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Observation of Circulation of Immiscible Mineral Lubricant Oil in an Air-Conditioning Machine Charged with HFC Refrigerant*

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Abstract

By installing HFC134a on the air-conditioning machine designed for HCFC22, it was proved that a more efficient heat pump system could be operated without changing mineral lubricant oil. The circulation mechanism of mineral oil with HFC134a was investigated in comparison with that of HCFC22. It was shown by the flow visualization that the mineral oil was not solved in condensed HFC134a, but droplets of mineral oil were transported with condensed HFC134a at the outlet of condenser. The circulation of mineral oil with HFC134a was also confirmed by extracting the working fluid from the tubing of the air-conditioning machine under operation.

Key words: Heat Pump, HFC134a, HCFC22, Mineral Oil, Compatibility

1. Introduction

The quantity of HCFC refrigerant including HCFC22, generally used in legacy air-conditioning systems, must be reduced to 35% or less by 2010 to protect the ozone layer, and to be abolished by 2020, according to the Montreal Protocol(1). Therefore we need to urgently replace the refrigerant of legacy air-conditioning systems to the alternative one. HFC refrigerants and natural refrigerants, such as hydrocarbon and ammonia, are known as alternative refrigerants. However, natural refrigerants have problems of safety, *i.e.*, inflammability and toxicity. In addition, mixed HFC refrigerant, a kind of HFC refrigerant consisting of several refrigerants with different boiling points, also have a problem in handling, *i.e.*, the component ratio varies due to leakage during operation and replenishment. Contrary to these, HFC134a is a single (non-mixed) HFC refrigerant and has relatively small GWP (Global Warming Potential). Thus it could make the impact on global warming to a minimum.

On the other hand, we developed the methodology to improve the efficiency of legacy air-conditioning systems by installing the additional condenser (3), (4). Therefore, if HFC134a could be used in legacy air-conditioning systems with additional condensers, it could contribute to improving the ozone layer and global warming in addition to solving above-mentioned problems of natural refrigerants and mixed refrigerants.

However, it is known that mineral lubricant oil miscible in HCFC22 is immiscible in HFC134a. Lubricant oil in the compressor should be inevitably exhaled because of its structural mechanism. If exhaling of the lubricant oil would be continued without returning,

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the quantity of the oil would be decreased in the compressor. Due to this, the lubricating performance would be deteriorated and the compressor would lead to burn during operation. Moreover, if the lubricant oil would be stocked in the tubing, it would cause decrease of the diameter of the tube and prevent refrigerant from circulating throughout the system and thus might lead to the decrease of the performance of the heat exchanger. In order to avoid these problems, lubricant oil which is compatible to refrigerant is used to keep oil circulate throughout the system and its quantity inside the compressor constant. Therefore, the combination of HFC134a and mineral oil has not been in practice since compatibility is not good for air-conditioning systems.

Regarding the study on the behavior of mixing flow between refrigerant and incompatible mineral oil, although a lot of research in the static condition [(5)~(7)] has been done so far, a few research in the dynamic conditions have been done focusing on the flow in the capillary tube [(8)] or the measurement of the oil retention [(9)]. Since incompatibility between refrigerant and lubricant oil is also an important issue for natural refrigerants, including carbon dioxide, quite a few related studies are emerging recently [(10)].

We confirmed that replacement of the refrigerant from HCFC22 to HFC134a in legacy air-conditioning systems caused no problems for normal operation even though the mineral lubricant oil was used as it was [(4)]. In this study, we also observed that the operational performance was decreased by about 20 %, with lower operational pressure and lower refrigerant density of HFC134a, however, the pressure loss was almost the same because the volumetric flow rate of the refrigerant was same for both refrigerants. If we would keep the operational performance by enhancing the compressor work, the pressure loss could lead to larger one. Regarding the effect of the additional condensers, its installment improved COP by 3 % for HCFC22 and more than 10 % for HFC134a versus to the original operational condition with HCFC22. The replacement of the refrigerant would not deteriorate the reliability of the system because the pressure difference of the refrigerant during compression was smaller and the temperature after compression was lower. We also confirmed that normal operation had been continued for more than three years after the replacement of the refrigerant.

