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S. Yoshimura

Mitsubishi Electric Corporation

S. Wakamoto

Mitsubishi Electric Corporation

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DEVELOPMENT OF SLUDGE CATCHER FOR REFRIGERATORS AND AIR CONDITIONERS WITH HFC REFRIGERANTS

Susumu Yoshimura, Shinichi Wakamoto

Mechanical System Department, Advanced Technology R&D Center
Mitsubishi Electric Corporation 8-1-1 Tsukaguchi-Honmachi Amagasaki,
Hyogo 661-8661, Japan

ABSTRACT

Ester oils for HFC refrigerators and air conditioners are easily degraded by hydrolysis reactions etc. and various kinds of sludge are generated inside compressors. This sludge clogs narrow refrigerant ducts such as capillary tubes and expansion valves. It is best to remove it before it reaches these ducts to prevent blockades. Unfortunately, it is difficult to remove sludge dissolved in oil by filtering. This paper describes a sludge catcher we have developed that removes dissolved sludge by mixing the oil and the liquid refrigerant and depositing from them. We verified the principle of this sludge catcher experimentally. Furthermore, the effects of the flow-rate ratio of liquid refrigerant to oil and the flow pattern of the oil and refrigerant mixture on the amount of the sludge captured by the filter was evaluated. It is found that the amount of the captured sludge increased sharply at a specific flow-rate ratio.

INTRODUCTION

Ester oils for HFC refrigerators and air conditioners are more easily degraded by hydrolysis reactions etc., than those for conventional HCFC's. Various kinds of sludge are generated inside compressors. The sludge, which is dispersed and dissolved in oil, is conveyed into the refrigerant circuit. It adheres to and accumulates in narrow refrigerant ducts such as capillary tubes and expansion valves and clogs them. There have been some attempts^{(1) (2)} to improve oils and gain a deeper understanding of the generation mechanism. These have been based on a detailed chemical analysis aimed at reducing it.

In general, hydraulic machines control the number of contaminating particles in hydraulic fluid⁽³⁾, and this fluid is kept clean by various filters. In refrigerators and air conditioners⁽⁴⁾, a strainer removes comparatively large foreign matter such as dust and scale. Few, however, have been attempted to capture the sludge that migrates into the refrigerant circuit.

The authors have developed a sludge catcher capable of capturing the sludge dissolved in oil which is difficult to remove by filtering. We tested this ability by mixing oil and liquid refrigerant and depositing from them.

We report on these tests and describe the effects of several parameters on the characteristics of our sludge catcher.

EXPERIMENTAL DETAILS

1. Test oil

We synthesized model oil with ester oil in an autoclave to simulate degraded oil under practical conditions. Table 1 shows the synthesis conditions. These conditions simulate those inside a compressor. We assumed that the generation of sludge is due to heat deterioration and hydrolysis reaction.

The test oil was produced as follows. After the microparticles were sedimented and separated in the model oil, the supernatant liquid was diluted with new oil. Concentrations were 0.1 (Model oil:new oil weight ratio=1:9) and 0.3. In the sedimentation we left for 300 hr until the sedimentation phase completely reach to the base. We produced sufficient amounts of test oil in advance so that differences in the nature of test oils would not skew results.

An endurance test oil collected after a 2,000 hr test was performed to study the efficacy of the catcher. New oil was used to verify the veracity of our results. The endurance test oil was not diluted.

We assumed that particle components were larger than $2\ \mu\text{m}$, which is the detection limit in a light-block-type particle counter (UCC production, CM20). We measured the particle concentration of the test oil by using the above instrument, and we found only trace concentrations. The concentration was $0.1\ \text{mg/kg}$ or less for particles between 2 and $15\ \mu\text{m}$. It was $2\ \text{mg/kg}$ or less for particles larger than $15\ \mu\text{m}$ (assuming that particles were spheres and the specific gravity was 1) in both the model oil and the endurance test oil.

