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ABSTRACT

The critical problem of the HFC air conditioners is the deterioration of reliability caused by clogging of capillary tubes. This paper deals with how the problem was solved. The sludge produced on the sliding surface of compressors and the non-polar oils used during manufactures process do not dissolve in the HFC refrigerants. The sludge and process oils are highly viscous. Therefore, they can easily clog narrow passages such as capillary tubes and expansion valves. This paper focuses on the accelerated evaluation method of capillary clogging and the methods to prevent a HFC air conditioners from clogging. The clogging phenomenon is divided into four stages. First, the sludge is produced inside a compressor. Then, it is conveyed by lubricant to the capillaries or expansion valves. After it is separated from the refrigerants, it is deposited on the inner surface. The acceleration test was carried out by increasing the lubricant temperature and the refrigerant flow with different lubricants and compressors. The investigation results show that over the long period of operation the capillary performance with our swing compressors using the ether(PVE) based oil is equivalent to that of our rotary compressors using mineral oil with R22.

1 . INTRODUCTION

The critical factor for adopting HFC refrigerants in substitution for the HCFC refrigerant is the reliability of HFC refrigerants. Air conditioner manufacturers are conducting a number of studies to find solutions to the clogging caused by HFC refrigerants and lubricants.[1 - 4]

In order to solve these problems, it is necessary to investigate the reliability of HFCs. However, in general, it takes considerable time and effort to evaluate the durability and reliability of the HFC refrigerants. Therefore, We developed a less time consuming evaluating method to implement an early changeover from HCFC to HFC.

The HFCs does not dissolve sludge produced on the sliding parts of compressors. Nor does it dissolve auxiliary materials (such as lubricants) used during manufacturing processes such as rust proofing and cleaning processes. As a result, the HFC refrigerant systems are likely to clog narrow passages such as capillary tubes with by-products of materials used during manufacturing.

This paper reports on an accelerated evaluation method for prevention against clogging problems of the HFC refrigerant systems and discusses effectiveness of this method. The mechanism of clogging was derived from the results of durability test and divided into four stages: generation, transportation, deposit and adhesion. At each stage, the clogging process was accelerated in order to obtain the results within a short time.

In addition, we selected compressors and lubricants which are unlikely to clog and, as a result, were successful in preventing capillary clogging.

2. ACCELERATED EVALUATION METHOD AND TEST CONDITIONS

2-1 . Accelerated Evaluation Method

The test results show that the chemical deterioration of lubricants and refrigerants causes sludge. Based on the fact that the speed of this chemical deterioration is accelerated by temperature, we first tried to accelerate deterioration by raising the lubricant temperature. This method is commonly used in acceleration test.

We assumed that the rate of sludge generation can be accelerated by raising the lubricant temperature. In the durability test we operated the unit so that the lubricant temperature may rise higher than the normal and accelerate the rate of adhesive generation for evaluating the influence in a short time.

Table 1. shows the conditions for accelerated test and the parameters for evaluating reliability according to the clogging mechanism based on the results obtained from the durability test. The clogging mechanism is divided into 4 stages, (1) generation, (2) transportation, (3) deposit and (4) adhesion. An elements which greatly affect clogging are taken as parameters such as temperature at each stage.

Table 1. Parameter for Test Conditions

	Stage	Parameter
Capillary clogging	1. Production	Temperature *1 Compressor type *2
	2. Transport	Oil flow rate *1
	3. Deposit	Capillary inner dia. *1 Speed of refrigerant flow *1
	4. Adhesion	Components and quantity of contaminants *1 Compressor oil type *2

*1: Condition accelerated *2: Type compared

The degree of clogging was measured and evaluated by of flow rate drop through the capillary tube. We verified the flowing facts according to the durability test.

(1) The lubricant flow rate, the capillary inner diameter and, the component and quantity of contaminants are the factors which accelerate the clogging speed besides the temperature rise.

(2) The type of compressors and the chemical composition of synthetic lubricant are the factors which affect reliability of the system.

2-2 . Test Conditions

Table 2. shows the test conditions. The swing and rotary type compressors with R22, R410A and R407C were used for the test. Fig.2 shows the structure of the compressors. The vane of the rotary type is independent of the roller. On the other hand, the vane of the swing type is integrated with the roller which is called piston. The vane tip of the rotary forms a line contact, and is in the range of boundary lubrication. The specification of the heat exchangers for R22, R410A and R407C are all identical. The vane is specifically designed for HFC refrigerants.

