Korean J. Chem. Eng., **19**(2), 267-272 (2002)

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

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(*Received 21 March 2001 • accepted 22 November 2001*)

Abstract−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). The PVC material generates hazardous hydrogen chloride gas resulting from the combustion in the incinerators. The laboratory scale triboelectrostatic separation system consists of a fluidized-bed tribocharger, a separation chamber, a collection chamber and a controller. Negative and positive surface charges can be imparted to the PVC and PET particles, respectively, due to the difference of triboelectric charging series between the particles in the fluidized-bed tribocharger. They can be separated by passing through an external electric field. A highly concentrated PVC (91.9%) can be recovered with a yield of about 96.1% from the mixture of PVC and PET materials in a single stage of processing. For the removal of PVC from the two-component mixed plastics such as PVC/PET, PVC/PP, PVC/PE or PVC/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.

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

INTRODUCTION

More than 3 million tons of waste plastics was produced in Korea in 1996, so it is important to develop an economically satisfactory separation process to improve the recycling rate of industrial waste. Such waste causes serious environmental problems due to the disposal by landfill or incineration. In particular, 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 [Matsushita et al., 1999]. Because of its large volume fraction, a significant part of the landfill cost is attributed to plastics. Plastics as landfill also raises environmental concern since the material degrades very slowly. These concerns create a significant public pressure to recycle waste plastics. In order to reuse them, it is necessary to effectively separate waste plastics according to their qualities. Most commercial separators such as an air classifier, a centrifugal separator, and flotation system are based on the specific gravity. So, plastics of similar specific gravity such as PVC and PET are difficult to separate by this process.

Recently, a dry triboelectrostatic process has been considered to apply to recycle waste plastics. 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. Some of the mechanisms proposed for electrostatic contact charging are electron transitions between the materials coming into contact [Davies, 1967; Harper, 1967; Greason and Inculet, 1975] and ion exchange [Briick, 1981]. In a practical application of triboelectrification for plastic recycling, many researchers have been studying the separation experiments of various plastics by using a tribocharger such as a cyclone [Pearse, 1978; Yanar, 1995], a rotary blade [Matsushita et al., 1999], and a rotating tube [Inculet, 1994]. Also, Kang et al. [1999], Lu et al. [1999], Takeshita et al. [1999], Kim et al. [2000], and Lee et al. [2001] have been investigating the particle flow behavior and the stability of operation of a perforated plate type suspension bed in three-phase fluidized beds, respectively.

This paper investigates the technical feasibility of a dry triboelectrostatic process to separate PVC materials from mixed plastics into economically valuable products. The laboratory-scale electrostatic separation system consists of a fluidized bed tribocharger, a separation chamber, a collection chamber, and a controller.

TRIBOELECTROSTATIC SEPARATION

Electrostatic separation is a broadly applicable dry processing technique in the recycling plastic wastes, mineral processing industry, and coal beneficiation [Gupta et al., 1993]. This process separates materials based on one or more of their electrical properties such as work function or triboelectric charging series. When two materials are in contact, electrons move until the energy of electrons in each material at the interface is equalized. The material with a higher affinity for electrons gains electrons and charges negatively, while the material with the lower affinity loses electrons and charges positively. A measure of the relative affinity for electrons is called the work function. Table 1 shows the values of work function and specific gravity for various plastics. The work function of PVC and PET materials is 4.58 and 4.25 eV, respectively. When

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Table 1. The values of work function and specific gravity for various plastics

Polymer	Work function (eV)		Specific gravity
	Davies [1969]	Stellra [1970]	
PVC[a]	4.85±0.20	5.13	1.30-1.40
PET[b]	4.25±0.10	N/A	1.38-1.41
PS[c]	4.22±0.07	4.90	1.05-1.06
PE[d]	N/A[f]	4.90	0.91-0.97
PP[e]	N/A	N/A	0.907-0.93

[a]PVC: Polyvinylchloride
[b]PET: Polyethylene terephthalate
[c]PS: Polystyrene
[d]PE: Polyethylene
[e]PP: Polypropylene
[f]N/A: Not available

