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# Ultrasonic Cleaning of Used Plastic Parts for Remanufacturing of Multifunctional Digital Copier

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*A multifunctional digital copier or multi-function peripheral (MFP) is suitable for remanufacturing due to its high cost, long life, and fast replacement cycle. In the remanufacturing process of an MFP, the cleaning process to remove contaminants is the most time-consuming and labor-intensive job. The improvement of cleaning efficiency is essential to strengthen the competitive power of remanufacturing, especially in a high labor-cost country. In this study, a cleaning system is established for the remanufacturing process of MFPs. The system manipulates completely disassembled parts. Based on an analysis of the disassembly process, disassembled parts are classified into four groups, and cleaning methods for each group are determined. Ultrasonic performance tests to remove contaminants using several cleaning agents are executed, and one cleaning agent is recommended among them for cleaning MFP parts. The ultrasonic cleaning parameters of operation time and ultrasonic frequency are suggested. With the suggested conditions, an ultrasonic cleaning system with dipping, rinsing, and drying units is designed and fabricated. A field test is executed to find the optimal operating conditions. The productivity and economic improvements of the system are estimated, and the application is verified.*

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## 1. Introduction

The concept of sustainable development has been widely examined with respect to environmental effects and natural resource savings. To increase eco-efficiency, a sustainable system is generally envisaged as involving some form of recycling process. A recycling process can be classified into two types: product and material.[1] Product recycling is more environmentally-friendly as the disposed product is used in other products. Typical product recycling is reuse process. To reuse the old product, it might be repaired or remanufactured after it is disassembled completely.[1,2] Remanufacturing is an environmentally-friendly process to make a used product into one in like-new condition.

Multifunctional digital copiers or multi-function peripherals (MFPs) are suitable for remanufacturing due to their high cost, long life, and fast replacement cycle.[3] MFPs are usually leased with maintenance service, thus, the used MFP is replaced with a new MFP many times, even though it is still in a good condition. These old MFPs can be recycled by supplying them to customers who will be satisfied with MFPs that are cheaper and have lower-level functions than new MFPs. A used MFP may be provided as a "new" product through several levels of recycling processes: 1) inspection only, 2) partial repairing, and 3) complete remanufacturing. Companies can adopt one of these recycling levels from inspection-only to the full remanufacturing. The process used by Korean companies is usually partial repairing. After dissembling an MFP partially, they repair disabled components or simply replace to them with new ones. The reliability and price of the products are very low compared to new products. Most remanufacturing companies are small-sized, and the process is not systematic and is dependent on one or two experts. These experts operate the process in a man-oriented repairing system suitable to a small-sized company. To improve the MFP recycling industry, it is necessary to develop a systematic remanufacturing process and improve productivity.

The remanufacturing process consists of several steps including disassembly, cleaning, repairing, replacement, assembly, and inspection. In the remanufacturing process of an MFP, the cleaning process needed to remove contaminants is the most time consuming and labor-intensive job. The improvement of cleaning efficiency is essential to strengthen the competitive power of remanufacturing, especially in a high labor-cost country. Industrial cleaning technologies can be divided into two groups: wet cleaning and dry cleaning. Wet cleaning methods utilize water or organic materials as cleaning agents. Dry cleaning methods include physical and chemical removal technologies using $CO_2$, lasers, plasma, and ultraviolet lights. Although dry cleaning methods are known to be environment-friendly, much more development of their technologies is necessary due to their high equipment and operational cost. Many industry fields still adapt wet cleaning technologies due to the trade-off between the necessary cleaning level and cleaning costs.[4]

In this study, an ultrasonic cleaning system is established for the remanufacturing process of an MFP, which manipulates completely disassembled parts. The system was developed for the Canon 3300 - 6600 MFP series. The cleaning processes are designed for four groups of MFP components. Air blowing and wet cleaning are the most-widely-used techniques to clean parts, and the proposed system is designed based on these techniques. The cleaning tasks used for MFPs usually focus on external covers, doors, and internal parts that are made with polymers. Major contaminants of used MFPs are finger marks, toner cakes, oil-mixed toner, and tiny dust particles. Ultrasonic performance tests are executed with several cleaning agents to remove these contaminants, and an optimal agent is recommended. We designed an ultrasonic cleaning system with dipping, rinsing, and drying units with a suggested cleaning agent. The productivity and economic improvement is discussed to validate the application.

