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Triboelectrostatic Separation of PVC Materials from Mixed Plastics for Waste Plastic Recycling

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Abstract

Waste plastics amount is more than 3.5 million tons and 30% of industrial waste in 1998, Korea, but recycling rate of industrial waste plastics is quite low because the material separation technology from the mixed waste plastic powders is not commercially available so far. This study covers the triboelectrostatic separation of polyvinylchloride (PVC) materials from mixed plastics such as polyethylene (PE), polyethylene terephthalate (PET), polypropylene (PP), and polystyrene (PS). The laboratory-scale electrostatic separation system consists of a fluidized bed tribocharger, a separation chamber, collection chambers and controllers. PVC and PET powders can be imparted negative and positive surface charges, respectively, due to the difference of triboelectric charging series between particles and particles in the fluidized bed tribocharger, and can be separated by passing them through an external electric field. The extract content and yield of PVC separation from the mixed PVC and PET plastic powders are 90.0 % and 98.2 %, respectively. The electrostatic separation system using the fluidized bed tribocharger shows the potential to be an effective method for removing PVC materials from other mixed plastics.

Key words: Waste Plastics Recycling, PVC/PET Electrostatic Separation, Tribocharger, Extract Content, Yield

Introduction

Waste plastics are produced more than 3 million tons in 1996, Korea, but recycling rate of industrial waste plastics is quite low because there is no economically satisfactory separation process. Waste plastics causes the serious environmental problem due to the disposal by landfill or incineration. Especially, PVC material in the combustion of the incinerators generates hazardous hydrogen chloride gas, polychlorinated dibenzo-p-dioxins, and so on, which lead to air pollution and shorten the life of incinerators. Recently, a dry triboelectrostatic process has been considered to apply to recycle waste plastics. Triboelectrostatic separation is a broadly applicable dry processing technique in the mineral processing industry, coal beneficiation, and recycling wastes (Ban *et al.*, 1993; Gupta *et al.*, 1993; Inculet, 1984; Lee *et al.*, 2001). Especially, this process is useful to separates PVC from the mixed plastics, which is based on the difference in the surface charge of various components of the powder mixture by the particle-to-particle impact and the particle-to-wall impact. This study covers the triboelectrostatic separation of polyvinylchloride (PVC) materials from mixed plastics such as polyethylene terephthalate (PET), polyethylene (PE), polypropylene (PP), and polystyrene (PS).

Triboelectrification mechanisms of plastic particles

Fig. 1 shows the principle of triboelectrification by the particle-to-particle impact and the particle-to-wall impact. Tribocharging is the process whereby a charge exists on a material after the part of a solid/solid contact. The magnitude of the final charge will actually be the result of two processes; the charge transfer that occurs during the contact, and the charge backflow that occurs as the materials are parted (Kelly and Spottiswood, 1989).

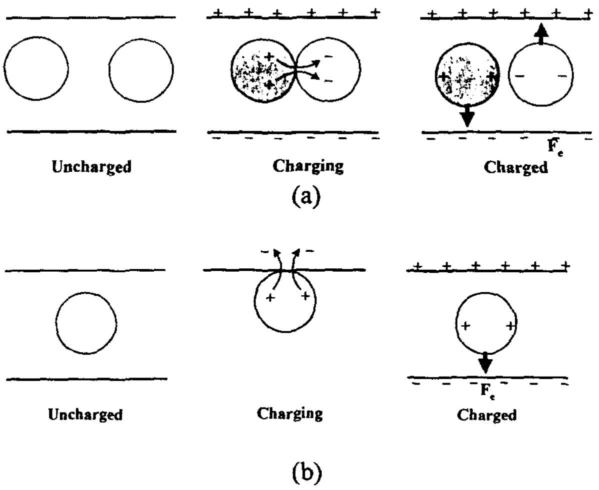
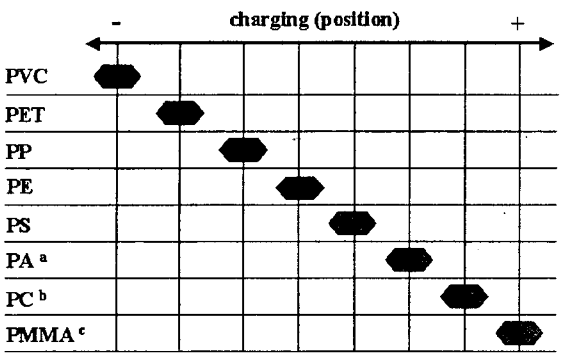


Fig. 1. The principle of the triboelectrification (Kelly and Spottiswood 1989).: (a) particle-to-particle impact; (b) particle-to-wall impact.



a PA: Polyamids
b PC: Polycarbonate
c PMMA: Polymethylmethacrylate

Fig. 2. Triboelectric charging series of various plastics (Brandrup *et al.*, 1996).

