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Abstract: Triboelectrostatic separation of PVC and rubber from covering plastics in communication cable scrap has been performed. In this work, particles charged as positive (+) and negative (−) according to the difference of work function of each material after tribo-charging can be separated through an opposite electric field. In charger material selection tests using a vertical-reciprocation charger, PVC and rubber particles in the covering plastics were charged with the opposite polarity in the charger material made of PP, HDPE, or PET. The difference of charge density (charge to mass ratio, nC/g) of the PVC and rubber was higher in the tribo-charger made of HDPE. Furthermore, in lab-scale triboelectrostatic experiments for separating the PVC and rubber, the charging efficiency of the mixed PVC and rubber increased when the air velocity was adjusted to over 8.2 m/s. The charge density, the electrode potential, and splitter position needed for the separation of the PVC were determined to be 25 nC/g, 30 kV and +2 cm, respectively. In the optimum conditions, we developed a separation technique that can separate up to 99.8% PVC grade with 95.0% of recovery from the covering plastics.

Keywords: Covering plastics, electrostatic, material separation, tribo-charging

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INTRODUCTION

At present, landfill and incineration of municipal solid waste have become more expensive and caused more environmental problems. In this regard, the disposal of plastics waste has become an important issue all over the world due to increasing their volume and the decreasing landfill capacity for disposal. Thus, the development of material separation technique that can recycle plastics waste to solve these disposal problems is a growing necessity (1–3).

Especially, the share of waste kinds of electric cables for power transmission, communication, and transportation generated from the electricity, electronics, and communication field are constantly increasing due to industrial development and the short life span of these equipments (4,5). Hence, recycling processes or separation techniques for these cables have also become an important topic. Generally, electric cables consist of metal conductors (copper or aluminum) and polymer insulators (PVC: polyvinyl chloride, XLPE: cross-linked polyethylene, PP: polypropylene, rubber). Figure 1 shows a flowchart of recycling particulate metals and plastics, including shredding and classification steps to separate covering plastics from communication cable scrap. The particulate copper and aluminum are recovered by induced electrostatic separation. The covering plastics after removing the metals can be separated into two groups of sink product (PVC/rubber) and float product (XLPE/PP) by wet gravity separation. However, these mixtures of XLPE/PP or PVC/rubber having

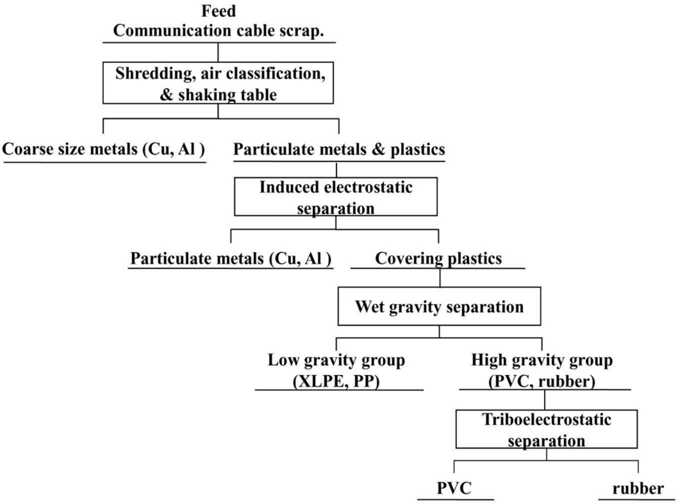

Figure 1. Flowchart of the recycling process for waste electric cable.

similar specific gravity are difficult to separate by a conventional method, and so are mostly land-filled or remain accumulated in the field, causing economic loss as well as environmental contamination (6,7). Especially, PVC among covering plastics pollutes the environment by generating hazardous HCl gas and dioxins. Also, PVC material not only creates difficulty in the recycling process, but also decreases the recycling ratio of plastics by forming compounds or deteriorating the nature of other materials even if a small quantity of PVC is present in main plastics (7–9).