## 2. Design of the Cleaning Process

### 2.1 Analysis of Cleaning Process in Partial Disassembly Line

The production line in remanufacturing companies can be classified into three tiers of disassembly and related cleaning operations. Tier 1 is simple inspection and a manual cleaning process to remove dust and dirt using air blowing without disassembly. Tier 2 is the partial disassembly operation, which consists of dust removal, wet cleaning, and parts exchange. Most used MFPs are remanufactured using a partial disassembly process. Tier 3 is an overhauling process with complete disassembly and component cleaning operations.

The cleaning process in tier 2 consists of air blowing, dipping, rinsing, manual cleaning, and drying operations. The air blowing operation is very dangerous to workers due to the flying particles, especially when emptying used toner cases. Manual cleaning operations to clean frames, covers, and external panels usually use water and cleaning chemicals. Often, the cleaning operations are "bottleneck" processes that delay the process, and cause high labor costs and low productivity.

### 2.2 Design of Cleaning Process for Complete Disassembly Line

Completely disassembled parts can be classified into four groups as shown in Fig. 1. Rack 1 includes single parts of covers, external panels, and internal parts mainly made with polymers. Parts in rack 1 are cleaned through a series of processes of air blowing, ultrasonic cleaning, water rinsing, and drying as in Fig. 2. Components in rack 2 are partially disassembled sub-assemblies made with various metals and polymers. Direct aqueous cleaning is impossible for these components. Additional operations of manual disassembly, fabric cleaning, and assembly are required for the parts in rack 2. Some parts are manually cleaned within the sub-processes of disassembly, fixing, and assembly. Components in rack 3 are electrical or mechanical moving parts. The cleaning process of electrical parts may include air blowing and the ultrasonic method using non-aqueous cleaners such as isopropyl alcohol (IPA) and hydrocarbon solvents. Mechanical parts such as gears and rollers are manually cleaned, and lubrication is applied. The last group shown in Fig. 1 is the main frame after disassembling parts and components. The main frame is manually cleaned using chemical agents due to its large size and metal composition.

Fig. 1 Grouping of MFP components for the cleaning process

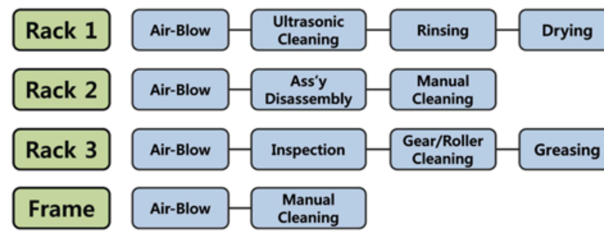


Fig. 2 Cleaning processes in four classified groups

## 3. Analysis of Cleaning Agents for Ultrasonic Cleaning

### 3.1 Cleaning Agents

Ultrasonic cleaning tests were performed to evaluate the performance of eight cleaning agents (A - H) and select an optimal agent. Agent A is an aqueous alkaline agent that is now being used by a Korean company. Components of agent A were analyzed with GC/ MSD (model 6890N/ GC 5973N MSD/ Agilent Technologies, USA), and the results are shown in Table 1. In Table 1, the intensity (area%) shows that the major component of agent A is 2-Butoxyethanol, which has the harmfulness levels of health and fire as 3 and 2 in MSDS, respectively. The chemical smell that occurs when agent A is used seems to be due to this component. The other seven alternative agents are all aqueous alkaline types that are less expensive, more cleanable, and less harmful to base materials compared to other types of agents.

