Recovery and Regeneration of CFCs Using Electrostatic Separation

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Abstract - CFCs have been widely used for air conditioner and other purposes. Due to significant effect of CFCs to global environment, recycle and reuse are recommended. Using electrostatic separation, we have developed an apparatus to remove impurities in refrigerants (CFCs, HFCs and HCFCs). Used refrigerants in air conditioning system contains deteriorated oil and other impurities. When used refrigerant are recovered by vacuum pump system, those impurities become mists in gas-phase the refrigerant. Those mists are charged by impaction to a fine needle. Charged mists can be separated by the following parallel plate in which a dc electric field is formed. This system has been proved to clean the recovered refrigerants to be able to reuse. This system will save total energy for recycle of refrigerants, and will contribute to improve the environment.

Keywords - CFCs, refrigerant, recycle, tribo-charging, separation

I. Introduction

Fluorocarbons (CFCs, HCFC), which are used as refrigerants in refrigeration and air-conditioning systems, may destroy the ozone layer if they are released into the atmosphere, resulting in an increase in the amount of ultraviolet radiation reaching the earth's surface and an increase in the incidence of skin cancer and cataracts, which may have a serious impact on ecosystems[1]. Alternative fluorocarbons (HFC) do not destroy the ozone layer, but have thousands of times more of the warming effect of carbon dioxide, resulting in an ongoing global temperature rise with various impacts on the global environment, including rising sea levels and the occurrence of natural disasters. Against this background, in Japan, it is mandatory that CFCs shall be recovered and detoxified, guided by the household recycling and CFC recovery and destruction methods[2]. However, the recovery rate of CFCs in commercial air conditioners is only at a low level, as low as 40%, and ozone layer destruction and global warming are concerned due to the release of unrecovered CFCs.

Although 62% of recovered CFCs are destroyed and detoxified in 2016, it requires more than 2kW of energy per kilogram to destroy CFCs[3].

Refrigerants Recycling Promotion and Technology Center (RRC) has reported that comparative examination by LCA (Life Cycle Assessment) is required, and the data on distillery regeneration or destruction treatment were collected and examined with the collaboration of three certified regeneration plants. As the result, the warming effect of the distillation regeneration is about 1/12th compared with the destruction treatment to convert to CO_2, and it was confirmed that the distillation regeneration is desirable[4-6].

Although CFCs are very stable substances that are less likely to change into other substances after using for many years, their performance as natural refrigerants becomes ineffective due to the incorporation of moisture and air into the encapsulated CFCs or the degradation of the refrigerator oil used by mixing them into the CFCs. The performance of CFCs can be recovered by removing impurities responsible for such reduced CFCs performance. Table 1 shows the quality regulations of CFCs. Considering the above-mentioned merits of CFCs regeneration, we investigated a methodology to regenerate CFCs by removing impurities in degraded CFCs. As the specific target values for the regeneration, the CFC quality regulation shown in Table 1 was assumed. In addition, from a practical point of view, the development of a device that can easily be regenerated at the recovery site of CFCs was kept in mind.

Since CFCs are low boiling substances, it is possible to separate and recover most of the impurities, including freezer oils, by gasification, but this gasification operation alone still leaves small amount of oil mists and moisture, etc. Achieving CFC quality regulations completely by excluding these trace impurity components was not easy, and an extensive research was necessary.

We found that frictional charging phenomena are available as a method for removing trace amounts of moisture and oil mists carried in CFC gas airflow when gasifying CFC. We have been conducting CFC airflow with adjusted flow rates through needle valves in various resin tubes to investigate the tribo-electricity of impurities and separation of charged impurity particles in CFC[7]. In the course of the experiment, it was surprising that the charge of impurities was extremely high when passing through a needle valve used for flow regulation. Previously, we reported the effects of needle valve diameter, flow rate, and charged filter potential on CFC regeneration, and based on the results[8], we again compared the charge amount of impurities in CFCs generated by contact between resin tubes and needle valves.

In this report, we measured and compared the amount of charge generated by friction between an oil mist and various resin tubes of different materials, as well as a needle valve.

Based on the results obtained here, a CFC regeneration device incorporating a needle valve was fabricated to meet a goal of fast processing speed and high quality

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TABLE 1: STANDARD FOR REFRIGERANT (JIS K 1517)

Refrigerant	CFC12
Purity (%)	Above 99.5
Oil (HBR) content (%)	Less than 0.01
Acid content (%)	Less than 0.0001
Moisture content (ppm)	Less than 10

regeneration of CFCs. The regeneration experiments were conducted to complete the commodity model, which is the final shape, and its regeneration ability was measured.