The landfill and incineration of plastics waste have been restricted by laws of most countries. The recycling of plastics waste has been promoted by the enforcement of the extended producer responsibility (EPR) system of Korea since year 2003 (10). Therefore, the development of material separation technique for covering plastics in waste electric cable is increasingly necessary to meet the stringent requirements.

Physical separation techniques for waste plastics can be classified as electrostatic separation, dry and wet gravity separation, froth flotation, near infrared rays (NIR), and color sorting (11–13). Gravity separation and froth flotation are considered costly. In the gravity separation of PVC, PET, PS, ABS and rubber, their specific gravities are similar to one another and in the froth flotation, disposing directly of wastewater containing flotation agents pollutes groundwater. Also, NIR separation and color sorting are limited to large-size articles such as bottles or containers and difficult to separate mixed plastics having similar properties such as characteristic peaks and colors (8,10,14). Electrostatic separation methods for separating mixed materials include corona discharge, electrostatic induction, and triboelectrostatic separation. Corona discharge and electrostatic induction can separate a mixture of conductor/non-conductor (metal/insulator), whereas the triboelectrostatic method has an advantage of separating different types of materials (7,15,16). It has been used originally for processing valuable minerals such as coal and fly ash (3,19).

Tribo-charging occurs when particles are charged with opposite polarities by particle-particle and particle-surface charging mechanisms, due to their work function or the triboelectric series (15,17,18). For example, selective separation of two different materials is impossible without changing the surface polarities of at least one of them. Hence, selective charging of materials is an important parameter and the triboelectric series is widely used as an indicator of selective charging of plastics in triboelectrostatic separation. The triboelectric series which represents the degree of the work function values of materials can be arranged in the following sequence: (negative) HPVC-SPVC-COPP-HOMOPP-LDPE-HDPE-PET-RUBBER-HIPS-Calibre-ABS-GPPS-PMMA (positive) (3,20,21).

Figure 2 shows mechanisms of tribo-charging. When two materials are brought into contact or collision, a charge transfer can occur between

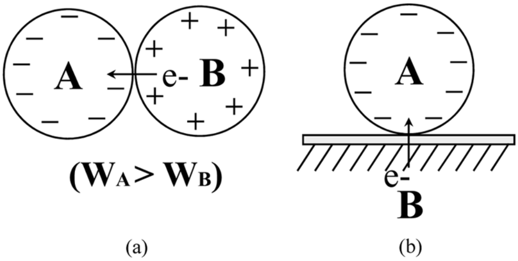

Figure 2. Electrification of materials by tribo charging: (a) particle to particle, (b) particle to surface.

them until their Fermi levels equalize by the work function difference between the two materials. Then, the material with high work function is charged negatively and the low work function positively. Then, the positively charged material is moved toward the negative electrode and the negatively charged material positive electrode (22–24). Figure 2(a) shows the triboelectrification of particle-particle, and Fig. 2(b) shows that of particle-surface charging mechanism (15,17). In triboelectrostatic separation, the selective charging and optimum charge density of materials are the most important parameters. Therefore, this separation method can improve the separation efficiency by developing proper charger materials and tribo-chargers. Triboelectrostatic separation is much cheaper and separation efficiency is much better than that using the above-mentioned conventional separation methods (12,19,22).

The objective of this study was to develop a simple, reliable, and relatively inexpensive technology for the effective triboelectrostatic separation of PVC particles from covering plastics in scrap communication cable, based on the control of the electrostatic surface property of PVC and rubber particles. Hence, we designed and assembled a lab-scale triboelectrostatic separator unit, including a fluidized bed tribo-cyclone charger and investigated several factors such as air velocity, electrode potential, and splitter position influencing separation efficiency in triboelectrostatic separation.

EXPERIMENTAL

Materials

Communication cable scrap was shredded, air-classified, and separated with a Wilfley concentrating table at a local plant. A fraction of $-8\,\mathrm{mm}$

particulate plastics (polyvinyl chloride, rubber) was obtained and electrostatic-separated inductively, rejecting most copper and aluminum particles.