Several basic properties that affect cleaning performance were measured. The pH, surface tension, and water content were measured using a pH meter (HI8424, Hanna Instrument, USA), Surface Tensiomat 21 (Fisher Scientific Co., USA), and a moisture titrator (MKS-500, Kyoto Electronics Co., Japan), respectively.[5,6] The retail

Table 1 Compounds of cleaning agent A

| No. | Compound | Intensity (Area%) |
|---|---|---|
| 1 | 2-Butoxyethanol | 82.554 |
| 2 | N,N'-Bis-(2-hydroxyethyl)-oxamide | 4.088 |
| 3 | N-Benzoyl-3-(hydroxymethyl)piperidine | 3.204 |
| 4 | 2,6,6-Trimethylbicyclo[3.1.1]hept-2-ene | 1.349 |
| 5 | 6,6-Dimethyl-2-methylene-bicyclo[3.1.1]heptane | 1.235 |
| 6 | 1,4-Diphenyl-1,3-butadiene | 1.184 |
| 7 | Hexane | 0.665 |
| 8 | Octane | 0.624 |
| 9 | Decane | 0.624 |
| 10 | 1,1-Dibutoxybutane | 0.545 |
| 11 | trans-5-Methyl-2-1-(methylethyl)-Cyclohexanone | 0.486 |
| 12 | 1-Methyl-4-(1-methylethenyl)-cyclohexene | 0.463 |
| 13 | 1-Butanol | 0.365 |

Table 2 Physical properties of cleaning agents

| Cleaning agents | pH | Surface tension (mN/m) | Water content (%) | Price ($/ 1000 ml) |
|---|---|---|---|---|
| A | 13.1 | 32.5 | 94.5 | 4.5 |
| B | 12.8 | 31.4 | 95.6 | 2.3 |
| C | 12.5 | 34.6 | 94.4 | 2.5 |
| D | 13.6 | 35.8 | 95.2 | 4.3 |
| E | 13.2 | 32.5 | 94.8 | 9.1 |
| F | 12.7 | 33.3 | 95.2 | 6.8 |
| G | 12.6 | 31.2 | 95.5 | 4.5 |
| H | 13.2 | 34.8 | 94.4 | 3.8 |

prices of agents in the Korean market were also surveyed to consider the cost aspects. As shown in Table 2, pH values of all cleaning agents tested in this study are in the range of 12.5 to 13.6, which shows that the agents are strongly alkali. Their values of surface tension are relatively low, in the range of 31.2 to 35.8 mN/m. Their water contents are 94.4 to 95.6%, which are typical in aqueous cleaning agents. The foamability of aqueous cleaning agents with surfactants as their additives were evaluated since excessive foam might have a negative effect on their usage.[7] It causes contaminant residue and a longer rinsing time. 30 ml of each agent in a mass cylinder was shaken three times, and its defoaming rate was observed over time by the naked eye. The foamability test results are shown in Fig. 3. Agents E and F show a superior deforming rate comparing to other agents. Agent D and G also show good usability compared to the present agent A. Others exhibited the same level of deforming rate as agent A.

### 3.2 Preliminary Test

Pre-tests were performed to evaluate the performance of eight cleaning agents (A - H), and select several optimal agents for the main ultrasonic cleaning test. The specimens were made with 2 × 4 cm ABS plates. 0.5 g of toner particles in 10 ml of methanol were applied on the plate surfaces. Then, the specimens were dried at 90 for 3 days. Ultrasonic Multi-cleaner W-113 (Honda, Japan) was used with a 45 kHz ultrasonic frequency. Cleaning was performed at 25 ± 1°C for 1, 3, 5, 10, and 30 min, and specimens were observed by the naked eye.