II. EXPERIMENTAL METHOD

A. Charge measurement

The experimental setup for measuring the charge amount of refrigerator oil in CFCs is shown in Fig. 1. First, a cylinder for CFCs recovery was filled with CFCs mixed with HCFC22 and refrigerator oil (SUNISO 3GS) at a weight-ratio of 9:1 to generate the gas mixture of CFCs and oil mists. The gas mixture was made by heating the cylinders, and the charge generated when the gas mixture was passed through the resin tubes or the needle valves was measured by a Faraday cage with an electrometer (Keithley 6514).

A.1. Influence of Resin Tube Materials on Charge Volume

We studied a variety of commercially available resin tubes because the amount of charge may vary greatly depending on the different materials of the resin tubes. The flow rate of the CFC gas mixture flowing through the resin tubes was measured using a flowmeter connected behind the Faraday gauge and adjusted to 11.6 L/min.

The resin tubes were made of Teflon, nylon, and polyethylene, all of which were made to be an outer diameter φ6mm× inner diameter φ4mm× length 1m.

A.2. Effect of the flow rate on charge

Flow velocity of the gas mixture in the resin tubes may influence tribo-electrification of oil mists. The effect of the tube diameter was also measured. Fluorine-resin tubes with different tube diameters, external diameter φ8mm× internal diameter φ6mm, external diameter φ6mm× internal diameter φ4mm, and external diameter φ4mm× internal diameter φ2mm (all lengths are 1m) were prepared, and the charge amount was measured by keeping the flow rate of CFCs constant at 11.6 L/min (flow rate ratio was 9:4:1).

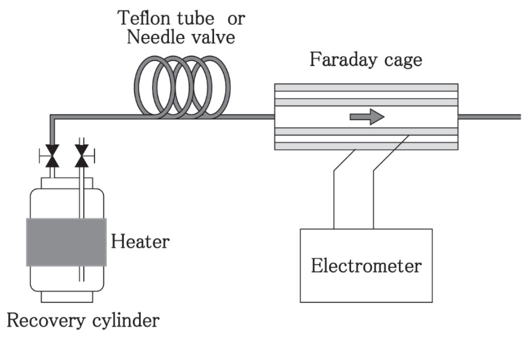

Fig. 1. Experimental setup

A.3. Comparison of charge volumes between resin tubes and needle valves

Resin tubes with a high charge amount were selected in the previous section and compared with the charge amount of the needle valve. The flow rates with the plastic tubes or the needle valves were both set to 11.6 L per minute as the same as in the previous section.

Measurement of the charge amount by the needle valve was performed by replacing the needle valve in Fig. 2 with the position of the Teflon tube in Fig. 1. The needle valve was a model AS2200-2 of SMCs make, and the material of the needle was brass and φ4mm in diameter.

B. CFC recycling experiment

A CFC regeneration experiment was carried out to confirm whether the CFCs could be actually regenerated by the charge separation device. The experiments used the Teflon tube and the needle valves selected in section A to compare the effect of the voltage applied to the dust collectors on the purity of the regenerated CFCs. In addition, a charge separation device optimized in previous experiments was incorporated to fabricate a commodity model, and a demonstration experiment was carried out on the regeneration ability. In addition, the same validation was performed for CFC HFC410A besides HCFC22.

B.1 CFCs recycling experiment

The CFCs-regeneration experimental setup is shown in Fig. 3. It consists of the needle valve to charge impurities in CFCs, the parallel plate-type dust collector to collect their impurities, a compressor to compress gasified CFCs, a condenser to cool and liquefy gasified CFCs, a recovery cylinder filled with CFCs before regeneration, and a regeneration cylinder filled with CFCs after regeneration.

The recovered CFCs are gasified in the cylinder by heating to generate gas-phase CFCs containing oil mists, which is passed through the Teflon tube or the needle valve for charging the oil mists suspended in the CFCs. The charged oil mist is then collected by the parallel-plate-type electrode with a dc electric field. The purified CFCs are then compressed by a compressor (Thomas 1/2HP oil-

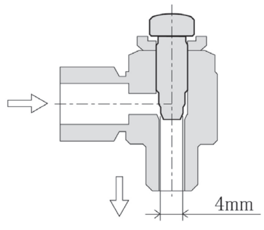

Fig. 2. Needle valve for charging

less method) and cooled and liquefied in a condenser. The liquefied CFCs are packed in the recycled CFCs cylinder.