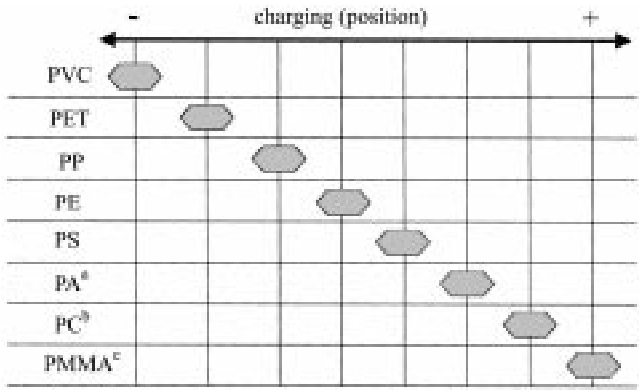

Fig. 1. Triboelectric charging series of various plastics [Brandrup et al., 1996].

PVC and PET particles come into contact with one another, the PVC becomes negative and the PET positive. The specific gravity for PVC materials is similar to that of PET materials. Therefore, PVC separation from the mixed of PVC and PET materials by density separation processes is difficult.

Fig. 1 shows the triboelectric charging sequence of various plastics [Brandrup et al., 1996]. 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 while the right one positively. 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. Accordingly, this process should ideally be used to separate binary mixtures. If a mixture has more than two plastics, it is very difficult to control the charging behaviour. However, PVC is an exception for this. As PVC is almost always negatively charged in relation to other plastics, it can usually be separated out from the mixtures of any number of plastics.

Fig. 2 shows the principle of electrostatic separation for separating PVC particles from the mixed plastics. It consists of the tribocharger to impart the charge on the particles and a separation chamber to collect the separate particles. The triboelectric charging on the particles can be carried out using the tribocharger such as a fluidized bed, a rotating tube, or a pneumatic conveyor. The selectivity and intensity of the charge can be increased considerably by setting environmental conditions, such as moisture content, temperature, and adding conditioning agents. Such positively or negatively charged particles are so highly charged that they can be deflected towards the appropriate counter-electrode in separation chamber through a high voltage electrical field, and thus be separated from one another. When PVC and PET particles come into contact with one another in the fluidized bed tribocharger, the PVC becomes negative and the PET positive. And both PVC and PET particles can be separated by passing them through an external field in the electrostatic separation plates.

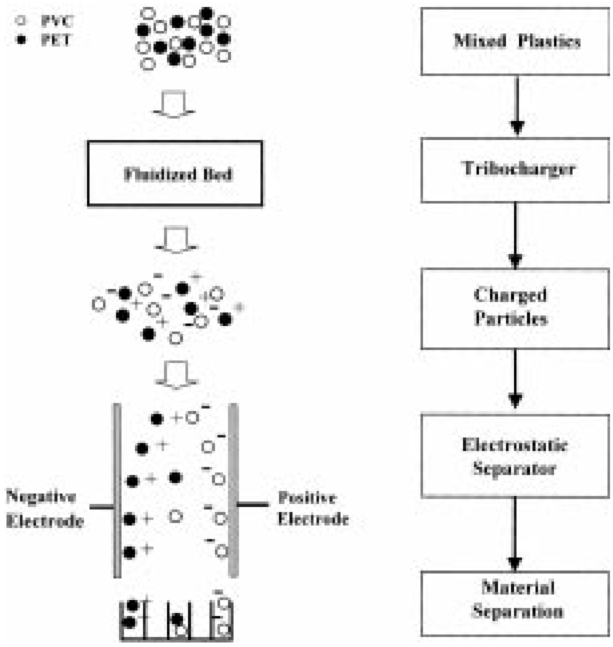

Fig. 2. Schematic diagram of the experimental system for electrostatically separating PVC from mixed plastics.