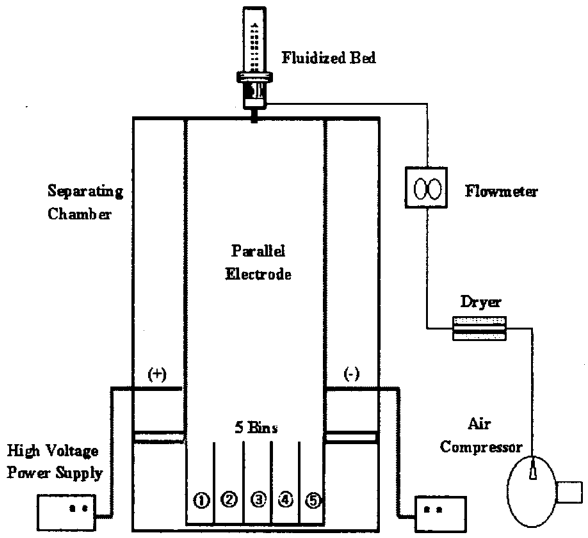


Fig. 3. A laboratory scale triboelectrostatic separation system.

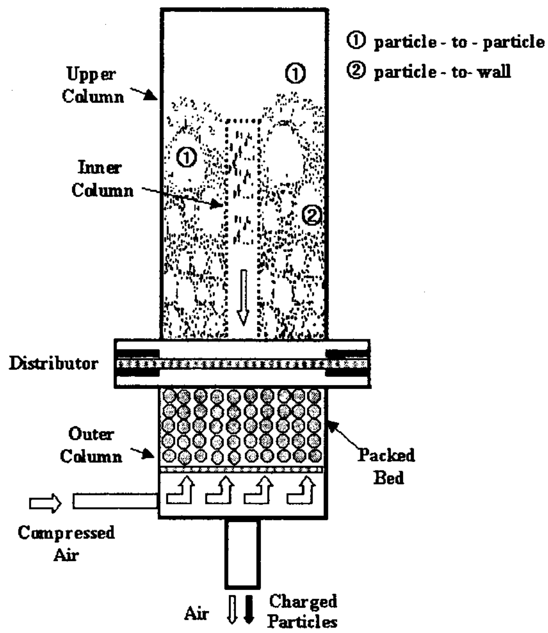


Fig. 4. Schematic diagram of fluidized bed tribocharger for charging mixed plastic particles.

Insulators can be ranked in an order (a triboelectric charging series) such that a material higher up the series will always charge positive when touched or rubbed with a material lower down, towards the negative end. A triboelectric charging series must exist if one particular mechanism (e.g. electron transfer) is always responsible for contact electrification, and the experiments of Davies (1970) and Duke and Fabish (1970) strongly suggest that at least some polymers and metals should form a triboelectric charging series. They have likewise extended their theory of metal-insulator electrification to the case of insulator-insulator contacts.

Fig. 2 shows the triboelectric charging sequence of various plastics. According to this, in principle all the plastics listed may be separated from each other, regardless of their density. The qualitative representation should be interpreted as follows: when two plastics come into contact the left one becomes negatively charged and the right one becomes positively charged. And the farther apart, the easier the selective charge exchange between two particles takes place. For example, if PVC is put into contact with PET, the PVC becomes negative and the PET positive. On the other hand, if PET is put into contact with PS, the PET becomes negative and the PS positive.

Experimental

Experimental Apparatus

Fig. 3 shows the schematic diagram of the laboratory scale triboelectrostatic separation system to separate PVC materials from mixed plastics. It consists of the fluidized bed tribocharger, the separation chamber with two plate electrodes, the collector and the high voltage power supply. Plastic particles are fluidized and charged inside the fluidized bed tribocharger. The charged particles are entrained in the separation chamber. As the particles fall through the chamber, they are deflected forward one electrode or the other, depending upon their charge. The positively charged particles during the fluidization process are deflected towards the negative electrode and the negatively charged particles towards the positive electrode. The bins closely located to the positive high voltage electrode collect the negatively charged material, while the opposite side bins collect the positively charged material. Materials having insufficient charge for separation are collected in the central area. After separation tests, the efficiency of the electrostatic separation can be obtained by measuring the mass of collected particles in each bin with an electrical digital balance (OHAUS-GT 4100).