A detailed view of the dust collectors is shown in Fig. 4. Parallel-plate electrode was installed in a plastic chloride tube with diameter of 110 mm and length of 200mm. Fifteen stainless steel electrodes with 48mm x 95mm, thickness of 0.8mm were constructed at 2-mm intervals. A DC power supply (Matsusada Precision Inc) was connected to the electrode alternately to form an electric field between the electrodes.

In the CFCs regeneration experiment, the voltage required for the removal of refrigerator oil in CFCs was measured. CFC obtained by mixing HCFC22 and refrigerator oil (SUNISO 3GS) in a weight ratio of 9:1 was prepared in the recovery cylinder, and the CFC was regenerated by passing through the dust collector at a flow rate of 11.6 L per minute. The flow velocity in the dust collector is 7.25m/min. The applied voltage necessary to reduce the oil residue in the CFCs less than 0.01% was determined.

The method for determining the percentage of refrigerator oil contained in CFCs (Oil content) is as follows: Collect 100g of sample from recycled cylinders into sampling cylinders (304 L HDF4-150 by Swagelok). Place the CFCs in an evaporating pan with heaters, evaporate all the CFCs and then weigh the refrigerating machine oil remaining on the evaporating pan with an analytical balance (Shimadzu AUX320). Evaporation residues are calculated by the following formula:

$$\text{Oil (HBR)Content} = \frac{\text{Weight of Remaining oil}}{\text{Weight of Sample}} \times 100$$

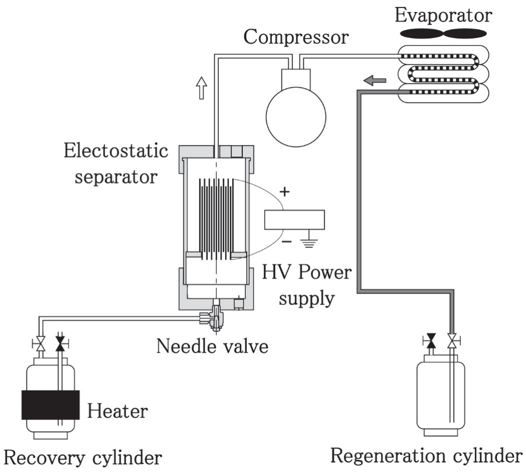

Fig. 3. CFCs recycling system

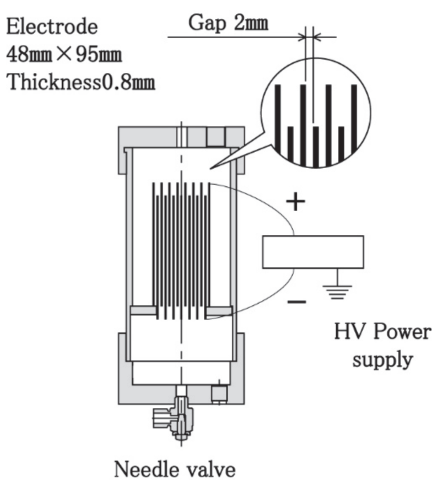

Fig. 4. Electrostatic separator

B.2 Demonstration of CFC recycling

Based on the results of section B.1, a commodity model of a CFC-recycling device was fabricated, and the regeneration capacity was measured for HCFC22, and a similar demonstration experiment was carried out for. HFC410A.

The regeneration device system is shown in Fig. 5. The liquefied CFCs in the collected cylinders enter the heat exchangers. The gasified CFCs with impurities are introduced into the system. The oil mists are removed by the dust collector, and water in the CFCs is removed by passing through a container filled with 500g of molecular sieve (Union Showa 3A).

In the regeneration experiments, the recovery cylinders were prepared with a mixture of 10% refrigerator oil (SUNISO 3GS) and 100ppm water in weights of HCFC22. The mixture was regenerated using the regeneration device shown in Fig.5. 600V was applied to the dust collector. The refrigerator oil and water content in the recovered CFCs were checked. The oil content was measured with the same manner as in 2.2.1, and the water content was measured with a water content measuring device (A-2200 manufactured by HIRANUMA SANGYO Co., Ltd.).