2. Experimental apparatus

Figure 1 shows our experimental apparatus and Table 2 shows its main specifications. The apparatus has a mixing tube in which the oil and the liquid refrigerant are mixed continuously. It also has a mix-promoting tube in which the flow velocity is increased and a sludge catcher in which the deposited sludge is captured while moving downstream.

The liquid refrigerant and oil are conveyed by using a plunger pump, and only the refrigerant is evaporated in an evaporator after mixing. They are separated in an oil separator, and circulated individually. The oil-level in the tank is adjusted regularly by a regulator.

The sludge catcher consists of a top-opened cylinder-style filter element made of sintering metal. Its pores are $7\ \mu\text{m}$, which is one size larger than the $2\ \mu\text{m}$ pores in the oil and refrigerant filter. Figure 2 shows a schematic view of the sludge catcher. This catcher shown is equipped with nozzle which is described later. The oil and refrigerant filter prevent the wear particles of the pump from flowing into the circuit.

The dummy tubes (ID $4.2\ \text{mm}$, $390\ \text{mL}$) are located upstream and downstream of the sludge catcher to demonstrate that sludge adheres to ducts other than tubes in which the amount of the adhesion was measured individually. Temperature and pressure were measured with a thermocouple and pressure transducer.

3. Experimental conditions

The refrigerant was R407C. We evaluated the effects of parameters suspected of influencing the disposition process in the oil and liquid refrigerant mixture. Specifically, they were (1) the flow ratio of the liquid refrigerant to the oil [liquid refrigerant flow rate/(liquid refrigerant flow rate + oil flow rate)], (2) the flow pattern of the oil and refrigeration mixture inside the mixing tube, and (3) the upstream presence of a nozzle. The flow pattern was varied by mixing the preheated hot oil and liquid refrigerant and evaporating a portion of the liquid refrigerant. The quality of the refrigerant inside the mixing tube was calculated based on the heat balance during mixing. The flow-rate ratio was varied by adjusting the flow rate of the refrigerant and the flow pattern inside the mixing tube while keeping the oil flow rate constant. The test specimens and conditions are summarized in Table 3.

4. Experimental method

Figure 3 shows the test flow. We washed all of the ducts in the apparatus before each experiment. First, they were washed with new oil. After installing the washing filter with a porous size of $2\ \mu\text{m}$ (smaller than that used in the experiment for the position of the sludge catcher) and refilling the new oil, the next washing operation was carried out. The washing was done at a refrigerant flow rate of $22\ \text{kg/h}$ and an oil flow rate of $1.7\ \text{kg/h}$. A single phase flow was used for all experiments. This operation was finished after the pressure difference before and behind the washing filter reached a stationary value. Washing took at least one hour even when the pressure difference was not changed first.

We exchanged the washed filter element, and we used a new element for the sludge catcher in each experiment.

After the test we removed the filter element in the sludge catcher, the oil and the refrigerant filter, the mixing tube, the mix-promoting tube and the dummy tube. The refrigerant was purged, and the sludge was recovered by ultrasonic cleaning with the solvent (chloroform) individually. Finally, after the solvent was dried, the remainder was weighed, and the amount of sludge became the oil concentration removed, measured by GPC (Gel permeation chromatography, solvent: THF,

detector: RI) to determine a net amount of sludge. Furthermore, all recovery of the sludge confirmed by comparing the weight of the washed filter element with that of element before the experiment.

All experiments were done under the same conditions and procedures except for some parameters which were changed to improve experimental accuracy.

RESULTS AND DISCUSSIONS

1. Capture rate

Table 4 shows the test conditions, and Figure 4 shows the average capture rate derived by dividing the amount of the sludge captured in the sludge catcher by the operation time. We found that the material recovered after the test was tacky and dark brown except in the test by new oil. This tacky substance consisted of the degraded ester oil, which was observed by using infrared spectroscopic analysis. The sludge catcher captured most sludge in the filter element. We observed little adhesion to other parts such as the nozzle.