Therefore in this paper, we would study the mechanism of the circulation of refrigerant and mineral lubricant oil in legacy air-conditioning system for HCFC22 when simply replacing HCFC22 by HFC134a. Firstly, we test compatibility of refrigerant and mineral lubricant oil. Next, we visualize the circulation behavior of refrigerant and mineral lubricant oil under actual operation. Moreover, the existence of mineral lubricant oil in refrigerant is confirmed by extracting the working fluid from the tubing of the air-conditioning system under operation.

2. Compatibility Test

2. 1 Experimental Setup

We check the compatibility of HCFC22 and HFC134a with mineral oil in the static condition before observing it in the dynamic operational condition. Figure 1 shows the circuit chart of the compatibility experiment. The equipment consists of a glass tube covered with an explosion-proof tube made of acrylic resin, an incubator, a compressor and a vacuum pump. The resistible pressure of the glass tube is 5.0 MPa.

The glass tube in which refrigerant and mineral lubricant oil is enclosed is soaked in the incubator, and the whole system is set up statically so that there is no disorder of the liquid. When refrigerant is enclosed, the pressure is adjusted by the compression equipment. The temperature and pressure are measured by thermocouples inserted in the glass tube and the pressure gauge set up in the inlet zone of the glass tube respectively. The experimental conditions are almost reproduced corresponding to that of at the compressor inlet, the compressor outlet, the condenser outlet, and the additional condenser outlet. Table 1 shows the pressure and the temperature conditions of HCFC22 and HFC134a in the compatibility experiment. Four conditions are determined based on our previous experiment [(4)]. However, the pressure at the compressor outlet, the condenser outlet, and the additional condenser outlet cannot be precisely realized since the pressure is adjusted by the compression equipment made from a mechanical piston. Thus the values are thought to be "similar" to the real conditions. Mineral oil (Barrel Freeze 32s) is used as lubricant oil.

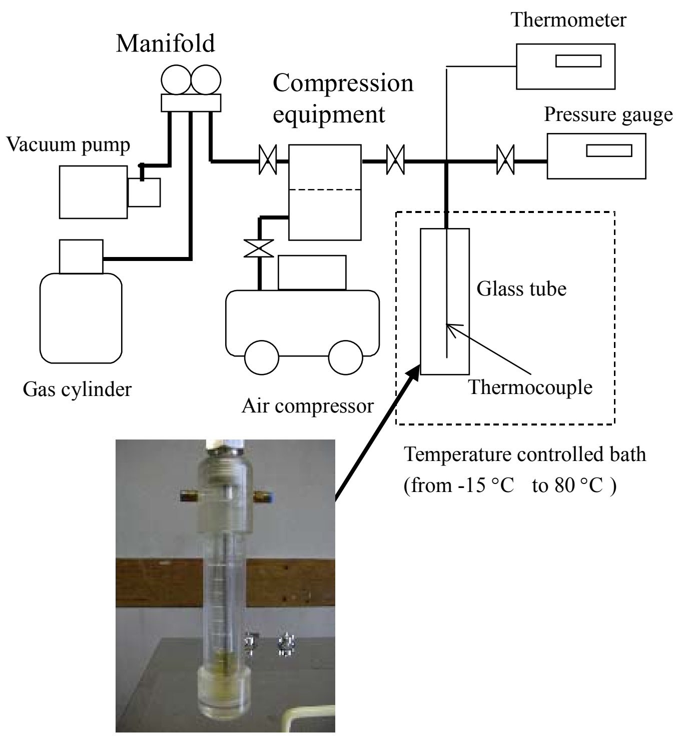


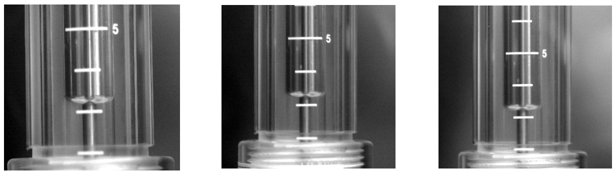
Fig. 1 Compatibility test equipment

Table 1 Experimental conditions (Compatibility test)

	HCFC22		HFC134a	
	Temperature [°C]	Pressure [MPa]	Temperature [°C]	Pressure [MPa]
Inlet of compressor	21.7	0.40	20.0	0.30
Outlet of compressor	72.3	1.77	72.7	1.30
Outlet of condenser	40.8	1.30	39.9	0.90
Outlet of additional condenser	37.8	1.25	36.5	0.79