EXPERIMENTAL

1. Triboelectrostatic Separation System

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 (650×470×1,000 mm^3) with two plate electrodes (450×1,000×5 mm^3), the collector (600×450×240 mm^3) and the high voltage power supply. The separation chamber contains two inclined aluminum plates which are applied a high voltage and disposed 100 mm apart from both sides of the separation chamber. The inclined plate electrodes are maintained at potentials of up to ±30 kV, thus producing a maximum potential difference of 60 kV between the electrodes. The collector containing five collection bins is placed at the bottom of the separation chamber to catch any entrained plastic particles. Plastic particles are fluidized and charged inside the fluidized-bed tribocharger. The charged particles are en-

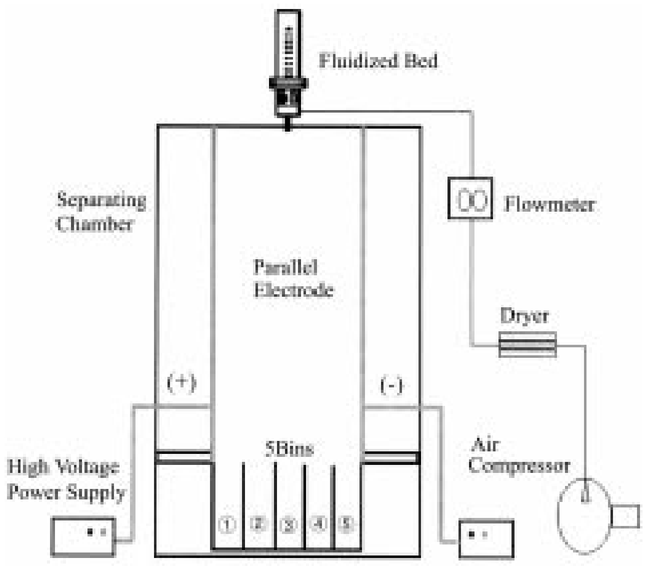

Fig. 3. Schematic diagram of electrostatics separation system using the fluidized bed tribocharger.

trained 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 particles which are charged positively during the fluidization process are deflected toward the negative electrode while the negatively charged particles toward 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).

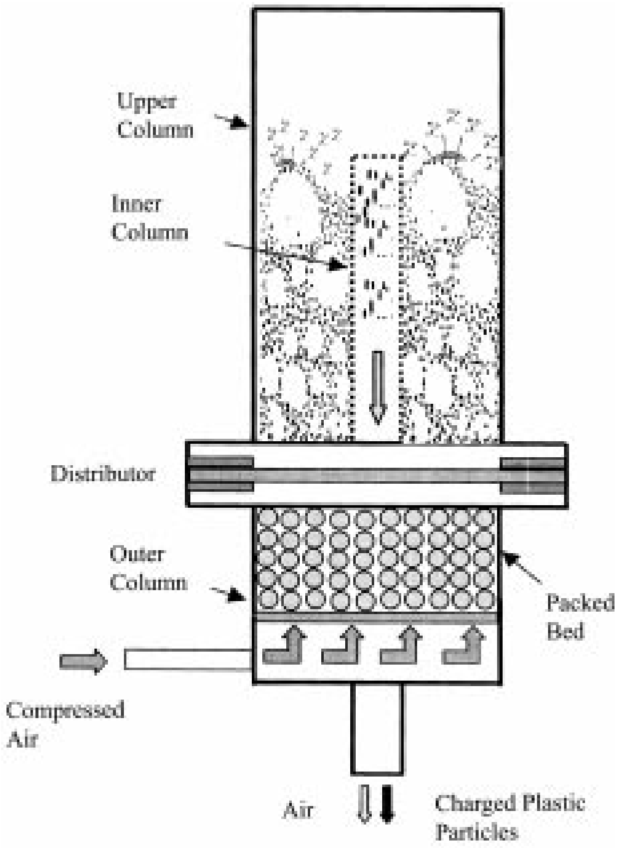

Fig. 4. Schematic diagram of the fluidized bed tribocharger for charging mixed plastic particles.

Fig. 4 shows the schematic diagram of the fluidized-bed tribocharger to impart the charge on test particles. The discharge from the fluidized bed is accomplished by means of 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 (Ψ50, 250 mm length) with a circle cross section. The bed is supported on a copper plate used as an air distributor with an opening size of 1.5 mm. 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.

2. Test Material and Conditions

Six types of plastics such as polyethylene telephtalate (PET), polyvinylchloride (PVC), polyethylene (PE), polystyrene (PS), and polypropylene (PP) are used in this study. Experiments are carried out with particles in granular form, of irregular sharpe, 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 2 shows the experimental conditions for the 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 silica-gel before an inlet to the apparatus.

