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Alkylbenzenes for Split Air Conditioner with R-410A Part 2: Oil Return Characteristics

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ALKYLBENZENES FOR SPLIT AIR CONDITIONER WITH R-410A
PART 2 ; OIL RETURN CHARACTERISTICS

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ABSTRACT

Alkylbenzenes(ABs), which are immiscible or barely miscible with HFC refrigerants, are chemically stable and show better anti-wear properties than polyolesters(POEs). The objective of this study is to examine the oil return characteristics of ABs with R-410A used in residential split air conditioners. The flow pattern of HFC refrigerant/AB mixtures in the refrigerant circuit is observed and the minimum refrigerant velocities to keep oil flow smooth in the liquid line are determined. In addition, the oil level inside the compressor and cycle performance of R-410A/AB with an improved refrigerant circuit are measured and compared to R-410A/POE. From these results the potential use of the low viscosity ABs with HFC refrigerants in residential split air conditioners is confirmed.

INTRODUCTION

For protection of the ozone layer, R-410A(R-32/R-125 ; 50/50wt.%) is selected as an alternative refrigerant for a residential spilt air conditioner with a rotary compressor. In the development of the air conditioner with HFC refrigerants, the selection of lubricants which affect reliability and performance of the air conditioner is important. Although the new synthetic lubricants, polyolesters(POEs) are miscible with HFC refrigerants over a wide range of temperatures, POEs have two major drawbacks: hygroscopicity and high cost. Especially in the case of using POEs as a lubricant for a rotary compressor, it is difficult to obtain good anti-wear properties at the vane and rolling piston[1],[2]. Therefore, we have investigated the potential use of alkylbenzenes(ABs) in air conditioner with a rotary compressor. Although ABs are chemically stable and show better anti-wear properties, have a lower cost than POEs, ABs are immiscible or barely miscible with HFC refrigerants. So it is important to obtain the proper oil management techniques to ensure that oil return to the compressor is achieved.

This paper presents the experimental results of the flow pattern of immiscible refrigerant/lubricant mixtures, the minimum refrigerant velocities to keep oil flow smooth in the liquid line, and the oil level inside the compressor and cycle performance of R-410A/AB with an improved refrigerant circuit.

FLOW OF REFRIGERANT AND ALKYLBENZENE MIXTURES IN LIQUID LINE

Experimental Equipment and Procedure

The mechanism of oil transport in the liquid line is quite different between the miscible refrigerant/oil mixtures and immiscible refrigerant/oil mixtures. When the oil and refrigerant are miscible, there exists only single phase flow. When they are immiscible, as in the case of HFC/AB, there is two-phase flow. To evaluate oil circulation in the liquid line, the observations of the flow pattern and the measurements of the minimum velocity to keep oil flow smooth, the accumulation of oil in the liquid line are conducted. The experimental equipment is illustrated in Figure 1.

The experimental equipment is made up of two loops: a refrigerant loop and an oil loop. The refrigerant loop consists of an inverter driven compressor, a condenser, an evaporator, an expansion valve, two oil separators, and an accumulator. The refrigerant flow rate is controlled by the rotational frequency of the compressor and the expansion valve, and measured by the mass flow meter located in the liquid line. The oil loop consists of an oil pump, an oil separator, and an oil tank. The oil flow rate is controlled by the oil pump, and measured by the mass flow meter located in the outlet of the oil pump. The liquid refrigerant-oil mixtures are generated at the outlet of the condenser, and then enter the test section. The refrigerant-oil mixtures leaving the test section, are separated into the liquid refrigerant and the oil by the oil separator. The liquid refrigerant is evaporated in the evaporator and then returns to the compressor. The oil separated in the oil separator flows into the oil tank.