2. 2 Results and Discussion

We first describe the result of the compressor inlet condition. Figure 2(a) shows sole mineral oil in the vacuum condition and Fig. 2(b) and (c) show the mixture of mineral oil and refrigerant in the compressor inlet condition. The oil level before enclosing refrigerant is the same position of the vacuum condition. Refrigerant is in the complete gas phase condition. Although there is no distinct change of the level of mineral oil of all cases, when HCFC22 or HFC134a is enclosed, vague shadows are observed for both cases because the fluctuation of refractive index is caused as a result of dissolving of refrigerant to mineral oil. However, the region of HFC134a where the fluctuation in refractive index occurred is smaller than that of HCFC22, thus it is thought that the amount of the dissolved HFC134a to mineral oil is less than that of HCFC22. This is also confirmed by Fig. 3 showing the change of the pressure of refrigerant confined in the test equipment. The pressure of HCFC22 is decreasing, however, that of HFC134a is almost constant.



(a) Vacuum/Mineral oil (b) HCFC22/Mineral oil (c) HFC134a/Mineral oil

Fig. 2 Solubility between refrigerant and mineral oil at the condition corresponding to the inlet of compressor

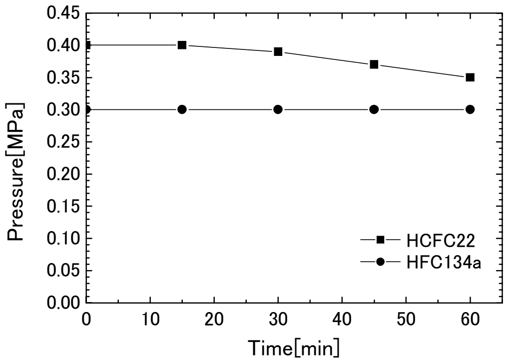
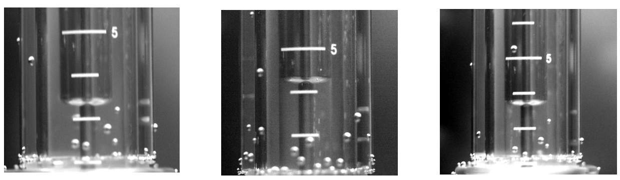


Fig. 3 Pressure change of refrigerant due to miscibility at the condition corresponding to the inlet of compressor

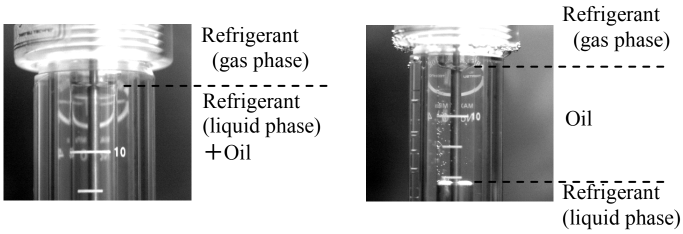
Next we describe the result of the compressor outlet condition. Figure 4(a) shows the sole mineral oil in the vacuum condition and Fig. 4 (b) and (c) show the mixture of mineral oil and refrigerant in the compressor outlet condition. The voids seen in Fig. 4 are adhered outside of the glass tube. The oil level before enclosing refrigerant is the same position of the vacuum condition. Refrigerant is in the complete gas phase condition. As seen in Fig. 4, the level of mineral oil is pointed at 3.3 ml in the vacuum. When HCFC22 is enclosed, the level changes to 4.2 ml. When HFC134a is enclosed, the level changes to 3.8 ml. Moreover, bubbles are generated from the inside of mineral oil for both HCFC22 and HFC134a while decompressing after the experiment. Thus it is thought that at the compressor outlet condition, more quantity of HCFC22 and HFC134a dissolved to mineral oil than at the compressor inlet condition. Furthermore, fewer quantity of HFC134a is thought to be dissolved than that of HCFC22.