Test results for eight agents are shown in Table 3. Most of the agents

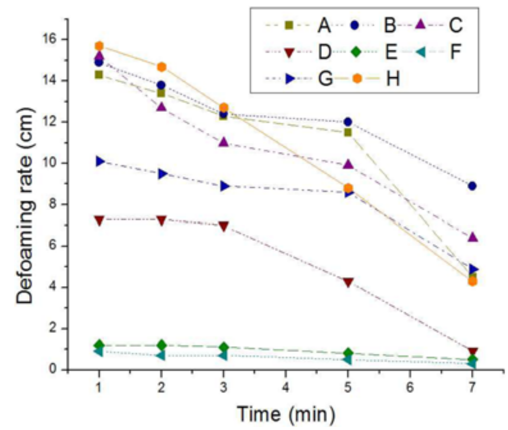



Fig. 3 Deforming rates of various cleaning agents

Table 3 Cleaning performance of eight cleaning agents

| Cleaning agents \ Cleaning time (min) | 1 | 3 | 5 | 10 | 30 |
|---|---|---|---|---|---|
| A | △ | △ | △ | △ | ○ |
| B | △ | ○ | ◎ | ◎ | ◎ |
| C | △ | △ | △ | ○ | ○ |
| D | △ | △ | △ | ○ | ○ |
| E | △ | △ | △ | △ | △ |
| F | △ | ○ | ○ | ◎ | ◎ |
| G | △ | ○ | ◎ | ◎ | ◎ |
| H | △ | △ | △ | △ | ○ |

◎ : Good ○ : Fair △ : Bad

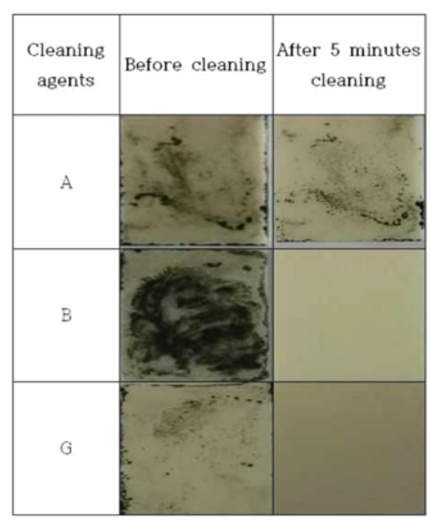



Fig. 4 Comparison of cleaning performance of agents A, B, and G

show superior cleaning performance compared to agent A. Especially, cleaning agents B and G are so powerful that contaminants may be completely removed in 5 min. Agent F shows that it can remove contaminants in 10 min. Specimens with contaminants and cleaning results for agents A, B, and G are shown in Fig. 4.

### 3.3 Main Test

The main test was performed with cleaners A and G selected in the pre-test. Although agent B was the most cost-effective and showed

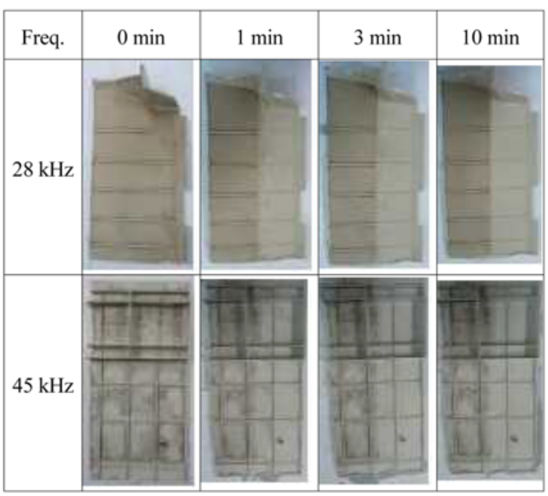
Table 4 Cleaning performance of cleaners for MFP panels

(a) Agent A

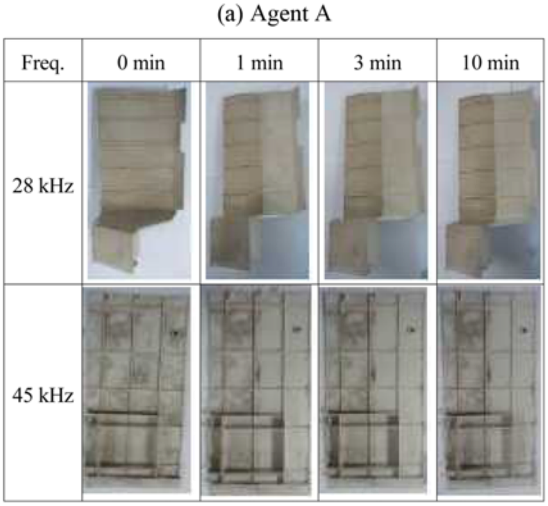
| Ultrasonic wave frequency \ Cleaning time (min) | 1 | 3 | 5 | 10 | 30 |
|---|---|---|---|---|---|
| 28 kHz | △ | △ | ○ | ◎ | ◎ |
| 45 kHz | △ | △ | △ | ○ | ○ |
| 100 kHz | △ | △ | △ | △ | △ |

