	0.21	-	-	0.43	-

Table8: Ra (μm), sub bearing (roller side)

Period h Oil VG	New	500	1000	2000	4000
AB 10	0.14	0.16	0.13	0.09	0.10
AB 15	0.14	0.12	0.13	0.26	0.10
AB 22	0.14	0.10	0.10	0.10	0.09
AB 32	0.14	0.14	0.19	0.11	0.25
MO 38	0.14	-	0.17	0.11	0.22
POE 68 N	0.14	-	-	0.18	-
POE 68 Y	0.14	-	-	0.13	-

Table 9: Ra (μm), main bearing (vane end)

Period h Oil VG	New	500	1000	2000	4000
AB 10	0.23	0.17	0.18	0.23	0.12
AB 15	0.23	0.17	0.20	0.19	0.15
AB 22	0.23	0.19	0.13	0.16	0.14
AB 32	0.23	0.19	0.21	0.15	0.22
MO 38	0.23	-	0.28	0.12	0.16
POE 68 N	0.23	-	-	0.30	-
POE 68 Y	0.23	-	-	2.78	-

Table 10: Ra (μm), sub bearing (vane end)

Period h Oil VG	New	500	1000	2000	4000
AB 10	0.12	0.12	0.13	0.16	0.14
AB 15	0.12	0.13	0.18	0.22	0.28
AB 22	0.12	0.12	0.09	0.13	0.10
AB 32	0.12	0.15	0.24	0.12	0.27
MO 38	0.12	-	0.23	0.10	0.25
POE 68 N	0.12	-	-	0.20	-
POE 68 Y	0.12	-	-	1.14	-

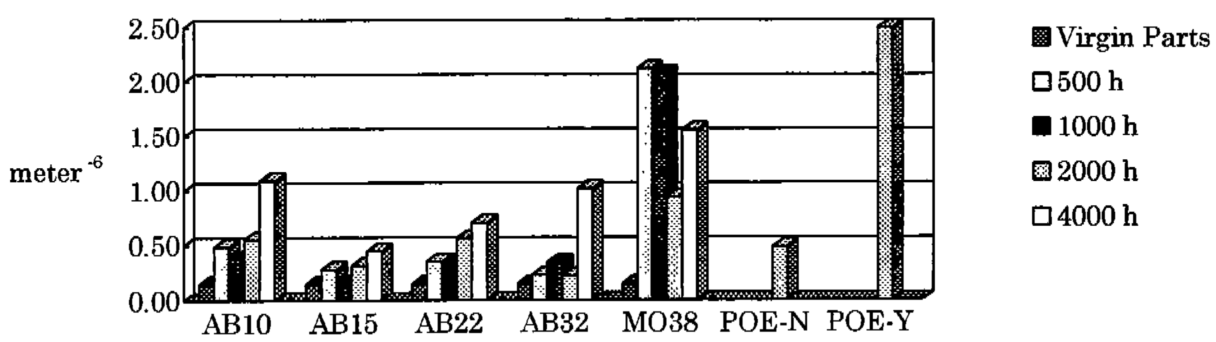

Figure 2: Surface roughness Ra(μm), vane nose

Table 11: Physical properties of tested lubes

	Period, h	AB 10	AB 15	AB 22	AB 32	MO 38	POE 68 N	POE 68 Y
Viscosity mm^2/s @ 40deg C	1000	10.4	14.9	20.4	29.6	38.3	-	-
	2000	10.8	16.5	20.7	30.0	38.2	61.3	64.9
	4000	11.2	15.0	20.3	31.4	44.0	-	-
TAN mgKOH/g	1000	0.00	0.00	0.00	0.01	0.01	-	-
	2000	0.00	0.00	0.00	0.00	0.00	0.00	0.07
	4000	0.00	0.00	0.00	0.00	0.00	-	-
Color ASTM	1000	L2.5*	L2.5*	L0.5	L0.5	L1.5	-	-
	2000	L0.5	L1.5*	L0.5	L2.5*	L1.5	L1.5	L2.5
	4000	L0.5	L2.0*	L0.5	L0.5	L2.5	-	-
Contaminant mg/100 g oil	1000	1	1	6	3	27	-	-
	2000	2	8	9	9	49	17	4
	4000	8	2	3	5	37	-	-

* = slight orange color

Oil return tests

The test results are shown in the tables below. Here,

Pd = discharge pressure (MPa)

Ps = suction pressure (MPa)

Tcomp = temperature at the compressor bottom (deg. C)
Tdis-t = temperature at the discharge tube (deg. C)
Tcd-m = temperature at the middle of the condenser (deg. C)
Tcd-o = temperature at the exit of the condenser (deg. C)
Tev-m = temperature at the middle of the evaporator (deg. C)
Tac = temperature at the inlet of the accumulator (deg. C)
SG = oil level observed through the sight glass
OCR = oil circulating ratio (ml/min)

For AB operation, rigid two-phase separation of refrigerant and oil was observed at the start of compressor operation for both R407C and R410A. The condition changed to a single unified layer in just one or two minutes after the start of operation.