(a) Vacuum/Mineral oil (b) HCFC22/Mineral (c) HFC134a/Mineral oil

Fig. 4 Solubility between refrigerant and mineral oil at the condition corresponding to the outlet of compressor

Finally, we describe the result of conditions at the condenser outlet and the additional condenser outlet. Since no distinct difference is observed between both conditions, the result of condition at the additional condenser is only shown in Fig. 5. When refrigerant is enclosed in addition to mineral oil, two phase condition, the gas and liquid, is observed. In the case of HCFC22, we observe only refrigerant in the gas phase and the mixture of refrigerant and mineral oil in the liquid phase. However, in the case of HFC134a, we observe that from the top, the gas phase refrigerant, mineral oil and liquid phase refrigerant are separately layered in the tube. Thus we conclude that at the conditions of the condenser outlet and the additional condenser outlet, mineral oil is miscible to liquid phase HCFC22 and immiscible to the liquid phase HFC134a. The values listed in Table 1 corresponds to super heated conditions so that those cannot be gas-liquid two phase conditions. However, we observed two phase conditions because there might be measurement errors due to non-uniformities of temperature and deviations of saturated vapor pressure of refrigerant due to mixing with mineral oil.



(a) HCFC22/Mineral oil (b) HFC134a/Mineral oil

Fig. 5 Solubility between refrigerant and mineral oil at the condition corresponding to the outlet of additional condenser

Based on the above-mentioned results, we think that at the conditions of the compressor inlet and outlet there is no distinct difference in terms of the circulation between the cases of HCFC22 and HFC134a since mineral oil is miscible to both refrigerants although the miscible quantity are different. However, at the conditions of the outlets of the condenser and the additional condenser, there should be distinct difference between both cases since mineral oil is miscible to HCFC22 whereas immiscible to HFC134a.

3. Flow Visualization in the Circuit

3.1 Experimental Method

Figure 6 shows the circuit chart for the flow visualization experiment. An air-conditioning machine (Mitsubishi Heavy Industries; compressor power 2.5 kW, designed cooling output 11.6 kW, heating output 12.7 kW) with capillary tubes is used for the experiment. The major dimensions of the outdoor unit (FDC100H7) are: fin pitch: 1.8 mm (slit fin); heat transfer tube: inner diameter 7.94 mm × thickness 0.3 mm (bare tube), 2 arrays - 48 stages, frontal width: 832.4 mm, frontal area: 1.014 m^2, array pitch: 19.04 mm. Regarding the indoor unit (FDT100H7): fin pitch: 1.8 mm (louver fin); heat transfer tube; inner diameter 9.52 mm × thickness 0.305 mm (grooved tube), 2 arrays - 20 stages, frontal width; 786 mm, frontal area: 0.4 m^2; array pitch; 19.04 mm. Regarding the capillary tube for heating: inner diameter: 1.5 mm; outer diameter: 3.2 mm; length: 400 mm. Regarding the capillary tube for cooling: inner diameter: 1.2 mm; outer diameter: 2.5 mm; length: about 300 mm.

The external additional condenser (5.8 kW) is installed on the outdoor unit. HCFC22 and HFC134a are used as refrigerants. Mineral oil for HCFC22 (Barrel Freeze 32s) is used as lubricating oil for both refrigerants. The flow visualization equipments are installed at the outlet of the condenser and the additional condenser and the inlet of the compressor.

Figure 7 shows the rectangular tube for the flow visualization made of the stainless steel with two flat PIREX glass windows, a cross section of 15 mm height × 23 mm depth and 100 mm long for the inlet of compressor (6/8 inch), whereas a cross section of 7 mm height × 15 mm depth and 100 mm long for the outlet of the condenser and the additional condenser (3/8 inch).

A digital camera (Nikon D1) with a short focus lens (Micro NIKKOR, f = 55 mm) is used to take photographs of flows in rectangular tubes at an exposure time of 1/10,000 sec, with a back light of a 500 W daylight lamp. Experimental conditions for visualization, *i.e.* temperatures and pressures of refrigerants at the outlet of condenser, the outlet of additional condenser and at the inlet of compressor, are listed in Table 2. Note that temperature of refrigerant at the inlet of the compressor is different from that in the compatibility test because HFC134a is more super heated due to less quantity.

