Electrostatic Charging Measurement and PVC Separation of Triboeletrostatically Charged Plastic Particles using a Fluidized Bed Tribocharger

Jin-Hyouk Shin* and Jae-Keun Lee**

Abstract

A particle flow visualization, electrostatic charging measurement and separation of triboelectrically charged particles in the external electric field by a fluidized bed tribocharger are conducted for the removal of PVC particles from mixed waste plastics. The laboratory-scale triboelectrostatic separation system consists of the fluidized bed tribocharger, a separation chamber, a collection chamber and a controller. PVC and PET particles 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. To visualize these charged particles, He-Ne laser is used with cylindrical lenses to generate a sheet beam. In the charging measurement, the particle motion analysis system (PMAS), capable of determining particle velocity and diameter, is used to non-intrusively measure particle behavior in high strength electric field. The average charge-to-mass ratios of PVC and PET particles are -1.4 and 1.2 μC/kg, respectively. The highly concentrated PVC (91.9%) can be recovered with a yield of about 96.1% from the mixture of PVC and PET materials for a single-stage processing. The triboelectrostatic separation system using the fluidized tribocharger shows the potential to be an effective method for removing PVC from mixed plastics for waste plastic recycling.

Key Words : PVC Removal, Fluidized Bed Tribocharger, Triboseries, Flow Visualization, PMAS System, Triboelectrostatic Separation, Waste Plastic Recycling

1. Introduction

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[1~4]. Especially, this process is useful to separate 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. The particles charged by the

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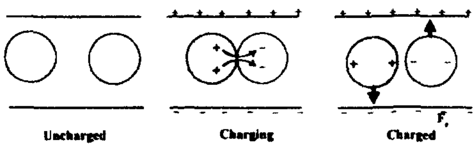
tribocharger can be separated by electrostatic force during passing through an external electric field. To attain high separation efficiency in the triboelectrostatic separation method, the particle charging measurement is the most important problem.

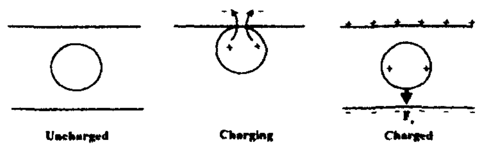
This paper describes to investigate the technical feasibility of a dry triboelectrostatic process to separate PVC materials from mixed plastics into economically valuable products. And particle trajectory analysis of triboelectrostatically charged particles in the external electric field is conducted, and charging measurements of triboelectrostatically charged particles by the fluidized bed tribocharger are conducted by the particle motion analysis system (PMAS) using various plastic particles. The PMAS being capable of determining particle velocity and diameter is used to non-intrusively measure particle behavior in high strength electric field. In the trajectory analysis, the charged particles entering the electric field are deflected to each electrode depending on their charge polarity.

2. 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[5]. 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. Davies[6] strongly suggests that at least some polymers and metals should form a triboelectric charging series.



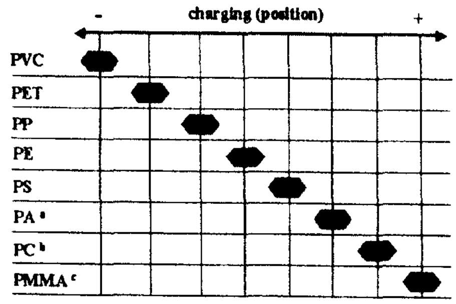
(a) particle-to-particle impact



(b) particle-to-wall impact

Fig. 1 The principle of the triboelectrification[5].

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.



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

Fig. 2 Triboelectric charging series of various plastics[7].

3. Experimental

3.1 Experimental Apparatus

Fig. 3 shows the schematic diagram of the fluidized bed tribocharger to impart the charging of test particles. The discharge of the fluidized bed is accomplished by a central pipe in the fluidized bed which is gradually moved downwards allowing the fluidized material to flow through the pipe while retaining its acquired charges. The fluidized bed consists of a acrylic and copper vessel (ϕ50×300 mm) with a circular cross section. The bed is supported on a copper plate used as air distributor with an opening size of 1.5 mm. 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.