(b) Agent G

| Ultrasonic wave frequency \ Cleaning time (min) | 1 | 3 | 5 | 10 | 30 |
|---|---|---|---|---|---|
| 28 kHz | ○ | ◎ | ◎ | ◎ | ◎ |
| 45 kHz | △ | △ | ○ | ○ | ○ |
| 100 kHz | △ | △ | △ | ○ | ○ |




(a) Agent A




(b) Agent G

Fig. 5 Cleaning performance of agents A and G

good cleaning performance, it was rejected since it showed a poor defoaming rate and is not easy to purchase in a large quantity to use in a small company. The cleaning targets were internal and external panels disassembled from an MFP and contaminated with toner cakes and bio-contaminants, respectively. Bio-contaminants are usually more difficult to remove than toner cakes. To evaluate the effect of the ultrasonic frequency, tests were executed at 28, 45, and 100 kHz for 1, 3, 5, and 10 minutes. Cleaning was applied to only one-half of the samples to evaluate the cleaning process by comparing the contaminated parts. Samples were observed by the naked eye.

The test results showed that both agents A and G could hardly remove contaminants at an ultrasonic frequency of 100 kHz. The results for 28 and 45 kHz frequencies are shown in Table 4. With agent A, contaminants were completely removed when the samples were cleaned at 28 kHz for more than 10 min. Using agent G at 28 kHz, contaminants were removed in 3 min. Applications of a frequency of 45 kHz resulted in less removal capability. Considering basic material properties and cleaning performance, agent G (Power P & B, Multicleaner Co., Korea) is estimated to be the optimal cleaning agent for ultrasonic cleaning of an MFP. Components of agent G were also analyzed using GC/MSD. The major component of agent G is alkylcyclotrisiloxane. Alkylcyclotrisiloxane is ecologically safe chemical that can be used for personal care or cosmetic products. Samples shown in Fig. 5 show the performance of cleaners A and G which were applied to the panels shown in the right half of the figures.

## 4. Design of Ultrasonic Cleaning System

Based on the results of the cleaning test, an ultrasonic cleaning system was designed. One of the important factors affecting the ultrasonic performance is the rack size. To clean the largest MFP components, the rack should be larger than 1000 mm in length. However, the rack should be as small as possible for ease of handling and to save electric power. Based on these requirements, the rack size was determined to be 700 (length) × 600 (width) × 600 (height) in mm. The MFP parts are to be located horizontally, more than 5 cm apart, in pre-determined positions at the disassembly process.

As shown in Fig. 6, the system consists of five steps: dipping, ultrasonic cleaning, ultrasonic rinsing, aqueous rinsing, and drying. Three ultrasonic vibrators of 28 kHz and 2 kW were used for each ultrasonic cleaning and rinsing tank.

A field test was performed to find the optimal operation temperature. As shown in Table 5, a complete cleaning was accomplished with 3 min operation at 30°C temperature.

Judging from the test results in this work, the ultrasonic cleaning step took less than 5 min. We estimated that the disassembling time for one MFP is 40 min, and about three racks of components exist. Thus, the system may be operated without time delay. Although the time for the drying step may be longer than 5 min for complete drying, additional manual work may be shorten the time by as much as required.

Table 6 shows the electric power needed for the operation of the cleaning system. 38.7 kW of total estimated power is required for its operation. Assuming that the system is operated for 8 hr a day, the total electric power to be consumed is estimated to be 6,192 kWh per month. Even though electric charges vary according to the season, their average cost may be assumed about $580 a month for the operation of an ultrasonic cleaning system in Korea.