As shown in Figure 4, the capture rate in the sludge catcher was between 0.5 and 6.5 mg/h, while the amount of sludge was between 3.5 and 5.5mg. This corresponds to the quantity of 10 to 130g over total operation time, assuming this time is 20,000 hours. The measuring result of a capture rate of about 0.3mg/h in the experiments No. 8 is concluded by systematic error because no tacky substance was observed. This error increased with the oil concentration of sludge. The amount of sludge adhered to the dummy tubes and that captured in the oil and refrigerant filters was approximately 1.5 mg or less. The above error in the amount of sludge adhered to the mixing tubes increased because oils tended to remain there. For these reasons, we only evaluated the amount of the sludge captured by the sludge catcher.

It was thought that the sludge dissolved in oil, including the particles $2\mu\text{m}$ or smaller, was deposited and aggregated as the particles over $7\mu\text{m}$ in the mixing process of the oil and liquid refrigerant because the sludge was captured in the $7\mu\text{m}$ filter after the oil and liquid refrigerant that passed through the $2\mu\text{m}$ filter were mixed.

Secondly, we studied about the effects of various parameters on the capture rate.

2. Effects of various parameters on capture rate

(1) Effect of flow-rate ratio of liquid refrigerant to oil

Figure 5 shows the relationship between the capture rate and flow-rate ratio of the liquid refrigerant. This data corresponds to experiments No.1-3 in Figure 4. The capture rate increased sharply at approximately 0.65. This seems to be because the solubility of sludge in the oil and liquid refrigerant mixture approaches that in the liquid refrigerant as the flow-rate ratio increase, and because the solubility of the sludge in the liquid refrigerant is lower than that in oil. However, the increase in flow rate was suppressed by the further flow rate. This seems to be because the total flow rate of the oil and liquid refrigerant mixture increases with the flow rate, and the captured sludge are re-entrained from the catcher by the increase in flow velocity, etc. It is expected that the flow-rate ratio has a maximum value in the capture rate.

(2) Effect of flow pattern inside mixing tube

Comparing the capture rates in the experiments No. 2 and 4 in Figure 4, we see that the condition of the two-phase decrease by an approximate factor of 3 compared with that of the single phase. This is due to the prevention of the aggregation of sludge particles deposited in the mixing tube by intervention of the vapor phase and the re-entrainment that caused by the increase in flow velocity described above.

(3) Effect of nozzle

The pore size of the filter element in the sludge catcher was $7\mu\text{m}$, and we predicted it could capture particles from 2 to $7\mu\text{m}$. We also studied the effect of a nozzle. The capture rate decreased by approximately 38% when the nozzle was installed, comparing with the capture rates in the experiments No. 4 and 5. The expected effect of the nozzle was not observed because the nozzle and filter element were far apart. By contrast, Marple et.al.⁽⁶⁾ observed that the capture efficiency for

particles from 2 to 7 μ m was increased by a nozzle. The reason for the reduction we observed is unclear.

(4) Effect of concentration of sludge

We found that the capture rate increased almost linearly as the concentration of sludge increased. This seems to be because the sludge corresponding to the increment of the concentration is all supersaturated and deposited.

3. Capture rate in endurance test oil

In experiment No. 7, a capture rate of 1.2 mg/h was observed in the endurance test oil, demonstrating the efficacy of our sludge catcher. This capture rate was a little higher than that in the other experiment with two-phase flow. This is due to the difference in the initial concentrations of sludge in the endurance test oil and model oil.

CONCLUSIONS

The following conclusions can be drawn.