Table 2. Experimental conditions for triboelectrostatic separation test

Parameters	Specification
Particle size	1.4-2 mm
Electric field strength	6 kV/cm
Air flow rate	110 *l*/min
Particle feeding rate	10 g/min
Relative humidity	43-54%
Air temperature	13-16 °C

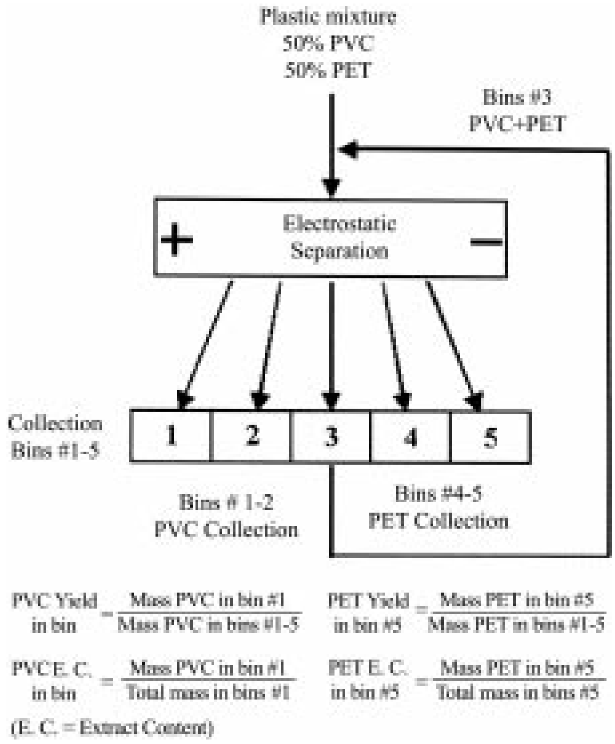

Fig. 5. Nomenclature used for the analysis of the results and the equations for the calculation of the yield and the extract content.

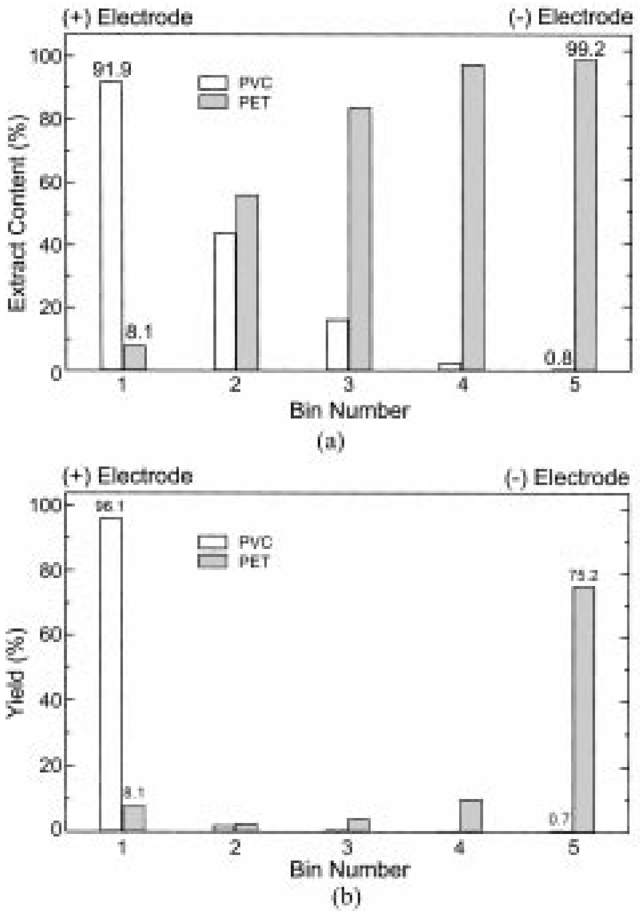

Fig. 6. Fractional yield and extract contents in five collection bins for PVC and PET.
(a) yield, (b) extract content

RESULTS AND DISCUSSION

The quality and effectiveness of the electrostatic separation process can be described in terms of the extract content and the yield defined below:

Extract content=Mass of the sought component in the extracted fraction(s)/Mass of the extracted fraction(s) (1)

Yield=Mass of the sought component in the extracted fraction(s)/Mass of the processed mixture (2)

Fig. 5 illustrates the nomenclature for the data analysis of the separation test. For two component mixed plastics of PVC and PET, most of the 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 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) become positively charged and are collected in bins #4 and #5 as shown in Fig. 6(b). A highly concentrated PVC (91.9%) with a yield of about 96.1% from the mixture of 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.