To observe the flow pattern of the refrigerant-oil mixtures, glass tubes are installed in the test section at the three directions: vertical upward, horizontal, and vertical downward. The glass tubes are of inside diameter 8mm. To measure the accumulation of the oil in the liquid line, the sampling tubes which have the shut-off valves are installed in the test section instead of the sight glasses. After detaching the sampling pipes from the test section, the weight of the refrigerant and the oil within the sampling pipes are measured, respectively. In the experiment, the liquid refrigerant velocities are varied from 0.01 to 0.2 m/s, and the oil circulation ratio which is defined as the ratio of the mass flow rate of oil to that of refrigerant-oil mixtures is from 1 to 5 wt. %.

Flow Pattern of Liquid Refrigerant and Oil Mixtures

The flow patterns for liquid refrigerant and AB mixtures in a 8mm pipe observed in case that the refrigerant liquid velocity is 0.15 m/s and the oil circulation ratio is 3 wt. % are shown in Figure 2. For vertical upward and vertical downward flow, a dispersed flow patterns with widely separated and nearly spherical oil bubbles are observed. The diameters of the oil droplet in the liquid line are varied from 0.1 to a few millimeters, and the moving velocity of the oil droplet depends on its diameters. For horizontal flow, the mixtures separate into two layers and oil is isolated in the upper layer, because the density of alkylbenzene is smaller than that of liquid refrigerant. Even if the oil circulation rate is increased up to 5 wt. %, the flow pattern of the mixtures is almost same as the Figure 2. However, when the oil circulation rate is 1 wt. %, no oil separated from the liquid refrigerant is observed.

Minimum Refrigerant Velocities in the Liquid Line

Since the density of the AB is smaller than that of the liquid refrigerant, the buoyant force acts on the oil droplet flowing inside the vertical tube. For vertical downward flow, oil circulation requires sufficient liquid momentum to overcome opposing buoyant forces acting on the oil. To find the minimum liquid refrigerant velocity at which oil circulation through the liquid line is possible, the diameters of the oil droplet at rest in the liquid line are measured by changing the liquid refrigerant velocities. The relationship

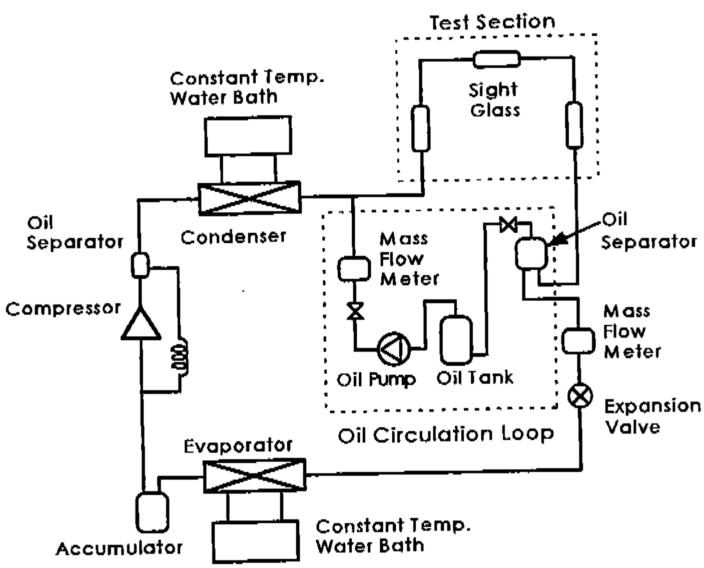

Figure 1 Experimental equipment

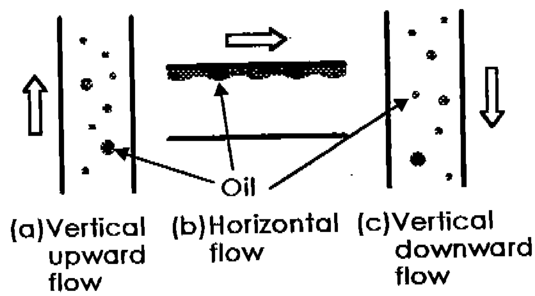

Figure 2 Flow pattern of immiscible refrigerant and oil mixtures in liquid line

between the diameter of the oil droplet and the minimum refrigerant velocity is shown in Figure 3.

