Triboelectrostatic Separation System for Separation of PVC and PS Materials Using Fluidized Bed Tribocharger

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A triboelectrostatic separation system using a fluidized bed tribocharger for the removal of PVC material in the mixture of PVC/PS plastics is designed and evaluated as a function of electric field strength, air flow rate, and the mixing ratio of two- component mixed plastics. It consists of a fluidized-bed tribocharger, a separation chamber, a collection chamber and a controller. PVC and PS particles can be imparted negative and positive surface charges, respectively, due to the difference in the work function values of plastics suspended in the fluidized-bed tribocharger, and can be separated by passing them through an external electric field. Experimental results show that separation efficiency is strongly dependent on the electric field strength and particle mixing ratio. In the optimum conditions of 150 lpm air flow rate and 2.6 kV/cm electric field strength a highly concentrated PVC (99.1%) can be recovered with a yield of more than 99.2% from the mixture of PVC and PS materials for a single stage of processing.

Key Words: PVC/PS Electrostatic Separation, Tribocharger, Extract Content, Yield, Air Flow Rate, Electric Field Strength, Mixing Ratio

1. Introduction

Disposal of waste plastics by landfill or incineration causes a serious environmental problem. Especially, PVC materials combustion in the incinerators generates hazardous by-products such as hydrogen chloride gas, polychlorinated dibenzo-p-dioxins, and so on. These gases lead to air pollution and shorten the life of incinerators. Because of its high volume and low density, a significant part of the landfill cost is attributed to plastics. Also, the landfill of plastics raises environmental concern as 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 the air classifier, centrifugal separator, or flotation system are based on the specific gravity. Recycling rate of industrial waste plastics is quite low because there is no economically satisfactory separation process.

A dry triboelectrostatic process is useful to separate PVC from the mixed plastics. The process 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 mechanism proposed for electrostatic contact charging are electron transitions between the materials coming into contact (Davies, 1969 ; Harper, 1967 ; Greason and Inculet, 1975 ; Lee and Kim, 2001) and ion exchange (Henry, 1953 ; Brück, 1981). In a practical application of triboelectrification for plastic recycling, many researchers have studied the separation experiments of various plastics

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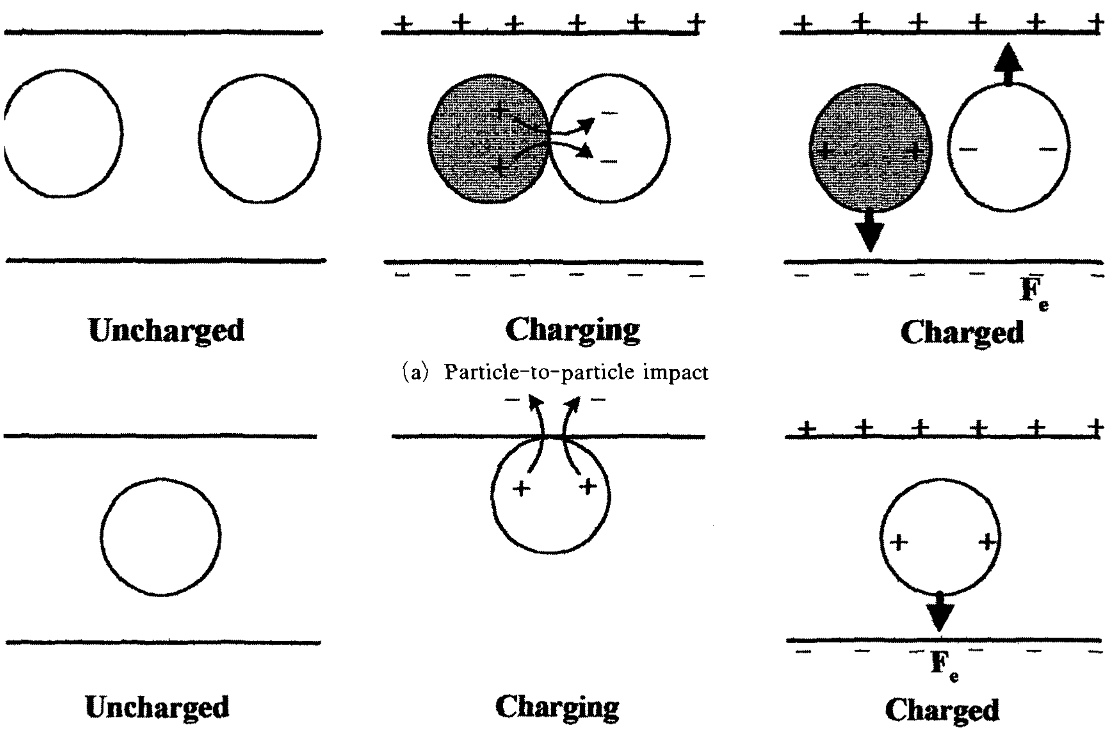
using the tribocharger such as a cyclone (Pearse, 1978), a rotary blade (Matsushita et al., 1999), and a rotating tube (Inculet, 1994). Also, Kim et al. (1996) and Takeshita et al. (1999) had investigated the particle flow behavior and the stability of operation of a perforated plate type suspension bed in three-phase fluidized beds.