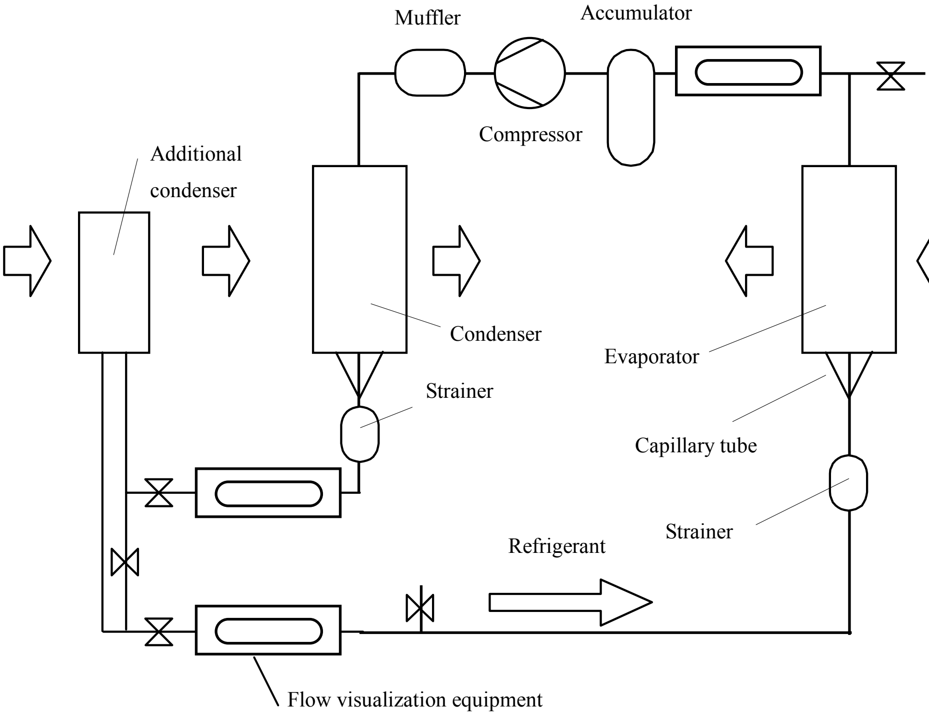


Fig. 6 Circuit chart with an additional condenser

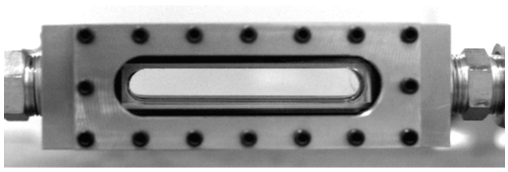


Fig. 7 Flow visualization equipment

Table 2 Experimental conditions (Flow visualization)

	HCFC22		HFC134a	
	Temperature [°C]	Pressure [MPa]	Temperature [°C]	Pressure [MPa]
Inlet of compressor	13	0.319	22	0.207
Outlet of condenser	35	1.50	35	0.93
Outlet of additional condenser	34	1.45	29	0.89

3.2 Results and Discussion

3.2.1 Experiment using HCFC22

Before operation, HCFC22 is in complete gas phase at the outlet of the condenser and any mineral oil is not observed. When the air-conditioning system starts, the liquid refrigerant comes into the tube with gas bubbles. As the operation goes on, the flow becomes stable, however, keeps being in gas-liquid two phase condition and never condensed completely. This is thought to be induced by installation of the additional condenser [(4)]. We observed that the condition at the outlet of the condenser was almost condensed in the case without an additional condenser. However, it was in gas-liquid two phase condition in the case with an additional condenser because installation of an additional condenser made the temperature of the inlet of the condenser higher.

The steady state condition is defined as the one where the temperature fluctuation is within 1 ^{o}C in 1 minute. Figure 8(a) shows the steady state flow of HCFC22 and mineral oil at the outlet of the condenser. It is thought that mineral oil is completely miscible to the liquid HCFC22 judging from the result of the compatibility test described in §2. When the air-conditioning system stops, the flow is becoming slow and the phase of HCFC22 changes completely from the liquid to the gas.

Before operation, HCFC22 is complete gas phase at the outlet of the additional condenser and no mineral oil is observed. When the air-conditioning system starts, liquid refrigerant comes into the tube with gas bubbles. As the operation goes on, the flow become stable and changed to complete condensed phase. The quality should be zero judging from the temperature and pressure at this moment. Figure 8(b) shows the flow of HCFC22 and mineral oil at the outlet of the additional condenser. Mineral oil is miscible in liquid phase HCFC22 and a homogeneous flow is observed at the outlet of the additional condenser. When the air-conditioning system stops, the flow is becoming transiently gas-liquid two phase condition again, and finally the gas phase only. Therefore it is thought that HCFC22 is completely condensed although mineral oil miscible to liquid HCFC22 is not observed.