The minimum velocity depends on the oil droplets diameter, and takes a maximum value, 0.08 m/s, in the case that the oil droplet diameter is approximately 1.8 mm. When the oil droplet diameter is less than 1.8 mm, the minimum velocity increases in proportion to the oil droplet diameter, because the buoyant force acting on the oil droplet increases in proportion to its diameter. In the case that the oil droplet diameter is more than 1.8 mm, the oil droplets are deformed, flattened horizontally, then the minimum velocity decreases. From these results, it is confirmed that even in the vertical downward flow the good oil circulation is achieved by keeping the liquid refrigerant velocity over 0.08 m/s regardless of the oil droplet diameters.

Accumulation of Oil in Liquid Line

Figure 4 shows the experimental results of the oil mass ratios in the horizontal tube, the vertical upward tube, and the vertical downward tube. The oil mass ratio is defined as the ratio of the amount of the oil to that of the liquid refrigerant-oil mixtures within the pipe. When the oil circulation rate is 1 wt. %, the oil mass ratios correspond to the oil circulation rate regardless of directions of the refrigerant flow. This means that the liquid refrigerant-oil mixtures flow as a homogeneous mixture (i.e., a no-slip situation). When the oil circulation rate is 3 or 5 wt. %, the oil mass ratios are 2~5 times as large as the oil circulation rate. This means that the oil moving velocity is smaller than the liquid refrigerant velocity, and the oil is accumulating in the liquid line. From these results, it is confirmed that non-accumulation of oil in the liquid line is achieved by keeping the oil circulation rate under 1 wt. %.

OIL RETURN CHARACTERISTICS IN SPILT AIR CONDITIONER

Test Unit and Test Conditions

The experiments to investigate the oil return characteristics of R-410A with alkylbenzene in an actual air-to-air split air conditioner are conducted. The test unit is illustrated in Figure 5, and its main specifications