Fig. 7 shows the separation results of the cumulative extract content and yield for a mixture of 50% PVC and 50% PET particles measured in each of the individual collection bins #1 to #5. For clarity, as shown in Fig. 7(a), the cumulative yield of PVC in bin #2 can be obtained from the ratio of PVC mass in two bins #1 and #2 divided by the supplied PVC total mass, while the cumulative extract content of PVC in bin #2 can be obtained from the ratio of PVC mass in two bins #1 and #2 divided by the mass of two bins #1 and #2 collected. PVC material can be recovered 96.1% at the extract content of 91.2% in bin #1, 98.2% at the extract content of 90% in two bins #1 and #2, 99% at the extract content of 86.5% in three bins #1-#3, 99.3% at the extract content 79.2% in the four bins #1-#4, and 100% at the extract content 50% in the five bins #1-#5. The number of collection bins for PVC recovery can be designed from the results of the cumulative yield and extract content. The higher

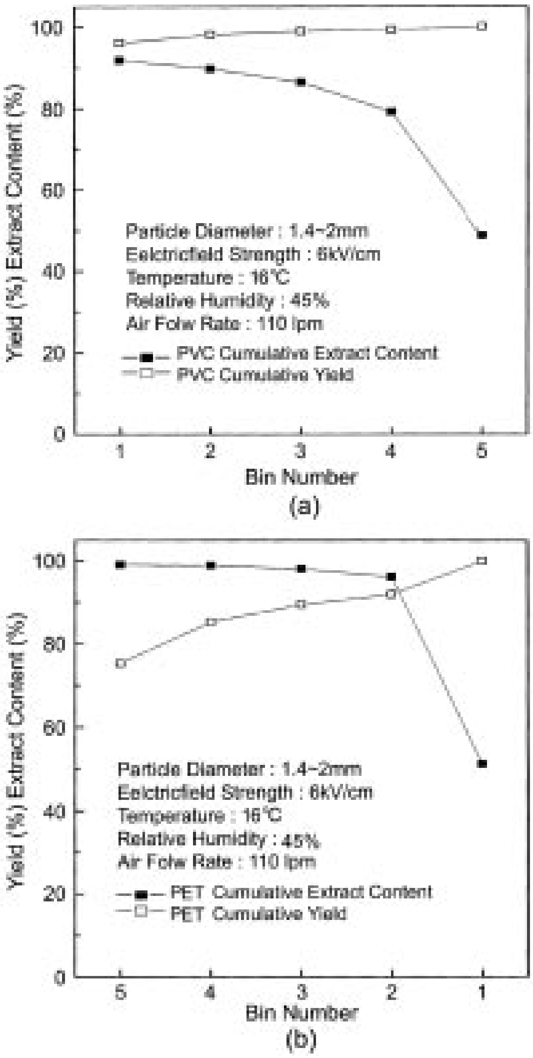

Fig. 7. The separation results of the cumulative extract content and yield for a mixture of 50% PVC and 50% PET particles. (a) PVC, (b) PET