Tests 1 and 2 were conducted with ABs (VG 10 and 22) and R407C, and the outdoor unit was set five meters above the indoor unit. The oil level in both cases was higher than the main bearing, and it maintained a sufficient height. After the operation, the components were detached and the quantity of the remaining oil in each part was measured. The quantity of remaining oil for AB VG 22 was slightly larger than that for AB VG 10, but the total remaining oil in the system was about 3 % of the charged oil.

Tests 3 and 4 were conducted with ABs and R410A under very similar test conditions. The outdoor unit was set five meters above the indoor unit. The OCR for AB VG 10 was twice as large as that for VG 22. The quantity of remaining oil for AB VG 22 with R410A was almost the same as that for AB VG 22 with R407C. The oil level in both cases was higher than the main bearing, and it maintained a sufficient height.

Tests 5 and 6 were conducted with ABs with R410A, and the outdoor unit was set five meters below the indoor unit. The OCR for AB VG 10 was smaller than that for VG 22, but the reason could not be determined. When the test results for tests 4 and 6 are compared, even though the alignment of the indoor and outdoor units was reversed, the OCR showed almost the same value when the same lube was used.

From the test results, the immiscible AB proved to be applicable to the new air conditioners with HFCs.

Table 12: Test 1, AB VG 10/R407C

Pd	Ps	Tcomp	Tdis-t	Tcd-m	Tcd-o	Tev-m	Tac	SG	OCR
2.24	0.434	71	99	51	46	-2	24	Full	4
2.55	0.482	74	105	56	51	1	22	Full	8
2.76	0.503	77	108	62	53	2	22	Full	13

The quantity of removed oil after the test: Condenser = 8 ml
Evaporator = 10 ml

Table 13: Test 2, AB VG 22/R407C

Pd	Ps	Tcomp	Tdis-t	Tcd-m	Tcd-o	Tev-m	Tac	SG	OCR
2.13	0.448	61	77	49	43	-1	11	Full	N.D.
2.55	0.489	64	88	56	51	1	6	Full	N.D.
2.72	0.496	70	93	60	54	2	6	Full	N.D.

The quantity of removed oil after the test: Condenser = 0 ml
Evaporator = 20 ml

Table 14: Test 3, AB VG 10/R410A

Pd	Ps	Tcomp	Tdis-t	Tcd-m	Tcd-o	Tev-m	Tac	SG	OCR
2.24	0.640	44	60	37	33	-2	11	Full	4
2.58	0.640	47	58	43	39	-2	6	Full	18
3.10	0.806	63	79	51	47	4	18	Full	12

Table 15: Test 4, AB VG 22/R410A

Pd	Ps	Tcomp	Tdis-t	Tcd-m	Tcd-o	Tev-m	Tac	SG	OCR
2.58	0.655	58	59	43	39	-2	7	Full	3
2.93	0.689	61	67	49	43	0	6	Full	7
3.17	0.820	65	76	52	49	4	14	Full	7

The quantity of removed oil after the test: Condenser = 10 ml
Evaporator = 10 ml

Table 16: Test 5, AB VG 10/R410A (The indoor unit was 5 m above the outdoor unit.)

Pd	Ps	Tcomp	Tdis-t	Tcd-m	Tcd-o	Tev-m	Tac	SG	OCR
2.65	0.813	64	69	44	41	4	17	Full	2
3.10	0.813	69	74	51	47	4	12	Full	6

The quantity of removed oil after the test: Condenser = 10 ml
Evaporator = 0 ml

Table 17: Test 6, AB VG 22/R410A (The indoor unit was 5 m above the outdoor unit.)

Pd	Ps	Tcomp	Tdis-t	Tcd-m	Tcd-o	Tev-m	Tac	SG	OCR
2.62	0.758	59	69	44	39	2	13	Full	4
2.96	0.689	64	76	49	44	-1	4	Full	10
3.31	0.758	70	84	54	48	2	11	Full	9

Table 18: Test 7, MO VG 56/R22

Pd	Ps	Tcomp	Tdis-t	Tcd-m	Tcd-o	Tev-m	Tac	SG	OCR
2.07	0.379	93	96	55	65	-1	22	Full	N.D.
2.41	0.413	104	108	62	66	1	22	Full	N.D.
2.76	0.517	109	117	68	66	7	15	Full	N.D.

Summary

For antiwear properties between the vanes and rollers, ABs with R407C were superior to the other combinations, the current mineral oil with R22, and POEs with R407C. Among the ABs, only VG 10 created a slightly higher amount of wear compared with the other viscosity grades at the vane and roller, but it did not show any significant difference in the other sliding parts.

In the oil return tests, the liquid refrigerant was discharged and the mixture became a clear single phase in one or two minutes after start-up. Quite good oil return was observed for ABs in split air conditioner units. No significant difference was found between AB VG 10 and VG 22 in regard to the oil return properties.

Reference

1) Sunami, M., Saito, M., Takigawa, K., Suda, S., Sasaki, U.: Proc., Int. Refrigeration Conf., Purdue (1996) 303.
2) Sunami, M., Takigawa, K., Suda, S.: Proc., Int. Refrigeration Conf., Purdue (1994) 153.