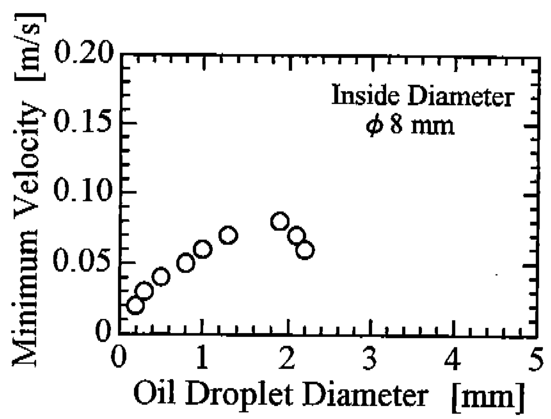

Figure 3 Minimum refrigerant velocities in the liquid line

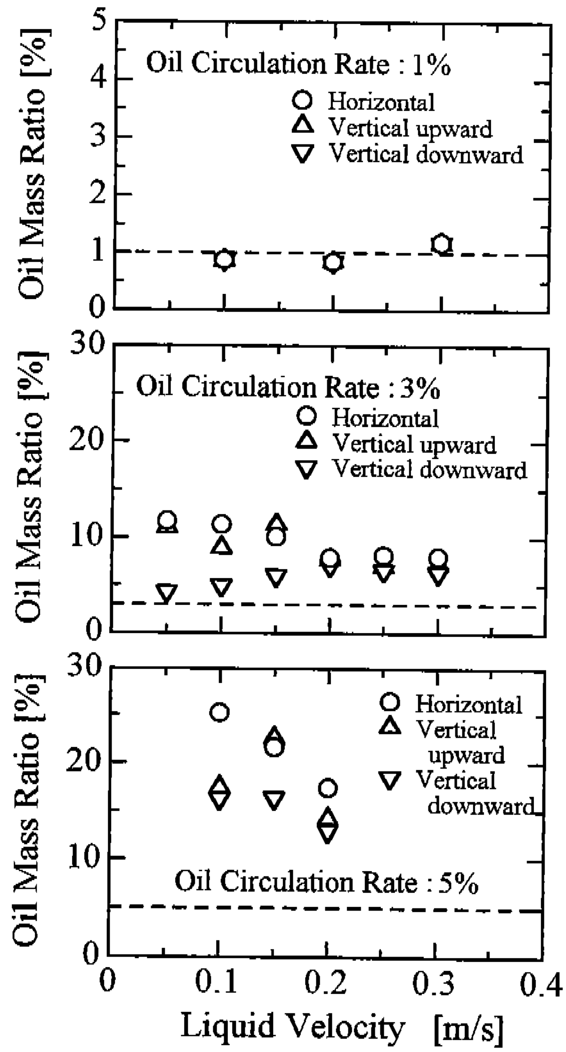

Figure 4 Oil mass ratios in the liquid line

are listed in Table 1. The test unit consists of an inverter driven rotary compressor, outdoor and indoor heat exchangers, an electronic expansion valve, and a reversing valve. The rated heating and cooling capacities of the test unit are 4.2 kW and 2.8 kW, respectively. The compressor has three sight glasses to observe the liquid level in the compressor, as shown in Figure 6. The liquid level includes the level of the oil and the refrigerant when the liquid refrigerant is present in the compressor. The liquid level are observed with video cameras.

Based on the results discussed in the above section, the modifications for the test unit to ensure the oil return are as follows; (1)The tubes of liquid line are chosen of such a size that the refrigerant velocity is maintained more than 0.08 m/s. (2)The oil flow rate from the compressor is reduced, so that the oil circulation rate in the unit is maintained less than approximately 1 wt. %. (3)Each of the suction pipes in the compressor suction muffler has a hole to reduce the amount of oil accumulating in the suction muffler, as shown in Figure 6.

Two tests are selected to evaluate the oil return performance as severe conditions. For each of these tests the liquid level in the compressor is measured as a function of time after the compressor start up. The first test is the flooded start condition in the heating mode. In this test, the liquid refrigerant is migrated from the outdoor heat exchanger to the compressor before the start of the compressor. For