The purpose of this study is to investigate the optimal conditions for maximizing the separation efficiency in dry triboelectrostatic process to separate PVC and PS materials using a fluidized-bed tribocharger. The laboratory scale electrostatic separation system used in this investigation consists of the fluidized-bed tribocharger, the separation chamber, the collection chamber, and the controller. Separation testing is conducted for different air flow rates, electric field strengths, and particle mixing ratios.

2. Triboelectrostatic Separation

Figure 1 shows the principle of triboelectrification by the particle-to-particle impact and the particle-to-wall impact. Tribocharging or frictional charging is the process whereby a charge exists on a material after the part of a solid/solid contact. When two materials are brought into contact, charge is transferred between them until their Fermi levels equalize. The material having a higher work function gains electrons and is charged negatively, while the material having the lower work function loses electrons and is charged positively. The work function or contact potential is defined as the difference between the energy of an electron at the Fermi level inside the surface of the material and an electron at rest in vacuum outside the material, and the Fermi level is defined as the level at which the probability of finding an electron is 0.5. Therefore, the material of higher work function which has higher affinity for the electron, gains the electron from the material of lower work function. When two materials with different work functions come into contact, electrons will flow from one with the higher work



(a) Particle-to-particle impact

(b) Particle-to-wall impact

Fig. 1 Principle of triboelectrification (Kelly and Spottiswood, 1989)

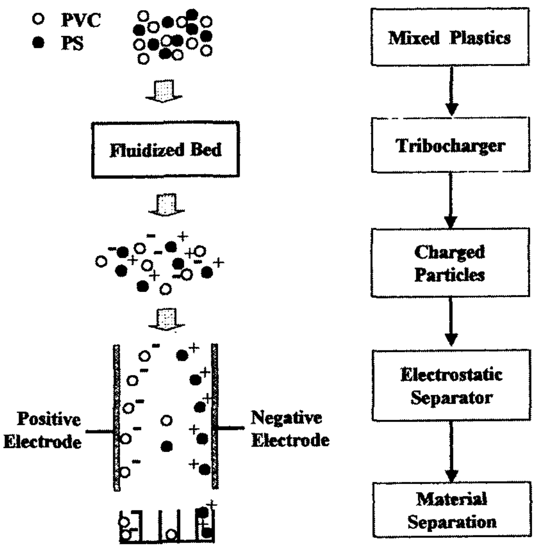


Fig. 2 Schematic diagram of experimental system for electrostatically separating PVC from mixed PVC/PS particles

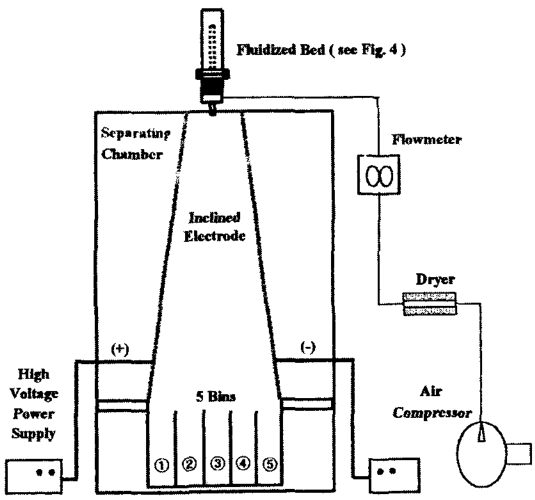


Fig. 3 Schematic diagram of electrostatics separation system using fluidized-bed tribocharger

function to the other until the Fermi levels of the materials will be equilibrated (Mukherjee, 1987 ; Fraas, 1962).