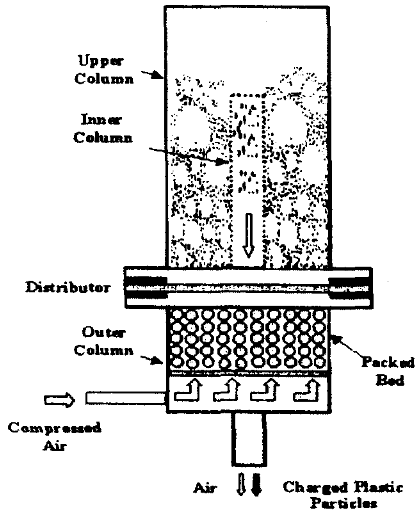


Fig. 3 Schematic diagram of the fluidized bed tribocharger for charging of mixed plastic particles.

Fig. 4 is the schematic diagram for the flow visualization of the charged particles. It consists of a fluidized bed tribocharger made of the copper tube, a separation chamber, optical systems, and data processors. Triboelectrically charged particles entering the separation chamber applied the electric field, deflects to the separation plate depend upon the polarity of charged particles. To visualize the charged particle trajectories in the separation chamber, a 300 mW Ar-ion laser (5500A-00, Ion Laser Technology) is used with a cylindrical lens system to generate a laser sheet. For the laser sheet, the particles are illuminated as short streaks, or more likely spots. The laser sheet is aligned vertically to examine particle behavior with and without an electric field. A still camera (FM2, Nikon) is used to record the

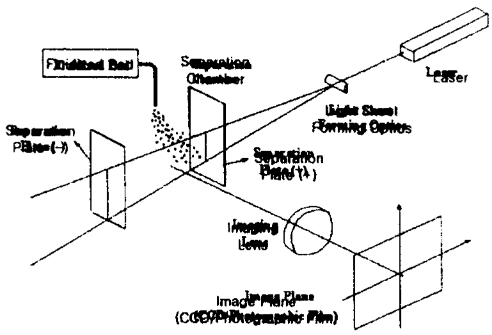


Fig. 4 Schematic diagram of the flow visualization of the charged particles[8].

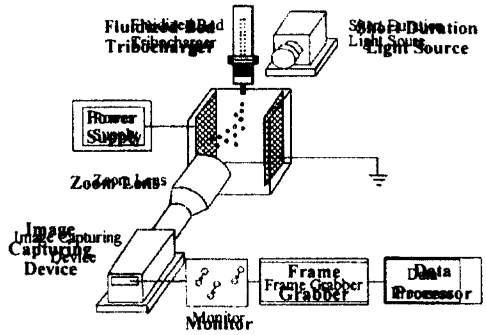


Fig. 5 Schematic diagram of the PMAS system[8].

scattered light of the particle while illuminating the chamber with the laser sheet.

Fig. 5 represents the schematic diagram of the PMAS for measuring the particle charging and the tribocharging system. The tribocharger is fluidized bed to provide particle-to-particle and particle-to-wall contact. The separation chamber contains two parallel copper plates (300×400 mm) applied the electric field (200 kV/m) and are disposed 100 mm apart at both sides of the separation chamber. The charged particles into the fluidized bed travel in the separation chamber with the applied high voltage potential and deflect to the opposite electrode. The PMAS consists of the dual-type short light duration source, (up to 65,500 sec), microscopic optics (magnitude factor 5), CCD camera (TM-1001, 1024×1024 pixels, Plunix) and the data processor. A pair of particle images with a short time interval is recorded by the CCD camera, and analyzed by an image grabber board connected to a personal computer.

Fig. 6 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 type electrodes, the collector containing five collection bins 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. After separation tests, the efficiency of the electrostatic separation can be obtained by measuring the mass of collected particles in each bin with electrical digital balance (OHAUS-GT 4100).

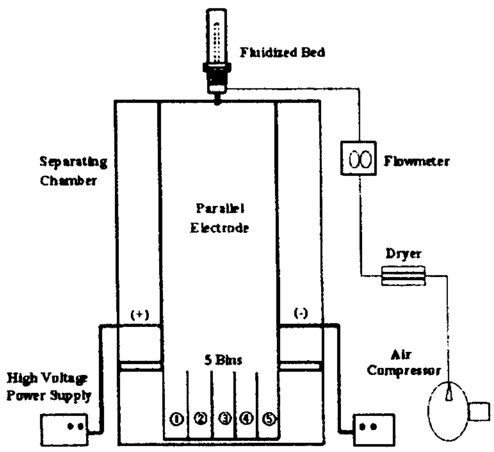


Fig. 6 A laboratory-scale triboelectrostatic separation system.