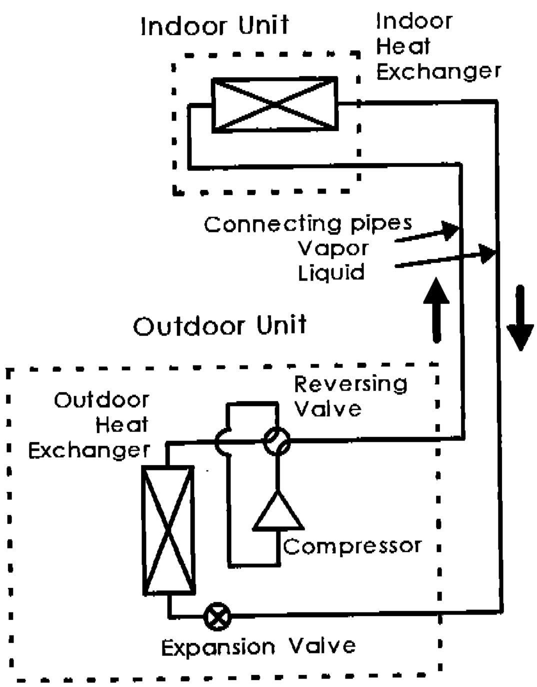

Figure 5 Test unit

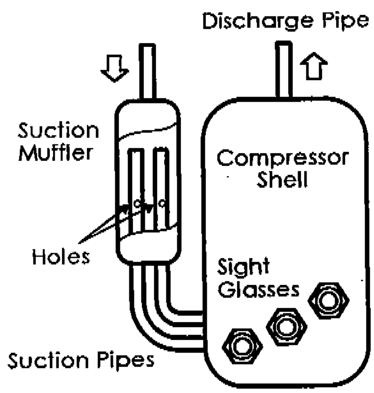

Figure 6 Test compressor

Table 1 Main specifications of test unit

Elements		Specifications
Compressor		Rotary compressor with two cylinders (Displacement 9.2 cm^3)
Outdoor Heat Exchanger		Plate fin and tube heat exchanger ϕ 9.52, 4 parallel passes, inner grooved tube
Indoor Heat Exchanger		Plate fin and tube heat exchanger ϕ 7.00, 2 parallel passes, inner grooved tube
Expansion Devise		Electronic expansion valve
Connecting Pipe	Liquid	ϕ 6.35 mm Length 5 m
	Vapor	ϕ 9.52 mm Length 5 m
Refrigerant		R-410A (R-32/R-125 ; 50/50 wt. %)
Lubricant		Alkylbenzene, VG22

this test, the indoor environment is maintained at 20 ℃ dry bulb and 15 ℃ wet bulb while the outdoor environment is maintained at 7 ℃ dry bulb and 6 ℃ wet bulb. The second test is the oil pump out test[3]. In this test, 60% of initially charged oil is drained from the compressor, and the drained oil is injected into the compressor discharge line before the start of the compressor. This test reveals the time required for the oil to return in the event of a catastrophic oil pump out. The oil pump out test is conducted at the same indoor conditions of the first test while the outdoor environment is maintained at 2 ℃ dry bulb and 1 ℃ wet bulb.

Test Results

Figure 7 shows the liquid level in the compressor observed at the sight glasses as a function of time under the flooded start condition. Before the start of the compressor, the oil inside the compressor is separated from the liquid refrigerant. Soon after start-up, the liquid level in the compressor increases rapidly. This occurs because the liquid refrigerant and oil which present inside the outdoor heat exchanger and the compressor suction muffler flow into the compressor. After this, the liquid level decreases. After the first 8 minuets the oil level continues to increase and reaches a steady state level eventually. The steady state oil level which is about 90 % of the amount of initially charged oil, remains constant for duration of the test. This oil level is sufficiently higher than the critical oil level for oil pickup The liquid refrigerant inside the compressor is disappeared within about 10 minutes of staring up.

Figure 8 shows the liquid level for the oil pump out test results. In this test, two viscosity grades of AB, VG22 and VG68, are used to investigate the effect of viscosity on oil return characteristics. Although the liquid levels of both viscosity grades oil show similar tendency and the steady state oil levels of both viscosity grade oil are almost the same, the time required for stabilization of the liquid level depends on the oil viscosity. For VG22, a steady state oil level is achieved within approximately 20 minutes. For VG68, it takes approximately 60 minutes to achieve the steady state oil level. From these results, it is confirmed that AB with a viscosity grade from VG22 to 68 reliably returns to compressor. The amount of oil accumulation in the refrigerant cycle is almost constant in the viscosity range from VG22 to 68.

PERFORMANCE OF SPILT AIR CONDITIONER WITH ALKYLBENZENES

Test Unit and Test Conditions

The tests to investigate the effect of the oil viscosity on the cycle performance for the split air conditioner with AB are conducted by using the test unit showed in Figure 5. Alkylbenzenes with a viscosity grade from VG15 to 68 are used in these tests. A polyolester of a viscosity grade of VG56 is

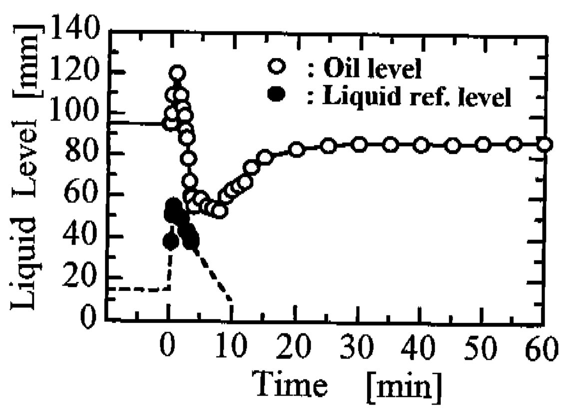

Figure 7 Change in liquid level under flooded start condition.