The particulate mixture containing covering plastics was separated by wet gravity into low-gravity fraction (XLPE and PP) and high-gravity fraction (PVC and rubber). The latter containing 5.4% rubber and 94.6% PVC was shredded with a cutting mill (pulverisette 19, Fritsch GmbH, Germany) and sieved into a fraction of −4.0 +1.6 mm. The initial charge of the particles in this fraction charged by a cutter was neutralized with a discharger (Kasuga Denki Inc., Japan) and finally, the neutralized particles were tribo-electrostatically separated. Virgin rubber and PVC in a −4 mm size-class used only in charger material selection tests were also obtained from a local petrochemical plant.

Experimental Procedure

Two types of electrostatic charging equipment were employed for experiments. The first type was a charger consisting of a vertical reciprocator and charging bottles. This equipment has been used for charger material selection. The bottles were made of different plastic materials such as polytetrafluoroethylene (PTFE), hard polyvinyl chloride (HPVC), polypropylene (PP), high density polyethylene (HDPE), polyethylene terephthalate (PET), high impact polystylene (HIPS), acrylonitrile butadiene styrene (ABS), or polymethyl methacrylate (PMMA). The charger was designed to charge the particles into a charging bottle by reciprocation.

The other type consisted of a cyclone charger and a triboelectrostatic separator as shown in Fig. 3. It was also divided into 4 zones: feeding zone, charging zone, separation zone, and collecting zone. After PVC and rubber were fed into the cyclone charger made of HDPE material with air, the PVC and rubber were charged with opposite polarity each other because of their work functions. Then, a charger was selected based on the work function value between those of the PVC and rubber. The charged particles were deflected under the influence of the electric field between the electrodes which were connected to a high-voltage power supply at ±30 kV.

The charge of particles was measured with a Faraday cage (Model KQ-1400, Kasuga Denki Inc., Japan). For example, the (+) charge on the particles induced the (−) charge on the surrounding cage and the charge induced on the inner wall of the cage was equal in magnitude but opposite in sign to the introduced charge and then the charge of the same magnitude and sign appeared on the outside of the cage and

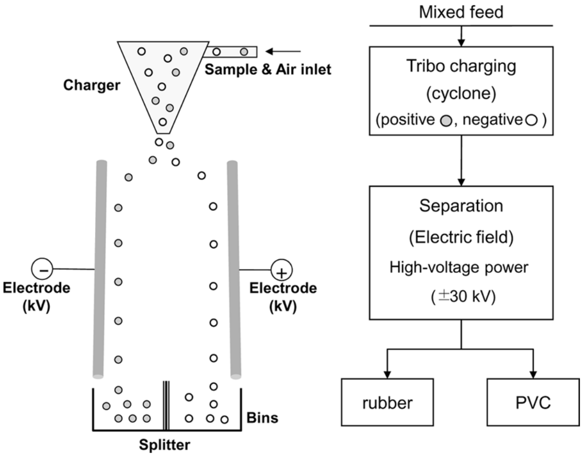

Figure 3. Schematic diagram and flow sheet for triboelectrostatic separation.

thus, final charge was measured with an electrometer collected with a Faraday cup. The weight of particles was measured with an electronic balance. Hence, the charge density of particles was determined based on charge to mass ratio in nC/g.

In addition, the data shown in figures are average values of the tests repeated at least three times. The relative humidity in a chamber equipped with all apparatuses was kept at less than 30% since it was regarded as a very important factor in triboelectrostatic separation. In this paper, various factors such as charger materials influencing charge density and separation efficiency of PVC and rubber as a function of air velocity, potential difference, and splitter position have been investigated.