Fig. 4 shows the schematic diagram of the fluidized bed tribocharger to impart the charging of test particles. The fluidized bed consists of acrylic and copper vessel with a circle cross section. The bed is supported on a copper plate used as an air distributor with fine holes. To minimize charge leakages by conduction, the fluidization column is insulated from the supports by means of a thick layer of silicone rubber. Plastic particles are fluidized by a compressed air inside the fluidized bed, and charged by particle-particle and particle-wall frictional contact. The mechanism by which charges segregate when two materials are brought into contact has been explained in terms of electron exchange. The number and direction of the electrons that transfer between two materials depend on numerous variables such as the bulk chemical composition of materials, surface moisture and roughness, particle size and sharpness, tribochager type, orientation of materials during contact, area and duration of contact and relative velocity of materials (Lee *et al.*, 2000).

Test materials and conditions

Five types of plastics such as polyvinylchloride (PVC), polyethylene telephtalate (PET), polyethylene (PE), polystyrene (PS), and polyprophylene (PP) are used in this study. Experiments are carried out with particles in granular form, of irregular shape, and of the size range of 1.4-2 mm., Since triboelectric charging depends not only on the chemical constitution of the particles to be separated, but also on their surface condition, particles are washed out with water and dried to remove the charge and ensure a similar surface state of particles before each experiment.

Table 1 shows the experimental conditions for triboelectrostatic separation of PVC particles from two-component mixed plastics in this study. The particle feeding rate and the electric field are 10 g/min and 6 kV/cm, respectively. All experiments are carried out at room temperature and ambient relative humidity (43-54 RH %). The fluidizing air is dried in a tower packed with silicagel before an inlet to the apparatus.

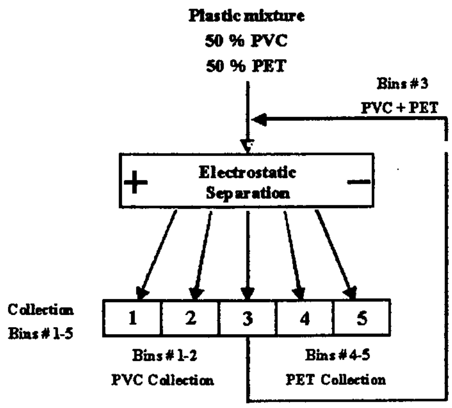
Table 1. Experimental Conditions for Triboelectrostatic Separation test.

Parameters	Specification
Tribocharger	Fluidized Bed
Plastic Particles	PVC, PET, PP, PE, PS
Particle Size	1.4 – 2 mm
Electric Field Strength	6 kV/cm
Air Flow Rate	110 lpm
Temperature	18 – 22 °C
Relative humidity	43 – 54 %

Results

Fig. 5 illustrates the nomenclature for the data analysis of the separation test. For two component mixed plastics of PVC and PET, most of PVC particles (the left one of triboseries) are collected in bins #1 and #2, while PET particles (the right one of triboseries) are collected in bins #4 and #5. In the central bin #3, PVC and PET would require a second stage of processing. PVC yield in bin #1 is described by the ratio of PVC mass collected in bin #1 by PVC mass collected in bins #1-5. By weighing the mass collected in each of bins and taking into account the respective extract contents, the extract content and yield for each component can be calculated.

Fig. 6 shows the fractional extract content and yield of PVC and PET materials among the five collection bins placed at the bottom of the separating chamber. The separator is operated in this case with a 50/50% mixture by mass of PVC and PET at 6 kV/m electric field strength and 10 g/min particle feeding rate. For the extract content shown in Fig. 6(a), bin #1 collects 91.9% pure PVC whereas bin #5 collects 99.2% pure PET. For the yield of PVC and PET as shown in Fig. 6(b), bin #1 collects 96.1% from the mass of PVC supplied whereas the rest of bins #2-5 collects 3.9%. In case of PET, bin #5 collects 75.2% from the mass of PET supplied. Most of PVC particles (the left one of triboseries) become negatively charged and are collected in bins #1 and #2, while PET particles (the right one of triboseries) becomes positively charged and are collected in bins #4 and #5 as shown in Fig. 6(b). The highly concentrated PVC (91.9%) with a yield of about 96.1% from the mixture of



$$\text{PVC Yield in bin \#1} = \frac{\text{Mass PVC in bin \#1}}{\text{Mass PVC in bins \#1-5}} \qquad \text{PET Yield in bin \#5} = \frac{\text{Mass PET in bin \#5}}{\text{Mass PET in bins \#1-5}}$$

$$\text{PVC E.C. in bin \#1} = \frac{\text{Mass PVC in bin \#1}}{\text{Total mass in bins \#1}} \qquad \text{PET E.C. in bin \#5} = \frac{\text{Mass PET in bin \#5}}{\text{Total mass in bins \#5}}$$

(E. C. = Extract Content)

Fig. 5. Nomenclature used for the analysis of the results and the equations for the calculation of the yield and the extract content.