The work function values of PVC, Copper and PS materials are 4.85, 4.38 and 4.22 eV, respectively (Davies, 1969 ; Fomenko, 1972). When PVC and PS particles inside the copper surface of the fluidized-bed tribocharger come into contact with one another, the PVC becomes negative and the PS positive.

Figure 2 shows the principle of electrostatic separation for separating PVC and PS particles mixture. It consists of a tribocharger to impart the charge on the particles and a separation chamber to collect the separate particles. When PVC and PS particles come into contact with one another in the fluidized-bed tribocharger, the PVC becomes negatively charged while the PS becomes positive. Once charged PVC and PS particles can be separated by passing them through an external electric field in the electrostatic separation plates.

3. Experimental

3.1 Triboelectrostatic separation system

Figure 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 ($650 \times 470 \times 1{,}000\ mm^3$) with two plate electrodes ($450 \times 1{,}000 \times 5\ mm^3$), the collector ($600 \times 450 \times 240\ mm^3$) and the high voltage power supply. The separation chamber contains two inclined aluminum plates which are applied a high voltage and disposed 150 mm apart from both sides of the separation chamber. The inclined plate electrodes with 5° inclined angle 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 entrained in the separation chamber. As the particles fall through the chamber, they are deflected toward 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).

Figure 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 (ϕ50,250 mm length) with a circular cross section. The bed is supported on a copper plate used as the air distributor with an opening size of 1.5 mm. To minimize charge leakage by conduction, the fluidization column is insulated from the support by a thick layer of silicone rubber. During fluidiztion, the plastic particles acquire electrostatic charge due to triboelectrification. The introduction of the fluidizing gas, typically compressed air, should not introduce a significant charge to the bed of particles. When plastic particles are fluidized by compressed air over minimum fluidizing air flow rate inside the fluidized-bed tribocharger, plastic particles traveling upward in the wake of air bubbles are replaced by particles traveling downward and charged by particle-particle and particle-wall frictional contact. Increasing the air bubble size brings about an increase in the degree of charging. Since bubbles of greater diameter rise more rapidly, the intensity of the bed-particle movement in the vicinity of the bubble must also increase. The mechanism by which charges segregate when two materials are brought into contact has been explained previously. 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.

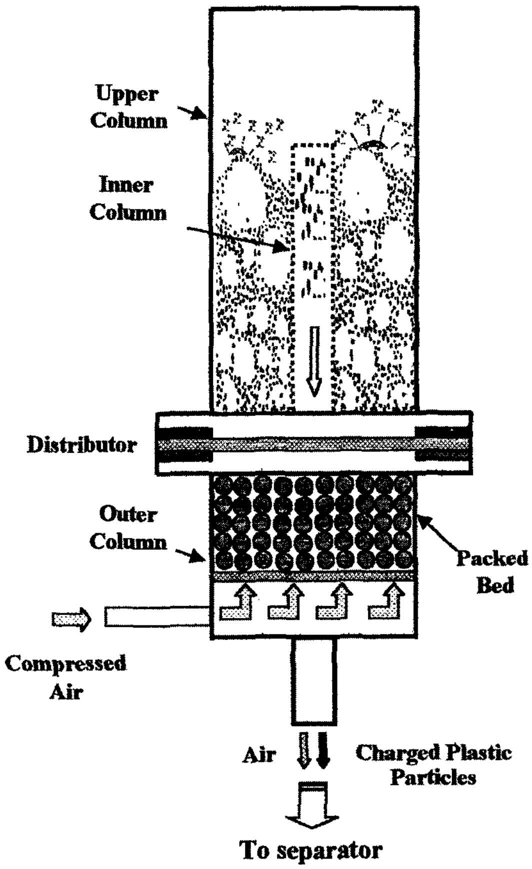


Fig. 4 Schematic diagram of fluidized bed tribocharger for charging mixed plastic particles