Before operation, HCFC22 is in gas liquid equilibrium condition at the inlet of the compressor since the compressor is located lower position of the system. When the air-conditioning system starts, the liquid refrigerant is flown out and the flow becomes the gas phase condition. Then we observe a little liquid on the bottom of the flow visualization equipment. As the flow becomes stable, the liquid is separated from refrigerant and flows along the walls. The liquid is thought to be mineral oil containing a little gas phase of HCFC22 judging from the result of the compatibility test described in §2. Figure 8(c) shows the flow of HCFC22 and mineral oil at the inlet of the compressor. The mineral oil is observed to be stacked at the stagnating region near the inlet of the flow visualization equipment. Thus it is thought that mineral oil is stacked in other stagnating region in the system. When the air-conditioning system stops, the mixture of the liquid HCFC22 and mineral oil is observed. The liquid HCFC22 and mineral oil are separated at first, however, becoming homogeneous gradually as in the pre-operation condition.

(a) Outlet of condenser (b) Outlet of additional condenser (c) Inlet of compressor

Fig. 8 Flow of HCFC22 and mineral oil

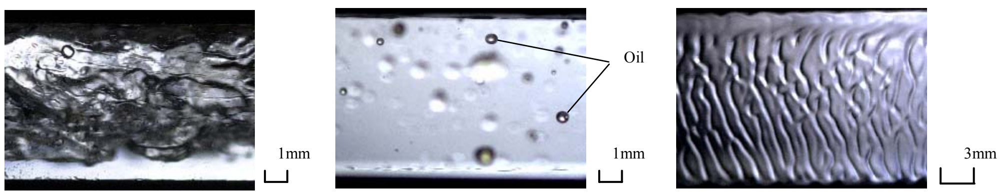
3.2.2 Experiment using HFC134a

Before operation, HFC134a is mostly gas phase at the outlet of the condenser and any mineral oil is not observed. When the air-conditioning system starts, the liquid refrigerant comes into the tube with gas bubbles. As the operation goes on, the flow becomes stable, however, keep being in gas-liquid two phase condition. Figure 9(a) shows flows of HFC134a and mineral oil at the outlet of the condenser. When the air-conditioning system stops, the flow is becoming slow and the liquid phase turns into all gas phase. Although bubbles prevent us from seeing mineral oil during the operation, as the flow goes stable, a little liquid which seems to be mineral oil is observed on the bottom of the flow visualization equipment.

Before operation, HFC134a is in complete gas phase at the outlet of the additional condenser and we observe droplets of mineral oil are adhered on the walls of the equipment. When the air-conditioning system starts, the liquid refrigerant comes into the tube with gas bubbles. Then we observe droplets of mineral oil in the liquid HFC134a. As the operation goes on, the flow becomes stable and completely condensed to be all liquid phase. The flow is sub-cooled condition judging from measured temperature and pressure. Figure 9(b) shows the steady state flow of HFC134a and droplets of mineral oil at the outlet of the additional condenser. Mineral oil is immiscible in liquid phase HFC134a and a flow of oil droplets in liquid phase HFC134a is observed at the outlet of the additional condenser. The mass ratio of mineral oil is about 0.1 wt% calculated from the volume of the droplets in Fig. 9. When the air-conditioning system stops, the flow is transiently becoming gas-liquid two phase again, and finally all gas phase. Then we observe droplets of mineral oil are adhered on the walls of the equipment.

Before operation, droplets of mineral oil are floating on the liquid phase HFC134a at the inlet of the compressor. When the air-conditioning system starts, the liquid refrigerant is flown out and becomes all gas phase. As the flow becomes stable, the liquid is separated from refrigerant and flows along the walls. Figure 9(c) shows the steady state flow at the inlet of the compressor. The liquid should be mineral oil contained a little gas HFC134a judging from the result of the compatibility test described in §2. This is similar to the case of HCFC22. When the air-conditioning system stops, mineral oil adhered on the walls comes down to the bottom of the equipment and the liquid HFC134a is coming in. Then we observe droplets of mineral oil are floating on the liquid HFC134a and flowing together with the HFC134a.

Similarly to the results of the compatibility test, we confirm in the flow visualization experiment that mineral oil is immiscible to HFC134a. However, droplets of mineral oil flow with the liquid HFC134a where HFC134a is in the liquid state. Furthermore there are no distinct difference in behavior of mineral oil between HFC134a and HCFC22 at the inlet of the compressor. Therefore, the circulation of mineral oil is confirmed at the exit of the condenser and the additional condenser and at the inlet of the compressor, even when HCFC22 is replaced by HFC134a.