Table 2. Test Unit Specification

1HP : Inverter heat pump room air conditioner

Refrigerant	R407C , R410A			R22
Lubricants (Viscosity)	POE (VG68)	PVE (VG68)	PVE/AB*2	Mineral oil (VG56)
Comp. type	Rotary*1	Rotary*1	Swing	Rotary*1
	Swing	Swing		

*1: The vane specifically designed for HFC is applied *2.AB: Alkyl benzene

Table 3. shows the characteristics of the lubricants. In order to verify the degree of influence of contamination and moisture, the whole system was thoroughly cleaned, and dehydrated. In order to maintain the temperature of discharge gas constant, the RPM of the compressor was controlled by an inverter. Every 500 hours of operation, the capillary tube was removed and the flow rate of nitrogen gas under the fixed differential pressure was measured. In addition, every 2000 hours of operation, the total acid number of the lubricant was measured. The evaluation was based on the flow rate drop ratio per operating hours and the total acid number increase per operating hours. After a certain hours of operation when the capillary clogged, it was cut and the sludge was analyzed with an optical microscope, and EDS / GPC molecular analyzers.

Table 3. Characteristics of Lubricants

Oil	POE	PVE	AB	Mineral oil
Structure	R-COO-R	R-O-R		
Polarity	yes	yes	no	no
Solubility of refrigerant	◎	◎	×	×
Solubility of contamination	×	△	◎	○
Thermal stability	○	○	○	○
Hydrolysis stability	△	○	○	○
Oxidation stability	○	△	○	○

◎=very good ○=good(HCFC-22/equivalent to mineral oil)
△=not very good ×=bad

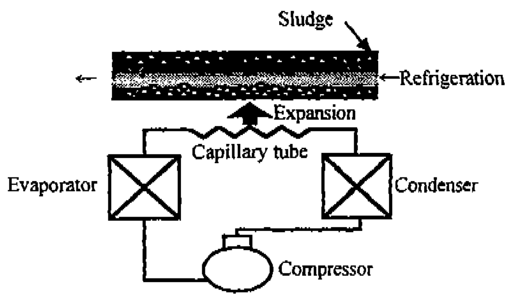

Fig. 1 Refrigerating Cycle of HFC Air Conditioning System

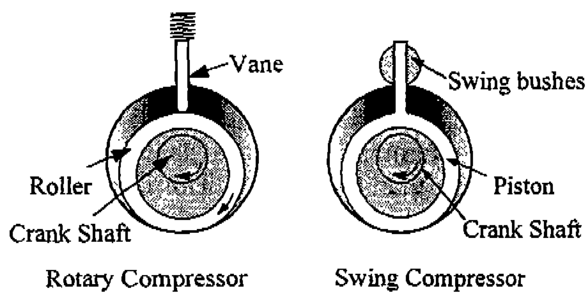

Fig. 2 Structures of Compressors

3. TEST RESULT

3-1. Accelerated Evaluation Result

(1) The effect of oil temperature

Fig.3 shows how the capillary clogging rate is affected by temperature. We tested the lubricants in the system at 110℃ and 140℃. We also conducted the test at the other temperatures between 50℃ and 140℃. These result agrees with the theory of Arrhenius which states that the clogging rate doubles by increase of every 10℃. Therefore, we verified how the temperature rise accelerates the capillary clogging. It means that the period for reliability test can be shortened to one eighth.

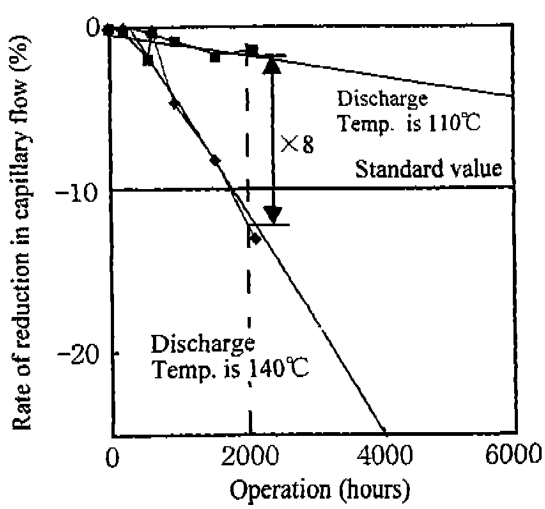

Fig. 3 Evaluation of Capillary Clogging by Temperature

(2) The effect of the lubricant flow rate

Fig.4 shows how the lubricant flow rate affects the capillary clogging. Fig.4 shows that the higher the lubricant flow rate is, the more the flow rate drops. This is because the sludge generated on the sliding surface of the compressor dissolves in lubricant and is discharged from the compressor. Fig.1 shows how the sludge adheres to the wall of capillary and leads to the clogging. It means that if the lubricant flow rate is increased, the clogging can be accelerated.