3.2 Test material and conditions

Table 1 shows the experimental conditions for separating PVC and PS plastic particles from two-component particle mixture using the fluidized bed tribocharger. Experiments are carried out with particles in a granular form of irregular shape with the size range from 1.4 to 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 with water and dried to remove the charge and ensure a similar surface state of particles before each experiment. The range of air flow rate and electric field strength are 110~190 lpm and 0.6~2.6 kV/cm, respec tively. All experiments are carried out at the

Table 1 Experimental conditions in separation of two component mixed plastics

Parameters	Specifications
Particle Materials	PVC, PS
Particle Size (mm)	1.4~2.0
Particle Feeding rate (g/min)	10
Electric Field Strength (kV/cm)	0.6, 1.7, 2.6
Air Flow Rate (lpm)	110, 150, 190
Particle Mixing Ratio (PS/PVC)	1, 3, 5, 7
Temperature (℃)	18
Relative Humidity (%)	30

temperature of 18 ℃ and the relative humidity of 30%. The fluidizing air is dried in a tower packed with silica-gel in the inlet to the apparatus.

4. 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

$$=\frac{\textit{Mass of the sought component in the extracted fraction(s)}}{\textit{Mass of the extracted fraction(s)}} \quad (1)$$

Yield

$$=\frac{\textit{Mass of the sought component in the extracted fraction(s)}}{\textit{Mass of the processed mixture}} \quad (2)$$

Figure 5 illustrates the nomenclature for the data analysis of the separation test. For two component mixed plastics of PVC and PS. Most of PVC particles charged negatively are collected in bins #1 and #2, while PS particles charged positively are collected in bins #4 and #5. In the central bin #3, PVC and PS 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.

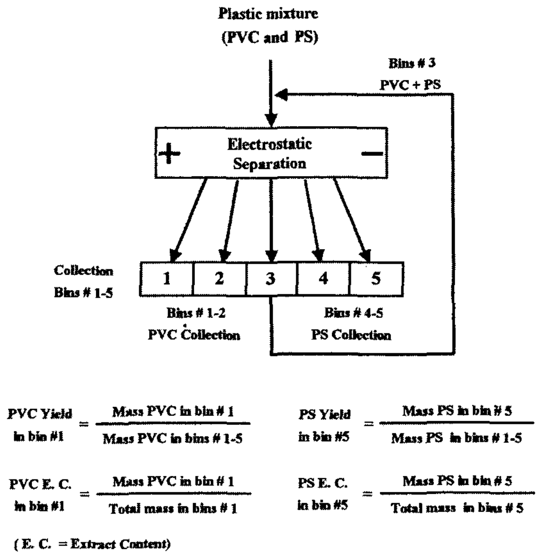
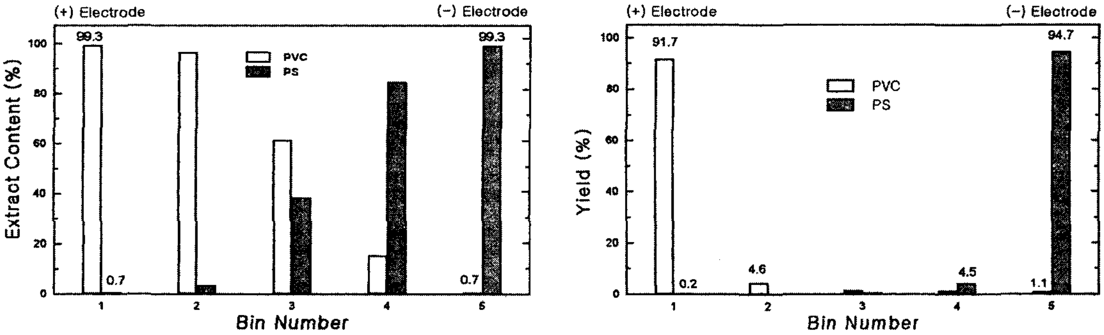