In addition, the regeneration performance for HFC410A, recently developed for air conditioners, was also verified. The recovery demonstration was made using a mixture of

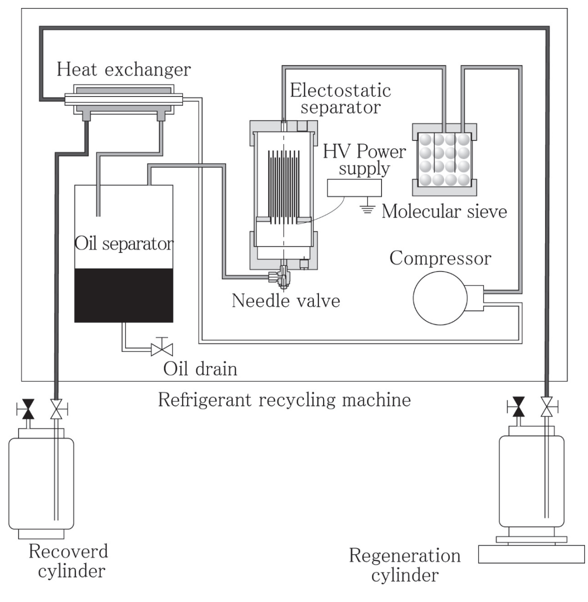

Fig. 5. CFCs recycling-machine system

10% refrigerator oil (SUNICE T-32) by wt. and 100ppm water-contaminated HFC410A.

III. RESULTS

A. Charge measurement

In this measurement, gasified CFCs with oil mists of 0.35% by weight was used.

A.1. Influence of material of the resin tube

The relationship between the material of the resin tube and the amount of charge is shown in Fig. 6. The CFCs were flowed through the resin tube for 60 s, and the charge acquired for 30 s from 30 s after stabilization of the flow to 60 s was accumulated because the charge was not stable during the first 30 s. As shown in Fig. 6. the mean values of the five measurements were 0.0032 μC/L for fluorine resin, 0.0022 μC/L for nylon, and 0.0017μC/L for urethane, indicating a statistically significant difference.

A.2 Effect of the flow rate on the charge

The charge-volume-ratio was measured using Teflon tube, and the effect of the flow velocity was examined. Due to the difference in the diameter of the tubes used, the flow velocity of CFCs is 3724 m/min for the inner diameter φ2mm, 931 m/min for the inner diameter φ4mm, and 413m/min for the inner diameter φ6mm.

The relationship between the flow velocity and the amount of charge is shown in Fig. 7. The same as in the previous section, the charge is indicated as the value of accumulating charge for 30 seconds after stabilized. The results indicate that the accumulated charge was not affected sensitively by the flow velocity within the tested condition. The same tendency is known in the case of transportation of powders[9].

A.3 Comparison of the charge with resin tubes and needle valves

The charging performance of Teflon tube φ6×φ4mm×1m selected in the previous section is compared with the needle valve as shown in Fig. 8. The charge in the figure is the accumulated charge for 30 sec sampling time. The flow rate of the mixed HCFC22 was set to 11.6 L per minute. The charge amount of the Teflon tube was 0.003 μC/L and that of the needle valve was 0.16μC/L. The charging with the needle valve was about 50 times higher than that of the Teflon tube. It was also confirmed that the charge was 0.001μC/L in the absence of the tube nor the needle valve.

Cause of the large amount of charge by the needle valve needs to be investigated. With the resin tube, the oil mists touch to the inner wall of the tube and the tribo-charging may take place, whereas in the needle valve, the oil mists first collide with the needle, resulting in miniaturization and an increase in surface area[10].

B. CFC recycling experiment

B.1 CFC recycling experiment

A CFC regeneration device incorporating a Teflon tube or needle valve was fabricated to measure and compare the voltage required for regeneration of CFCs. The results are shown in Fig. 9. As a result of measuring the voltage at which the refrigerator oil residue in the CFCs became less