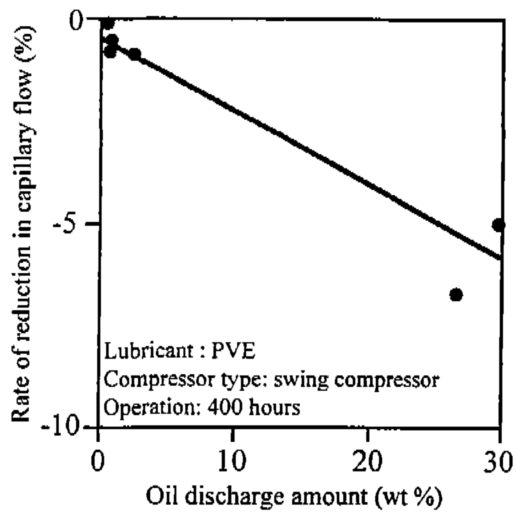

Fig. 4 The Relationship Between Oil Discharge Volume and Flow

(3) The effect of the inner diameter of the capillary

Fig.5 shows how the inner diameter of a capillary tubes affects the clogging. Under a certain amount of sludge circulation rate, the smaller the diameter is, the more the flow rate drops. The sludge when going through a smaller capillary adheres to the wall at a faster rate, because the inner surface area is small. It means that a smaller inner diameter accelerates the clogging.

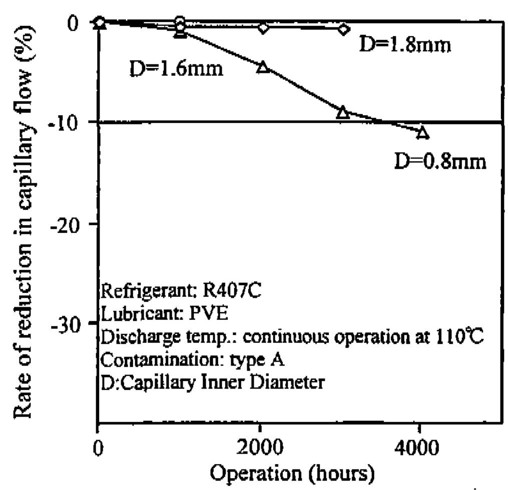

Fig. 5 Effects of Capillary Inner Diameter

(4) The effect of contamination

Fig.6 shows how the component and quantity of contaminants affect the clogging. Fig.6 shows that the type B contamination tends to cause the clogging faster than the type A. This is because the type B remarkably enhances the generation of sludge and other adhesives and thus accelerates the clogging. It means that the component and quantity of contamination accelerates the clogging.

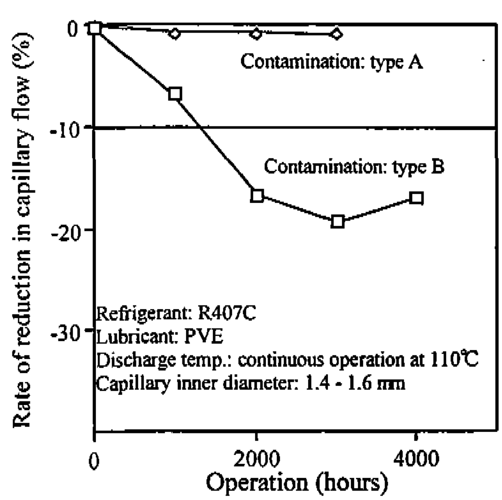

Fig. 6 Effects of Contamination on Capillary Clogging

3-2. Reliability Evaluation Results

(1) The Effects of Compressor types and lubricants

Fig.7 shows the test results of the compressor types and lubricants. The clogging caused by the swing type with PVE lubricant is the smallest, if the sludge circulating rate is maintained constant. The reasons why this combination is the best are as follow;

(1) The sliding surface of our swing type generates less sludge than that of our rotary type.
(2) PVE lubricants dissolves more contaminants than POE lubricants.
(3) Since PVE lubricants contain less extreme pressure additive than POE lubricants, PVEs do not easily cause generation of sludge.