Fig. 5 Nomenclature for analysis of results and equations for calculation of yield and extract content

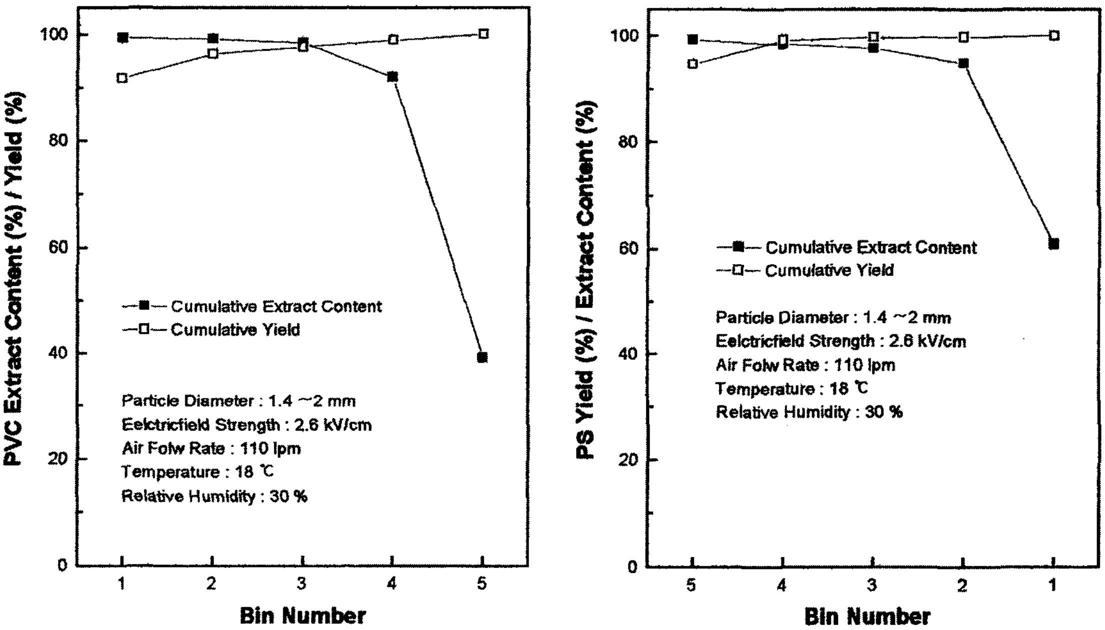
4.1 Extract content and yield of PVC/PS separation

Figure 6 shows the fractional extract content and yield of PVC and PS 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 PS at 2.6 kV/cm electric field strength and 10 g/min particle feeding rate. For the extract content shown in Fig. 6(a), bin #1 collects 99.3% pure PVC whereas bin #5 collects 99.3% pure PS. For the yield of PVC and PS as shown in Fig. 6(b), bin #1 collects 91.7% from the mass of PVC supplied whereas the rest of bins #2-5 collects 8.3%. In case of PS, bin #5 collects 94.7% from the mass of PS supplied. Most of PVC particles (the left one of triboseries) become negatively charged and are collected in bins #1 and #2, while PS particles (the right one of triboseries) becomes positively charged and are collected in bins #4 and #5 as shown in Fig. 6(b). A highly concentrated PVC (99.3%) with a yield of about 91.7% from the mixture of PVC and PS 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.



(a) Extract content (b) Yield

Fig. 6 Fractional extract contents and yield in five collection bins for PVC and PS



(a) PVC (b) PS

Fig. 7 Separation results of cumulative extract content and yield for mixture of 50% PVC and 50% PS particles