3.2 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. 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 flow visualization, charging measurement and triboelectrostatic separation of charged particles. All experiments are carried out at room temperature and ambient relative humidity (43-54 RH %).

4. Results

4.1 Particle Flow Visualization

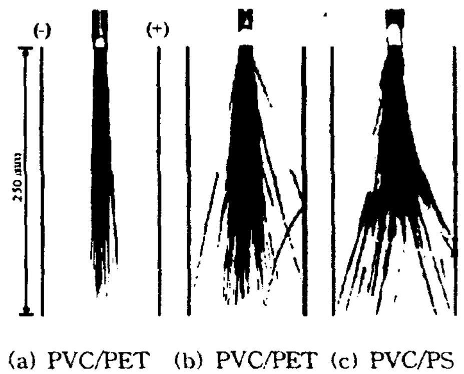
Fig. 7 is the particle flow visualization of triboelectrostatically charged plastic particles in the separation chamber. Fig. 7(a) shows the trajectories of PVC/PET particles with no electric field, it shows the general flow pattern of a circular jet. Fig. 7(b) shows the trajectories of PVC/PET particles with the electric field of 200 kV/m. When a high electric field was applied to electrodes, PVC particles with negative polarity are deflecting toward the positive electrode, and the trajectory profiles of the positively charged PET particles is deflected toward the negative electrode. And Fig. 7(c) shows the trajectories of PVC/PS particles with the electric field of 200 kV/m. It shows that PVC/PS particles have the bigger deflection angle comparing to PVC/PET particles. This result is well coincided with the results of Table 2. Also, it shows the various trajectories of charged particles such as a deflection, collision, bounding, attachment, and rebounding, etc. into the electric field. Since the bounding of particles acts as reason of the decreasing of the separation efficiency, it is important to solve the rebounding of particles by controlling the distance and inclined angle of electrodes.

Table 1. Experimental conditions for triboelectrostatic separation, particle flow visualization, and charging measurement.

Parameters	Specifications
Tribocharger	Fluidized Bed
Particle Materials	PVC, PET, PP, PE, PS
Particle Size (mm)	1.4 ~ 2.0
Electric Field Strength (kV/m)	200, 600
Air Flow Rate (l/m)	110
Particle Reynolds Number	70 ~ 300
Temperature (℃)	18 ~ 22
Relative Humidity (%)	43 ~ 54

4.2 Electrostatic Charging Measurement

Fig. 8 shows a charge-to-mass ratio (q/m) distribution for the mixture of PVC

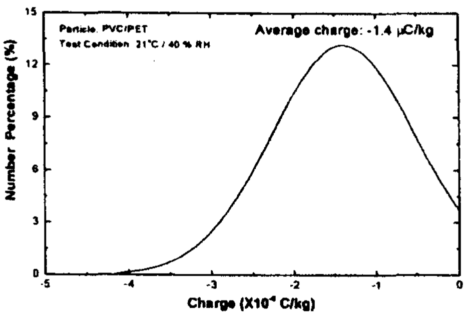


(a) PVC/PET 0 kV/m, (b) PVC/PET 200 kV/m, (c) PVC/PS 200 kV/m

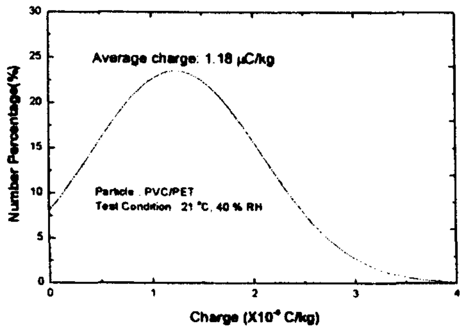
Fig. 7. Trajectory profiles of triboelectrostatically charged particles in the separation chamber.

and PET particles. Results show the bimodal charge distribution of PVC and PET mixtures as a result of addition of the two distributions of the components. The distribution indicated that some of the particles took on the charge opposite to the majority of the other particles. It is caused by the frictional contact of same particles or particle-wall frictional contact between the particles and Copper surface in fluidized bed tribocharger.' The average charge-to-mass ratio is -1.4 μC/kg for PVC particles, and 1.2 μC/kg for PET particles.