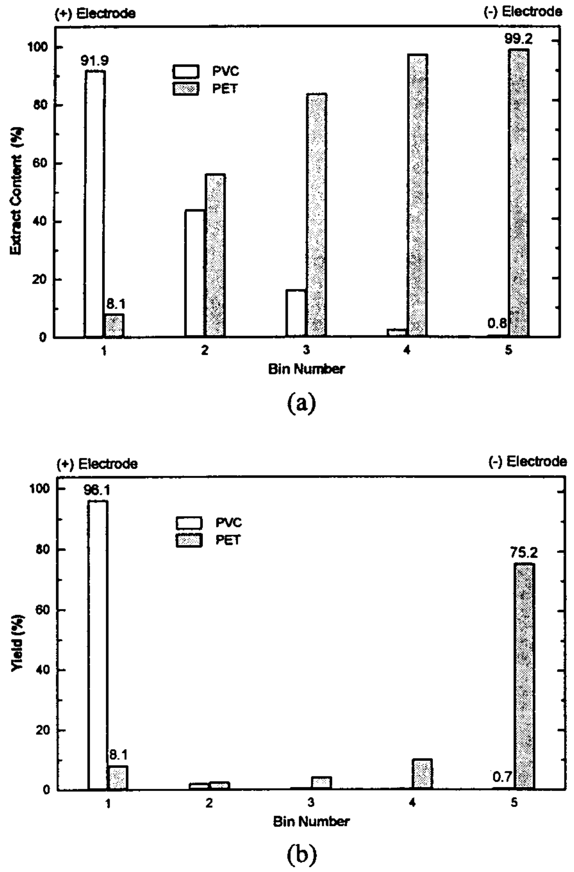


Fig. 6. Fractional extract contents and yield in five collection bins for PVC and PET. (a) extract content, (b) yield.

PVC and PET material is obtained in bin #1. In the central bin #3, the extract content of PVC is lower and would require a second stage of processing.

Table 2 summarizes a series of experiments carried out using the fluidized bed and several different mixtures of plastics. When PVC and other particles come into contact with one another in the fluidized bed tribocharger, as expected, the PVC particles (the left one of triboseries) show a tendency to become negatively charged and most of particles are collected in bins #1, #2, while other particles (the right one of triboseries) becomes positively charged and are collected in bins #4, #5. Thus for a single stage of processing and by combining the contents of four bins closest to each electrode, the separation experiment to remove PVC which generates hazardous hydrogen chloride gas in case of the combustion shows excellent tribo-electrification for all of the above plastics leading to essentially pure extract content (90 % or more) combined with several yields in excess of 96 %. This result shows the separation efficiency between different polymers depend on the triboseries and is nearly proportional to the tiboseries apart of each material (Lee *et al.*, 2000; Shin *et al.*, 2000).

Table 2. Experimental results of the electrostatic separation for PVC removal in two component mixed plastics.

Test Run	Mixture	Mixing Ratio (%)	Extract Content (%)	Yield (%)
# 1	PVC	50	90.0	98.2
	PET	50	98.9	85.3
# 2	PVC	50	98.3	98.7
	PP	50	99.2	96.6
# 3	PVC	50	96.0	99.0
	PE	50	99.9	96.3
# 4	PVC	50	99.2	96.3
	PS	50	98.5	99.2

Note: All experiments are carried out at room temperature (18 - 22 °C) and relative humidity (43 - 54 %)

Conclusions

The triboelectrostatic separator using the fluidized bed tribocharger is designed and evaluated to remove PVC materials from mixed binary plastics which PVC generates hazardous hydrogen chloride and dioxins gas in case of the combustion. The highly concentrated PVC (91.9%) can be recovered with a yield of about 96.1% from the mixture of PVC and PET material for a single stage of processing. For the removal of PVC from the two-component mixed plastics such as PET, PP, PE and PS, separation results show the recovery of 96~99% with the pure extract content in excess of 90%. The triboelectrostatic separation system using the fluidized bed tribocharger shows the potential to be an effective method for removing PVC from mixed plastics for waste plastic recycling.

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