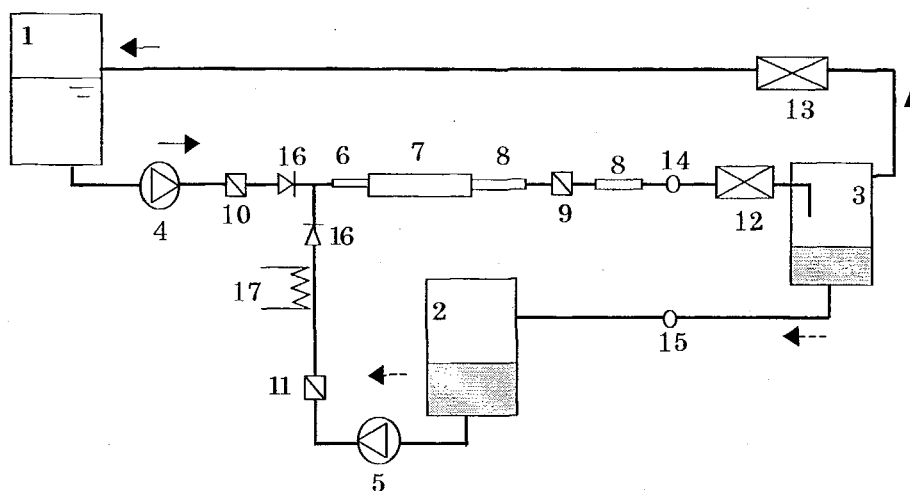
1. We observed a capture rate of sludge of approximately 1 mg/h, corresponding to 20 g over 20,000 hrs. The efficacy of our sludge catcher was demonstrated.
2. We evaluated the effects of the various flow-rate ratio of liquid refrigerant to oil [liquid refrigerant flow rate/(liquid refrigerant flow + oil flow)] on the capture rate and the flow pattern of the oil and refrigerant mixture in the mixing tube, we found that the capture rate increases sharply at a flow-rate ratio of 0.65, and the capture rate with two-phase flow was lower than under for single phase. The reason for the capture rate increase seems to be because the solubility of sludge in the oil and liquid refrigerant mixture approaches to that in the liquid refrigerant as the flow-rate ratio increase, and because the solubility of sludge in liquid refrigerant is lower than that in oil.

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Table 1. Synthesis conditions for test oil

Oil	Ester (POE, VG56)
Reaction promoting agent	Pure water (2000ppm) etc.
Temperature	175°C
Atmosphere	R134a
Reaction time	72 hrs
Time of sedimentation and separation of microparticles	300 hrs



1. Liquid refrigerant tank 2. Oil tank 3. Oil separator 4. Liquid refrigerant pump 5. Oil pump 6. Mix-promoting tube 7. Mixing tube 8. Dummy tube 9. Sludge catcher 10. Refrigerant filter 11. Oil filter 12. Evaporator 13. Condenser 14. Pressure regulator 15. Oil flow regulator 16. One-way valve 17. Heater

Figure 1. Schematic diagram of experimental apparatus

Table 2. Main specifications

Sludge catcher (Element)	Cylinder type made of sintered metal Filter area: 830 mm ² Porous size: 7 μm
Mixing tube	Glass ID 6 mm × 450 mmL
Mix-promoting tube	Copper ID 2.2 mm × 200 mmL

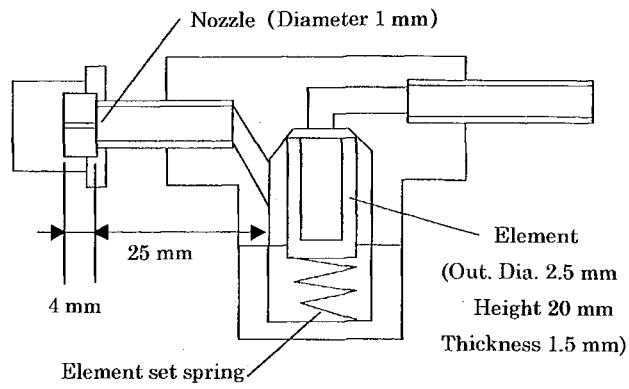


Figure 2. Schematic view of sludge catcher

Table 3. Test conditions

Refrigerant	R407C
Test oil	(1) Model oil + New oil (Concentration: ①0.1, ②0.3) (2) New oil (3) Endurance test oil
Oil flow rate (kg/h)	1.7
Oil amount (kg)	1
Refrigerant flow rate (kg/h) [Flow-rate ratio of liquid refrigerant (-)]	3.2-15.8 [0.65-0.90]
Nozzle	Present/Not present
Flow pattern inside mixing tube	Single phase/ two-phase flow
Temperature inside mixing tube (°C)	30
Operation time (hrs)	7