Fig. 9 shows the average charge-to-mass ratio for two component mixed plastics of PVC and other particles. When PVC and other particles come into contact with one another in the fluidized bed tribocharger, the PVC particles acquire a negative charge, while other particles are charged positively. The average charge-to-mass ratio depends on the triboseries and is nearly proportional to the triboseries apart of each material



(a)



(b)

Fig. 8. Charging distribution of PVC/ PET particles. (a) PVC, (b) PET.

4.3 Electrostatic Separation

The quality and effectiveness of the electrostatic separation process can be measured in terms of the extract content and the yield.

Fig. 10 illustrates the nomenclature of the data analysis. By weighing the mass collected in each of bins and taking into account the respective extract contents, one is able to calculate the yield for each component.

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

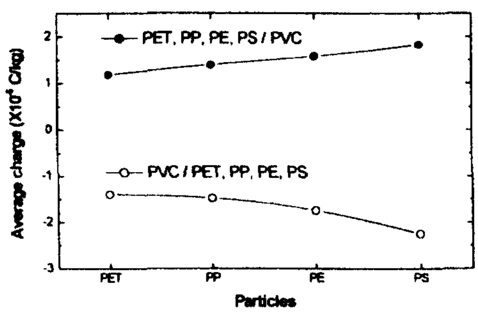
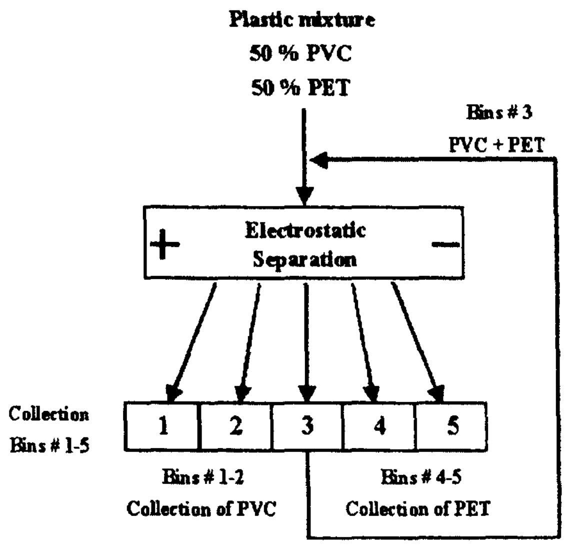


Fig. 9 Average charge of triboelectrostatically charged PVC and other particles in the fluidized bed tribocharger

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 triboelectrification 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 triboseries apart of each material[9, 10].

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

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



$$\text{PVC Yield} = \frac{\text{Mass PVC in bins \# 1-2}}{\text{Mass PVC in bins \# 1-5}} \qquad \text{PET Yield} = \frac{\text{Mass PET in bins \# 4-5}}{\text{Mass PET in bins \# 1-5}}$$

$$\text{PVC E. C.} = \frac{\text{Mass PVC in bins \# 1-2}}{\text{Total mass in bins \# 1-2}} \qquad \text{PET E. C.} = \frac{\text{Mass PET in bins \# 4-5}}{\text{Total mass in bins \# 4-5}}$$

(E. C. = Extract Content)

Fig. 10. Nomenclature used for the analysis of the results and the equations of yield and extract content.

5. Conclusions

A particle flow visualization, electrostatic charging measurement and electrostatic separation of triboellectrically charged particles in the external electric field by the fludized bed tribocharger are conducted for the removal of PVC particles from mixed waste plastics. PVC and other particles can be imparted negative and positive surface charges, respectively, depending on the difference of triboelectric charging series between particles and particles in the fluidized bed tribochar- ger, and can be separated by passing them through an external electric field. The average charge-to-mass ratio of PVC and PET particles measured by PMAS is -1.4 and 1.2 μC/kg, respectively. The highly concentrated PVC (91.9%) can be recovered with a yield of about 96.1% from the mixture of PVC and PET materials for a single stage of processing. This result shows the triboelectrostatic separation system using the fluidized tribocharger has the potential to be an effective method for removing PVC from mixed plastics for waste recycling.

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