(a) Outlet of condenser (b) Outlet of additional condenser (c) Inlet of compressor

Fig. 9 Flow of HFC134a and mineral oil

The oil retention in air-conditioning systems was recently evaluated using HFC410A and immiscible mineral oil [9]. It was proved that mineral oil circulated with HFC410A, though the amount of oil retention became larger than the polyol ester oil, which is miscible in HFC410A. This report also supports the circulation of mineral oil in the air-conditioning system with HFC134a.

4. Extraction of Working Fluids

4. 1 Experimental Method

In this experiment, the refrigerant and mineral oil are extracted from the air-conditioning system being in operation and measured the quantity of mineral oil in order to confirm the existence of mineral oil in working refrigerant.

The air-conditioning system installed with the additional condenser as well as the visualization experiment is used with the tubing system with a detachable valve by which refrigerant and mineral oil are extracted. The working fluid is extracted to the separation part of the tubing. Then, by switching the four-way valve, the separation part of the tubing contained the working fluid is separated from the main part of the tubing for the extraction. The working fluid is extracted at the inlet of the compressor and at the outlet of the condenser or the additional condenser. The mass of mineral oil is calculated by measuring the mass of the separation part with the electronic balance in vacuum condition, after extraction, and after evacuating gas refrigerant.

Four cases are experimented (HCFC22 /HFC134a and with/without the additional condenser) with Barrel Freeze 32s used as mineral lubricant oil. The temperature of inlet air of the indoor equipment is set to 27 ^{o}C and that of the outdoor equipment is set to35 ^{o}C.

4. 2 Results and Discussion

The experimental results at the compressor inlet and at the outlet of the condenser or the additional condenser are shown in Table 3. Since the existence of mineral oil is confirmed in all cases, we conclude that mineral oil is circulating with refrigerant. However, a quantitative comparison of weights of extracted fluids of each case is difficult because of the experimental errors. The differences in mass for each refrigerant are thought to be caused by the following situations:

(1) More mineral oil is trapped for HFC134a than HCFC22 at the outlet of the condenser or the additional condenser because mineral oil attached on the tube is also trapped in the case of HFC134a to which mineral oil is immiscible.

(2) More mineral oil is trapped for HCFC22 than HFC134a at the inlet of the compressor because more mineral oil is conveyed in HCFC22 which is miscible to mineral oil.

Due to (1) and (2), more mineral oil is required for operation with HFC134a.

Table 3 Weight of extracted oil

Condition	Oil mass [g]	
	Outlet of condenser / additional condenser	Inlet of compressor
HCFC22	0.16	0.49
HCFC22+AC	0.25	0.54
HFC134a	0.74	0.23
HFC134a+AC	1.00	0.30

Above-mentioned results are summarized that the existence of mineral oil is confirmed at the inlet of the compressor and the outlet of the condenser or the additional condenser for both HCFC22 and HFC134a. Based on this and the results in the flow visualization experiment, we conclude that mineral oil is circulating during operation for both HCFC22 and HFC134a although the composition of the mixture of mineral oil and refrigerant is different in the condensed phase of each refrigerant.

5. Conclusion

In this paper, we studied the mechanism of the circulation of refrigerant and mineral lubricant oil under operation.

Firstly, we tested compatibility of refrigerant and mineral lubricant oil and confirmed the gas phase HCFC22 was miscible to mineral oil however; the gas phase HFC134a was immiscible to mineral oil. Next, we visualize the circulation behavior of refrigerant and mineral lubricant oil under actual operation. Moreover, the existence of mineral lubricant oil in refrigerant is confirmed by extracting the working fluid from the tubing of the air-conditioning system under operation. Obtained results are summarized as follows:

(1) From the flow visualization experiment, we confirmed that when refrigerant was liquid phase, the mineral oil was miscible to HCFC22 and the oil and refrigerant flow compatibly, however; the mineral oil was immiscible to HFC134a and droplets of the oil flow with the refrigerant.

(2) From the extraction of working fluid, we again confirmed that mineral oil circulates throughout the air-conditioning circuit because the mineral oil was extracted at the inlet of the compressor and at the outlet of the condenser or the additional condenser.

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