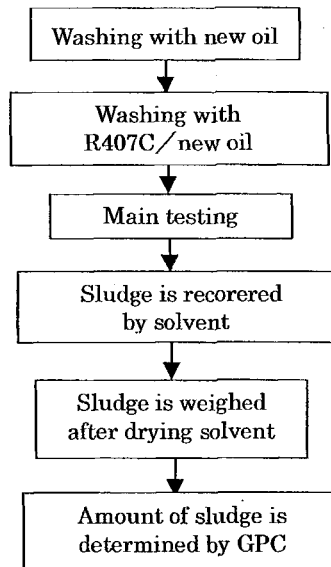


Figure 3. Flowchart of test

Table 4. Test conditions

Exp. No.	Test oil	Concentration	Oil flow rate kg/h	Ref. flow rate kg/h	Flow-rate ratio of liquid ref.	Flow pattern (quality)	Nozzle
1	Model oil	0.1	1.7	3.2	0.65	Single phase flow	Not present
2	↑	↑	↑	5.0	0.75	↑	↑
3	↑	↑	↑	15.8	0.90	↑	↑
4	↑	↑	↑	6.6	0.77	Single phase flow (0.12)	↑
5	↑	↑	↑	6.4	0.77	Two phase flow (0.10)	Present
6	↑	0.3	↑	5.9	0.78	Single phase flow	Not present
7	Endurance oil	1 (Not diluted)	↑	4.4	0.68	Single phase flow (0.17)	Present
8	New oil	↑	↑	5.2	0.75	Single phase flow	Not present

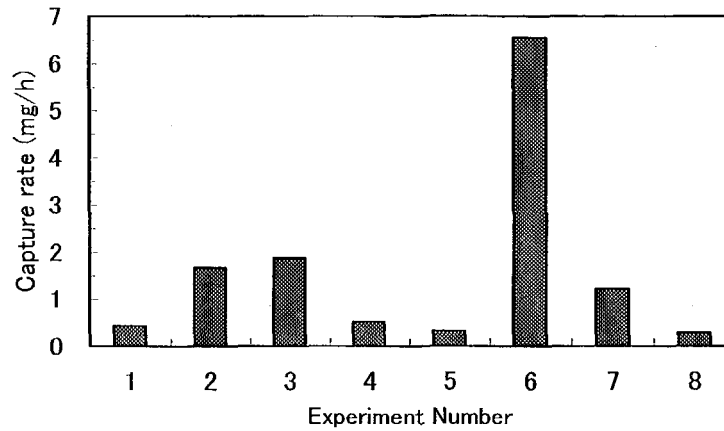


Figure 4. Capture rate of sludge

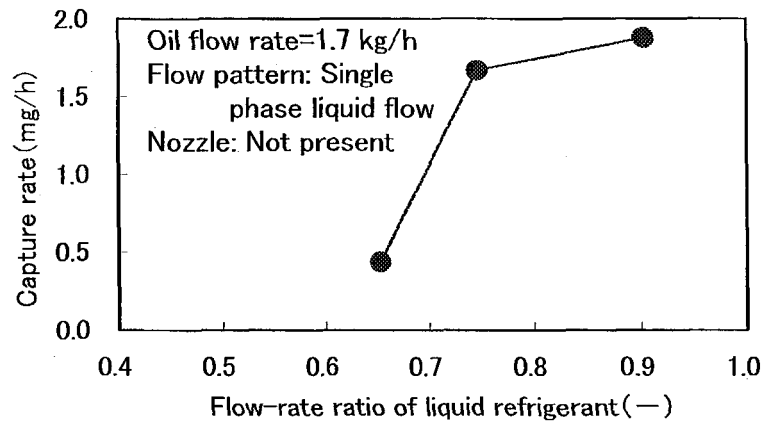


Figure 5. Relationship between capture rate and flow-rate ratio of liquid refrigerant