RESULTS AND DISCUSSION

Charger Material Selection and Charging Properties

Figure 4 shows the results of the charge polarity and charge density of virgin rubber and PVC determined using different charger materials and a vertical-reciprocator. Rubber and PVC in a charger made of PTFE, HPVC, ABS, or PMMA were charged as either the same polarity or hardly charged, but in that made of PP, HDPE, or PET, rubber were charged positively and PVC negatively. In case of the former, both rubber and PVC were charged positively in the charger made of PTFE,

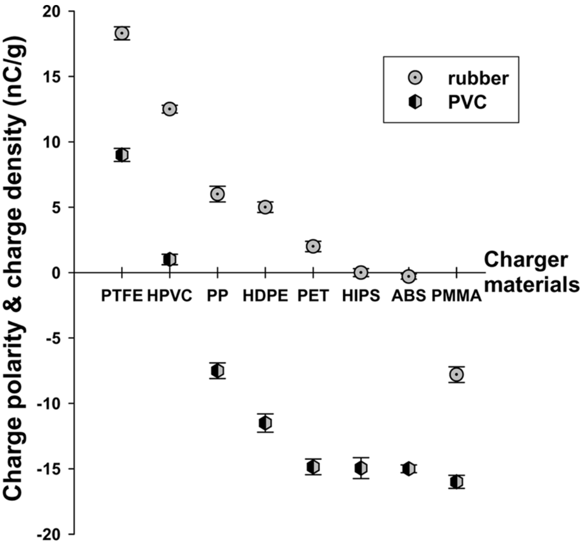

Figure 4. Charge polarity & density of PVC and rubber on charger materials (bottles). (120 sec. retention time, 250 frequency and 30% relative humidity).

HPVC because their work function is lower than that of PTFE or HPVC, whereas they were charged negatively in that of HIPS, ABS, or PMMA. In case of the latter, the charge polarity of rubber and PVC in a PP, HDPE, or PET charger is attributed to their work functions laid between PVC and rubber from the triboelectric series (3,21). Especially, the difference of charge density between rubber and PVC was found to be the maximum with HDPE charger compared to those with PP and PET. For example, the charge densities of rubber and PVC with the HDPE charger were +5.5 and −11.6 nC/g and so the charge density difference was 17.1 nC/g. Therefore, we selected the charger made of HDPE for subsequent tests separating rubber and PVC.

Figure 5 shows the effect of the retention time of particles in HDPE and HPVC chargers on the charge density of rubber and PVC. As shown in this figure, rubber and PVC in the HDPE charger are charged positively and negatively, respectively, whereas the both in the HPVC charger are positively charged. Especially, PVC particles in the HPVC charger has a linear function without the change of the charge density although the retention time increases. Thus, it proves that the HDPE material laid between the work function values of PVC and rubber is more effective than HPVC material since the HPVC work function value is laid far more negative in the triboelastic series. On the other hand, the charge density

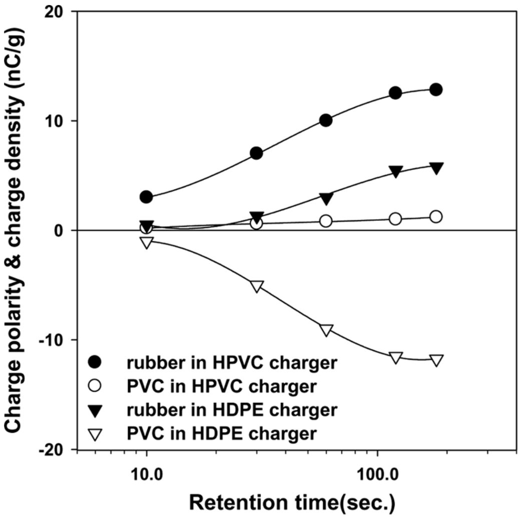

Figure 5. Effect of charger material and retention time on charge density of rubber and PVC. (HDPE charger, 250 frequency and 30% relative humidity).

of rubber and PVC in the HDPE charger and rubber in the PVC charger increases as the retention time in charger increases. Such surface charge of particles increases because of an increase in number of contact or collision between particles and an inner wall of charger with increasing the retention time. At this time, the charge transfer between them proceeds until their Fermi levels are equalized by the work function difference between the two materials (18,23,25). If the retention time is more than 120 sec, the particles have the saturation charge density without a clear variation. Therefore, the critical retention time in the vertical-reciprocation charger was determined to be about 120 sec.