Table 7 is a summary of the productivity and economic analysis of the introduction of an ultrasonic cleaning system in MFP

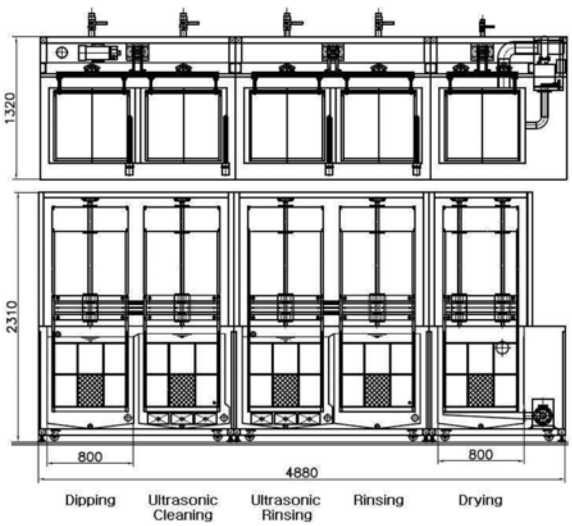


Fig. 6 Design of an ultrasonic cleaning system

Table 5 Field test results for optimal operation conditions

| Temp. (ºC) \ Cleaning time (min) | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 10 | △ | △ | △ | △ |
| 15 | △ | △ | △ | △ |
| 20 | △ | △ | △ | △ |
| 25 | △ | ○ | ○ | ○ |
| 30 | △ | ○ | ◎ | ◎ |
| 35 | △ | ○ | ◎ | ◎ |

Table 6 Estimation of electric power usage

| Process | Usage | Electric power (kW) |
|---|---|---|
| Dipping | Heater | 5 |
| Ultrasonic cleaning | Heater | 5 |
| | Ultrasonic unit | 3.6 |
| | Circulation pump | 0.75 |
| Ultrasonic rinsing | Heater | 5 |
| | Ultrasonic unit | 3.6 |
| Aqueous rinsing | Heater | 5 |
| Drying | Heater | 10 |
| | Blower | 0.75 |
| Total | | 38.7 |

Table 7 Comparison of productivity and economic analyses for manual and ultrasonic cleaning operations

| | Manual | Ultrasonic |
|---|---|---|
| Cleaning methods |  |  |
| Cleaning time (min/MFP) | 90 | 9 |
| Cleaning cost ($/MFP) | 10.5 | 1.5 |

remanufacturing. It takes about 1.5 hours to clean an MFP manually. However, since it takes 9 min to clean an MFP using an ultrasonic cleaning system, the cleaning time is reduced to one-tenth that of manual operation. As for the cleaning cost, labor charge is about $7/hr for a part-time worker in Korea. It makes manual cleaning cost $10.5 per MFP. Ultrasonic cleaning cost is estimated with two factors, which are electric cost and system depreciation. Assuming electric charge $0.9/kWh in Korea, electric cost is $0.3 per MFP. The ultrasonic cleaning machine costs $50,000, and the usage period is estimated as 10 years. Ultrasonic vibration components need to be replaced to new ones twice for 10 years, and it costs $20,000. As annual cleaning capacity is about 6000 MFPs, depreciation cost is about $1.2. Comparing to the manual cost of $10.5, total ultrasonic cleaning cost, $1.5, is much lower. Even though the initial investment cost is high, the system is judged to be more economical than hand cleaning, considering the high labor cost.

## 5. Conclusions

Most Korean companies dealing in used MFPs are generally small in size, and the market share is extremely small compared to that of new MFPs. As government increasingly recognizes the importance of remanufacturing and begins to allow official accreditation to limited products, many companies have an interest in the MFP remanufacturing industry. Although the partial disassembly and cleaning system may be applicable to this stage of remanufacturing, the complete disassembly system would be necessary in a short time.

The proposed cleaning system is for a remanufacturing process of MFPs that manipulates completely dissembled parts. For the cleaning processes designed for four groups of MFP components, the properties and cleaning performances of various cleaning agents were tested, and an optimal agent was determined. With the proposed system of dipping, ultrasonic cleaning, ultrasonic rinsing, aqueous rinsing, and drying, productivity is improved, and the system enhances the efficiency of the MFP remanufacturing industry.

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