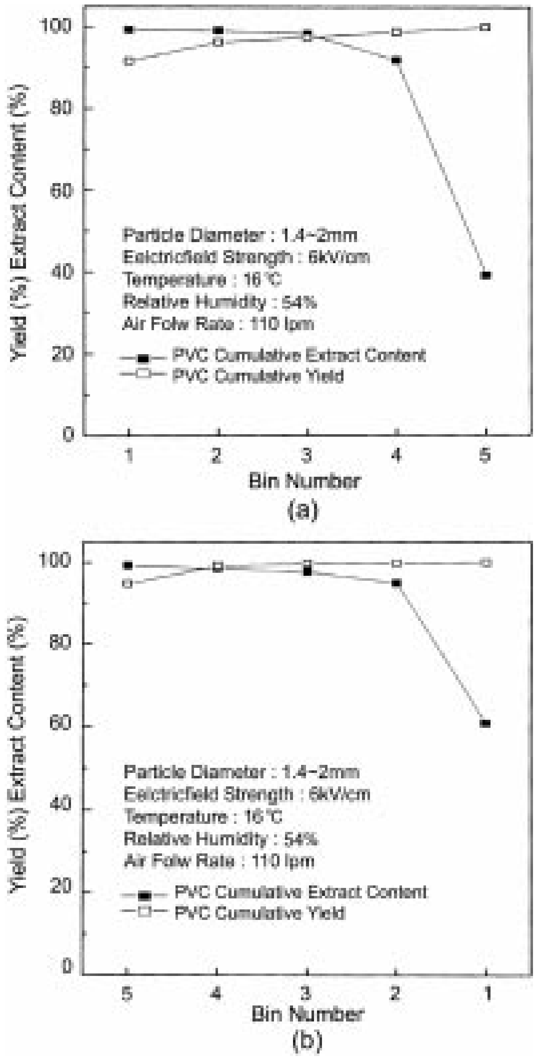

Fig. 8. The separation results of the cumulative extract content and yield for a mixture of 50% PVC and 50% PS particles. (a) PVC, (b) PS

the extract content of PVC gets, the lower yield that is produced. In Fig. 7(b), the cumulative extract content and yield of PET can be calculated from the starting bin #5 of the negative electrode which collects most PET particles. PET material can be recovered 75.2% at the extract content of 99.1% in bin #5, 85.3% at the extract content of 98.9% in two bins #5 and #4, and 100% at the extract content 50% in the five bins #1-#5. In summary, for a single stage of processing and by combining the contents of the two bins closest to the each electrode, it is possible to recover 98.2% of the PVC at the extract content of 90% and 85.3% of the PET with the extract content of 98.9%.

Fig. 8 shows the separation results of the cumulative extract content and yield for a mixture of 50% PVC and 50% PS particles measured in each of the individual collection bin #1 to #5. Triboelectric charging series between PVC and PS particles is much farther apart than that of other mixed plastics. In Fig. 8(a), PVC material can be recovered 91.7% at the extract content of 99.3% in bin #1, 96.3% at the extract content of 99.2% in two bins #1 and #2, and 100% at the extract content 39.1% in the five bins #1-#5. In Fig. 8(b), PS material can be recovered 94.7% at the extract content of 99.3% in bin #5, 99.2% at the extract content of 98.5% in two bins #5 and

Table 3. 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: Extract content and yield of PVC material are based on the mass collected in bins #1 and #2, while those of PET, PP, PE and PS are based on bins #4 and #5 as shown in Fig. 5.

#4. For a single stage of processing and by combining the contents of the two bins closest to the each electrode, it is possible to recover 96.3% of the PVC at an extract content of 99.2% and 99.2% of the PS with the extract content of 98.5%. The separation result for the mixture of PVC and PS shows much better the extract content and the yield than that of PVC and PET. It means that the farther apart two plastics are in the triboelectric charging series, the more easily charges can move between them and these materials can be separated easily.

Table 3 summarizes the separation results carried out by using the fluidized bed and several binary mixtures of plastics. When PVC and other particles come into contact with one another in the fluidized-bed tribocharger, the PVC particles (the left one of triboseries) show a tendency to become negatively charged and most of particles are collected in bins #1 and #2, while other particles (the right one of triboseries) becomes positively charged and are collected in bins #4 and #5. Thus for a single stage of processing and by combining the contents of two bins closest to each electrode, the extract content and yield of PVC material are based on the mass collected in bins #1 and #2, while those of PET, PP, PE or PS are based on bins #4 and #5. Separation results show the extract content of 90-99% and the yield of 85-99%. In particular, 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 that separation efficiency between different polymers depends on the triboseries and is nearly proportional to the triboseries separation of each material. Also, it implies that electrical characteristics of materials play an important role in triboelectrification.

CONCLUSIONS

A 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 dioxin gas in case of combustion. A 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 PVC/PET, PVC/PP, PVC/PE or PVC/PS, separation results show a 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.

ACKNOWLEDGEMENT

This study is supported financially by Pusan National University Research Grant and the Korea Science and Engineering Foundation through the Institute for Environmental Technology and Industry (IETI), Pusan National University, Korea (Project number: 99-10-04-01-A-3). The authors gratefully acknowledge the financial support.

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