Separation Properties of Covering Plastics

First, air velocity affecting tribo-charging and moving the PVC and rubber in a triboelectrostatic separator was estimated. Figure 6 shows the effects of air velocity on net-charge density and the separation efficiency of PVC in triboelectrostatic separation. The charge density of PVC increased as the air velocity increased and its saturation charge density was 25.0 nC/g at air velocites higher than 8.2 m/s. Such increase of the charge density of PVC particles occurs since the increase of air velocity in a cyclone charger causes the impact force and frequency between

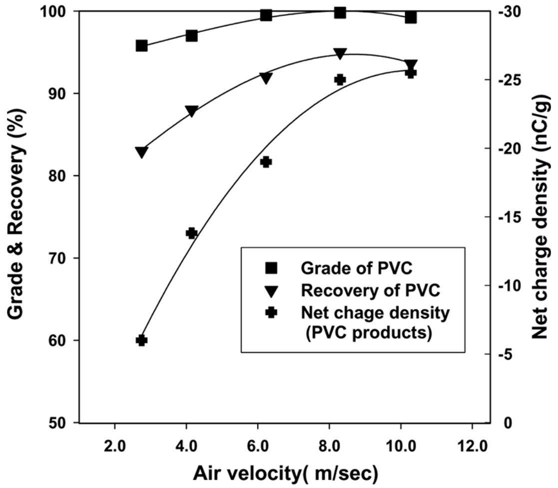

Figure 6. Effect of air velocity on separation efficiency of PVC in triboelectrostatic separation unit. (HDPE charger, 30% relative humidity, 30 kV electrode potential and +2 cm splitter position).

particles and their contacting surfaces to increase. It is due to an increase of electron transfer between materials with increasing exterior energy by air (20,23,25). In the case of the separation efficiency of PVC, after reaching the maximum (8.2 m/s), it decreased. This may lead to an increase of the gravity acceleration of the particles with an increase of the air velocity. Thus, some particles are moved toward the opposite collection bin after strongly colliding on a splitter or electrode and then the PVC grade and recovery decrease. Therefore, we confirmed that the air velocity affecting a net-charge density and the separation efficiency of covering particles in triboelectrostatic separation was 8.2 m/s.

Covering plastics charged in a cyclone charger is separated by splitter position and the electric field of electrodes in a triboelectrostatic separator. Hence, we investigated the effect of the electrode potential and splitter position for PVC grade and recovery from mixed covering plastics. As shown in Fig. 5 for charger material selection tests, rubber is charged positively and PVC negatively. If the charged particle approximates to the electric field which form between electrodes, electrostatic force is interacted by Coulomb's law (15,24). Therefore, the charged rubber and PVC will be deflected toward negative and positive electrode, respectively.

Figure 7 shows PVC grade and PVC recovery as a function of the electrode potential. The PVC grade and PVC recovery increase as the electrode potential increases. At 10 kV electrode potential, the PVC grade

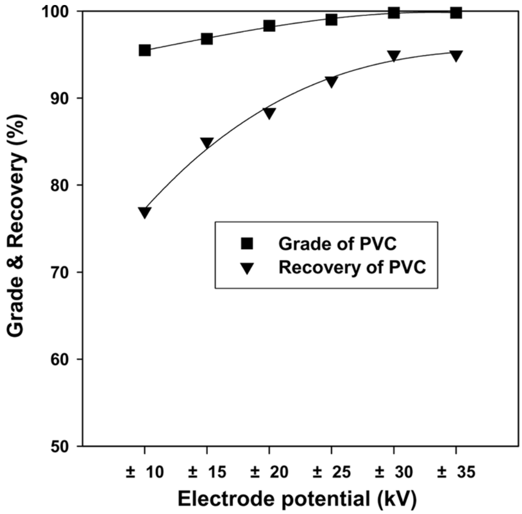

Figure 7. Effect of electrode potential on separation efficiency of PVC in tribo-electrostatic separation unit. (HDPE charger, 8.2 m/s air velocity, 30% relative humidity and +2 cm splitter position).