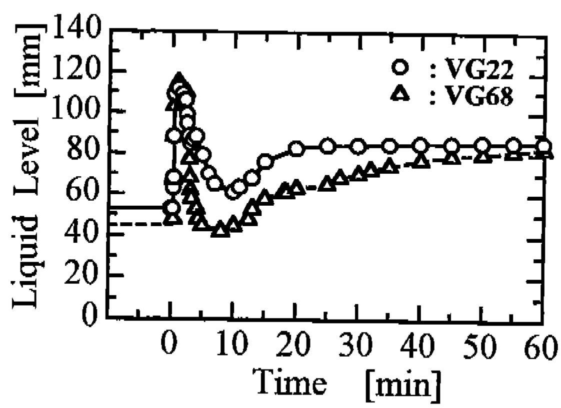

Figure 8 Change in liquid level under oil pump out condition.

also evaluated as references.

In the heating mode, the indoor environment is maintained at 20 ℃ dry bulb and 15 ℃ wet bulb while the outdoor environment is maintained at 7 ℃ dry bulb and 6 ℃ wet bulb. In the cooling mode, the indoor environment is maintained at 27 ℃ dry bulb and 19 ℃ wet bulb while the outdoor environment is maintained at 35 ℃ dry bulb and 24 ℃ wet bulb.

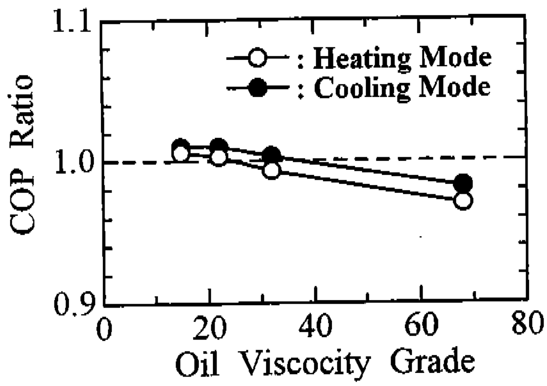

Figure 9 Relation between COPs and oil viscosity grades

Test Results

Figure 9 shows the test results of COP at heating and cooling rated capacity. The vertical axis indicates the ratio of COP with R-410A/AB to COP with R-410A/POE. The COP of the split air conditioner with R-410A/AB decreases with increase in the oil viscosity. Although the COPs with the lower viscosity ABs, such as from VG15 to 32, agree with that with the miscible oil within 1%, the COP with higher viscosity ABs, such as VG68, is 2 - 3% lower than that with the miscible oil. From these results, it is confirmed that no degradation in COP is obtained by using the low viscosity alkylbenzene.

CONCLUSIONS

To evaluate the oil return characteristic of alkylbenzenes(AB) with R-410A used in residential air conditioners, the flow pattern of HFC refrigerant/AB mixture in the refrigerant circuit is observed and the minimum refrigerant velocities and the accumulation of AB in the liquid line were measured. In addition, the oil level in the compressor and cycle performance of R-410A/AB with the split air conditioner were measured, and following conclusions were obtained.

(1)The minimum liquid refrigerant velocity in the vertical downward flow depended on the diameter of the oil droplet. However, the good oil circulation in the liquid line was achieved by keeping the refrigerant velocity over 0.08 m/s regardless of the oil droplet diameters.

(2)Non-accumulation of AB in the liquid line was achieved by keeping the oil circulation rate under 1 wt. %.

(3)The spilt air conditioner with R-410A/AB had reliable oil return characteristics even under severe conditions.

(4)By using the low viscosity AB, cycle performance of R-410A/AB was the same as that of R-410A/POE.

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