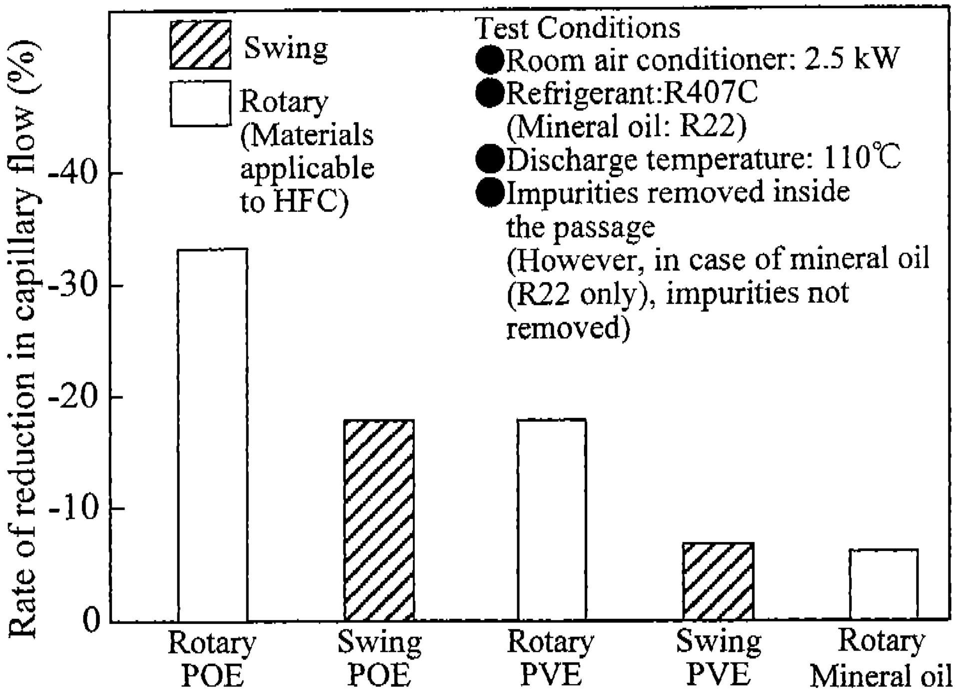

Fig. 7 Effect of Compressor Type and Oil

(2) The Effects of Adding inhibitor

Alkyl benzene is used as an inhibitor. Fig. 8 shows the test results of the PVE and the inhibitor added PVE. The flow rate drop of the inhibitor added PVE is approximately 50% less than that of PVE itself. This is because, as shown in Table 3,the inhibitor alkyl benzene has high solubility to contamination and sludge. The contamination degree of the system in Fig.8 is approximately 2 times of that shown in Fig.7.

Therefore, the effect of inhibitor is remarkable even when the contamination is greater.

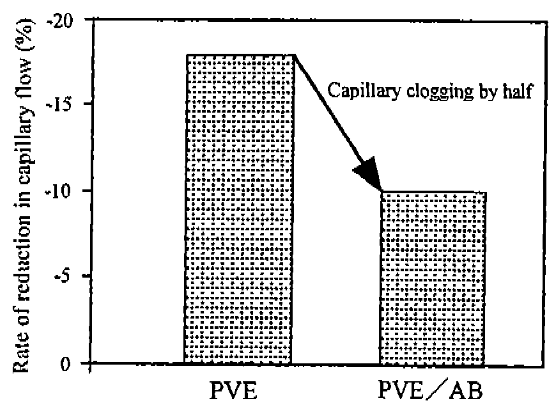

Fig. 8 Effect of Addition of Alkyl benzene

4. CONCLUSIONS

Based on the accelerated evaluation test results, we arrived at the following conclusions.

1) The accelerated evaluation method based on clogging mechanism is efficient and reliable.
2) The reliability of the swing type with HFC refrigerant and PVE lubricant is equivalent to that of the rotary type with R22 and mineral lubricant.
3) PVE with alkyl benzene inhibitor is effective for prevention of clogging.

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