was 95.5% and the PVC recovery 77%. It appears that a electrode potential of 10 kV is not strong enough to pull the charged particles toward the electrodes. The best results were obtained at 30 kV and at this time, the PVC grade and PVC recovery were 99.80% and 95.05%, respectively. The charge density of a particle is related to the energy of low electrode potential. If the charge density of the particles is high, they can be attracted by relatively low electrode potential for increasing separation efficiency (26,27). Therefore, we confirmed that the development of chargers and charging technology to maximize the charge density of a particle could improve the separation efficiency.

Figure 8 shows PVC grade and PVC recovery as a function of splitter position. " −" and " +" sign in the splitter position signify moving direction from the center to the negative electrode and the positive electrode, respectively. As shown in Fig. 8, the PVC grade increased as the splitter position moved to the positive electrode from the center, and the PVC recovery increased as the splitter position moved from the center to the negative electrode. The falling position of particles changes under the influence of the charge density of particles according to charging factors, namely the tribo series, charger material, air velocity, and relative humidity under a definite gravity force, drag force, and electrostatic force (14,24,27,28).

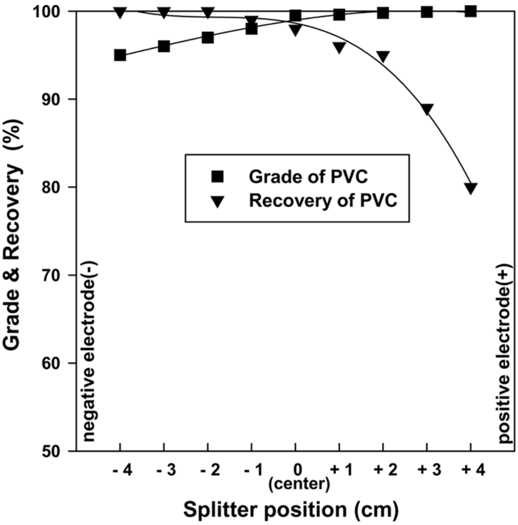

Figure 8. Effect of splitter position on separation efficiency of PVC in triboelectrostatic separation unit. (HDPE charger, 8.2 m/s air velocity, 30% relative humidity and 30 kV electrode potential).

PVC particles which have high negative charge density are strongly deflected to positive electrode but some PVC particles which have low or neutral charge density may fall freely or to the opposite side. Also, in the case of rubber, some rubber particles are not deflected to the negative electrode and behave similarly to PVC. Such behavior of particles deteriorates the separation efficiency for PVC and rubber. Considering the results, the optimum splitter position was found to move 2 cm from the center to the positive electrode. In this condition, the PVC grade and PVC recovery were 99.80% and 95.05%, respectively.

The next study will focus on the development of dry triboelectrostatic separation processes for recycling almost all types of covering plastics, including PVC/rubber/XLPE mixture or PVC/rubber/XLPE/PP mixture in electric cable scrap.

CONCLUSIONS

In this study, we have designed and assembled a laboratory-scale triboelectrostatic separator to separate covering plastics in communication cable scrap, and have studied several factors affecting the charge efficiency and the separation efficiency of plastics. In charger material selection tests using a vertical-reciprocation charger, the charge polarity and charge density of rubber and PVC are very effective with a tribo charger made of HDPE, and with the increase of retention time. In triboelectrostatic separation using a HDPE cyclone charger, the charge density of PVC considerably depended on the air velocity (25.0 nC/g at 8.2 m/s), and the optimal conditions for electrode potential and splitter position affecting the separation efficiency of PVC were over 30 kV and +2 cm from the center. Under these conditions, a PVC grade of over 99.80% and a PVC recovery of over 95.05% were successfully obtained.

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