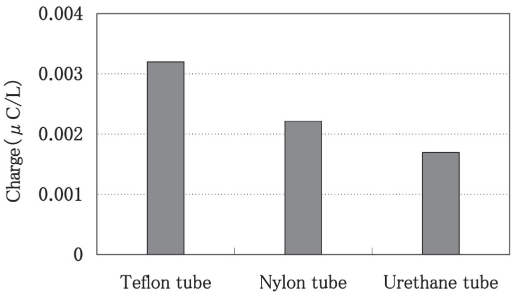

Fig. 6. Relationship between the charge and the tube material

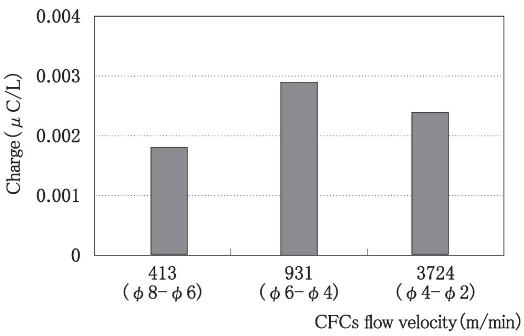

Fig. 7. Relationship between the charge and the CFCs flow velocity

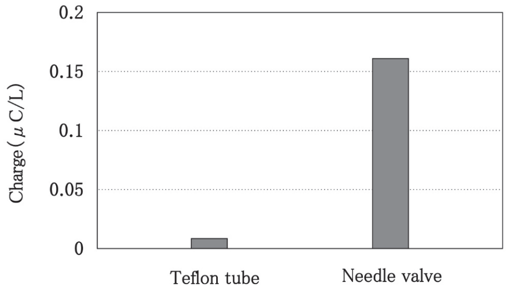

Fig. 8. Comparison of the tribo-charging characteristics of a needle valve and a Teflon tube

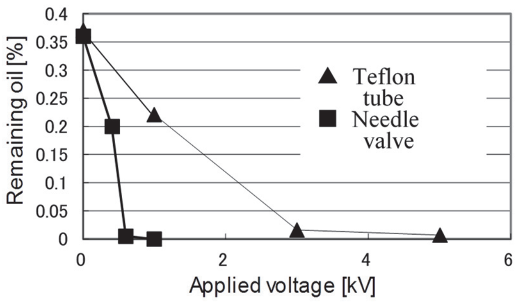

Fig. 9. Relationship between the remaining oil and the applied voltage

than 0.01%, 5 kV was required for the Teflon tube and 0.6kV for the needle valve.

The needle valve was superior as a simple charging device that could regenerate contaminated CFCs with a voltage of 0.6kV applied to the dust collectors.

B.2 Demonstration of CFC recycling

The results of regeneration by the CFC regenerator are shown in Table 2. Molecular sieves removed moisture and the percentage of refrigeration oil residue (Oil content) was found to satisfy the new CFC specification in Table 1. Good performances were obtained for the mineral oils used for CFC12, HCFC22. For the synthetic oils used for HFC410A, and other HFCs, the system was also proved to be effective.

TABLE 2: RESULT

Refrigerant	HCFC22	HFC410A
Purity (%)	99.5 or over	99.5 or over
Oil (HBR) content (%)	0.005	0.005
Acid content (%)	0.0001	0.0001
Moisture content (ppm)	10	7

IV. PRODUCTION

We succeeded in mass production of the regeneration device based on these results. The specifications of the sales model are shown in Table 3.

TABLE 3: SPECIFICATIONS

Product code No.	AR022
Recycle refrigerants	CFC12, HCFC22, HFC410A, HFC32
Recycle method	Electrostatic Separation and Recycle System
Compressor	750W Oil-Free
Weight	60kg
Extent (L×W×H)	562×538×976 mm

V. CONCLUSION

For the development of an electrostatic CFC regeneration device, the material of resin tubes and the flow velocity of gas-phase CFC on charging of impurity oil mists were investigated, and the amount of charge was measured. It was proven that the fluorine resin has the highest charge ability, and the effect of flow velocity of the CFC is not significant. We also compared the amount of charge generated by the Teflon tube and the needle valve, and found that the needle valve can charge 50-times more charge for the oil mists. The charged oil mists are removed using a parallel electrode system.

A commodity model was finally designed and the CFC regeneration test was performed. As a result, the device is capable of regenerating CFCs to the same level as new ones on-site at a flow rate of 11. 6 L per minute. This corresponds to the regeneration rate of 10kg CFCs in about an hour. For practical repairmen of an air conditioner using 10 kg of CFCs, this regeneration rate means that the old CFCs can be regenerated while the parts are replaced.

The results obtained in this study are summarized below.

(1) The charge of oil mists in CFCs by the needle valve is about 50 times higher than that by the resin tube.

(2) Using a needle valve for charging oil mists in CFCs and a parallel electrode system for collection, the oil mists in the CFCs can be removed to the quality level of the new product (CFCs quality regulation (JIS K 1517)).

(3) We have developed a compact and lightweight CFC recovery and regeneration system that can regenerate CFCs at a rate of 11 6 L per minute. This device can be carried to the recovery site.

(4) HFC410A, which has recently been used as a refrigerant for air conditioners, can also be regenerated effectively with this method.

(5) Using this effective regeneration apparatus for reusing CFCs, CO_2 generation can be reduced significantly compared to the destruction and production of CFCs. This device can contribute for the conservation of the global environments.

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