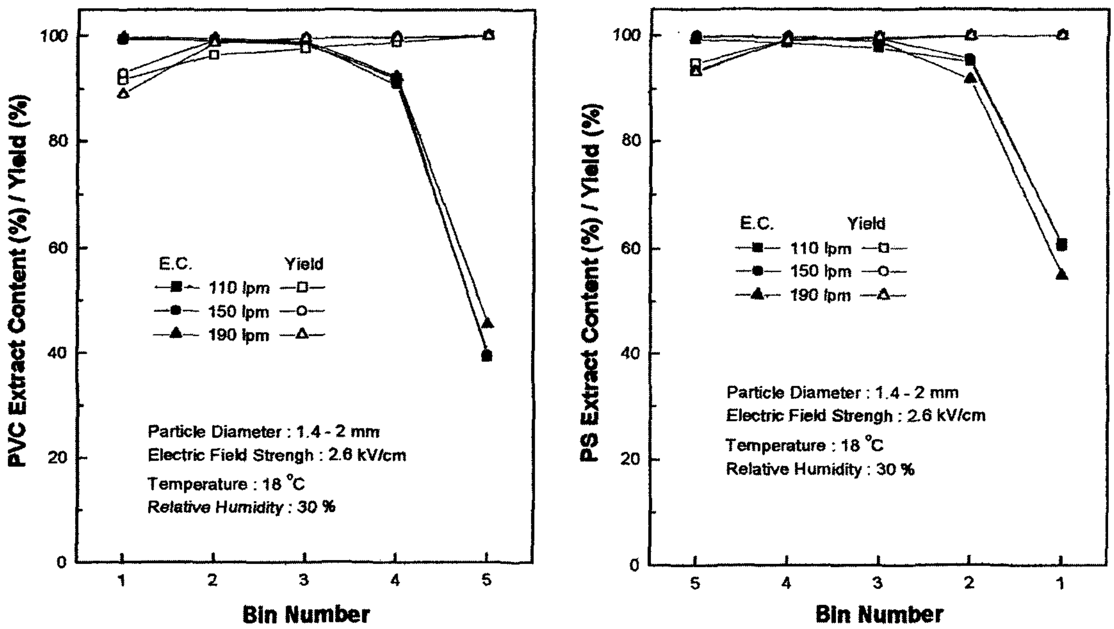
Figure 7 shows the separation results of the cumulative extract content and yield for a mixture of 50% PVC and 50% PS particles measured in each of the individual collection bin #1 to #5. For the better understanding shown in Fig. 7(a), the cumulative yield of PVC in bin #2 can be obtained from the ratio 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 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 40% in the five bins #1~#5. In Fig 7(b), the cumulative extract content and yield of PS can be calculated from the starting bin #5 of the negative electrode which collects most PS particles. 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 #4, and 100% at the extract content 60% 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 96.3% of the PVC at the extract content of 99.2% and 99.2% of the PS with the extract content of 98.5%.

4.2 Effect of air flow rate

Figure 8 shows the separation results of the cumulative extract content and yield as a function of air flow rate through the fluidized-bed tribocharger. A mixture of 50% PVC and 50% PS particles is measured in each of the individual collection bin #1 to #5. Particle diameter and the electric field strength are 1.4～2.0 mm and 2.6 kV/cm, respectively. The air flow rates are 110, 150 and 190 lpm. For the air flow rate of 110 lpm being indicative of minimum fluidizing air flow rate, PVC material can be recovered 91.7% at the extract content of 99.3% in bin #1 and PS material recovered 94. 7% at the extract content of 99.3% in bin #5. For the air flow rate of 150 and 190 lpm, the cumulative extract content and yield of PVC and PS particles is similar to that of 110 lpm. Air flow rate more than minimum fluidizing flow rate does not play an important role on the yield and extract content of PVC and PS particles. During fluidization and transport, PVC and PS particles acquire electrostatic charge due to the particle-to-particle and particle-to-wall contacts. Particles reach to the maximum charge values at the air flow rate of minimum fluidizing air flow rate. It is necessary to maintain the minimum fluidizing air flow rate for the fluidization of each particles.

4.3 Effect of electric field strength

Figure 9 shows the separation results of the cumulative extract content and yield as a function of electric field strength for a mixture of 50% PVC and 50% PS particles measured in each of the individual collection bin #1 to #5. The electric field strength is controlled by the high voltage power supply ranged from 0.7 to 2.6 kV/cm. The stronger the electric field strength is, the higher the separation efficiency is. The electric field strength has an influence on the electric force to charged particles in the electric field. An increase of the electric filed strength caused electric force to act on charged particles with their charge level



(a) PVC (b) PS

Fig. 8 Extract content and yield of PVC/PS as function of air flow rate

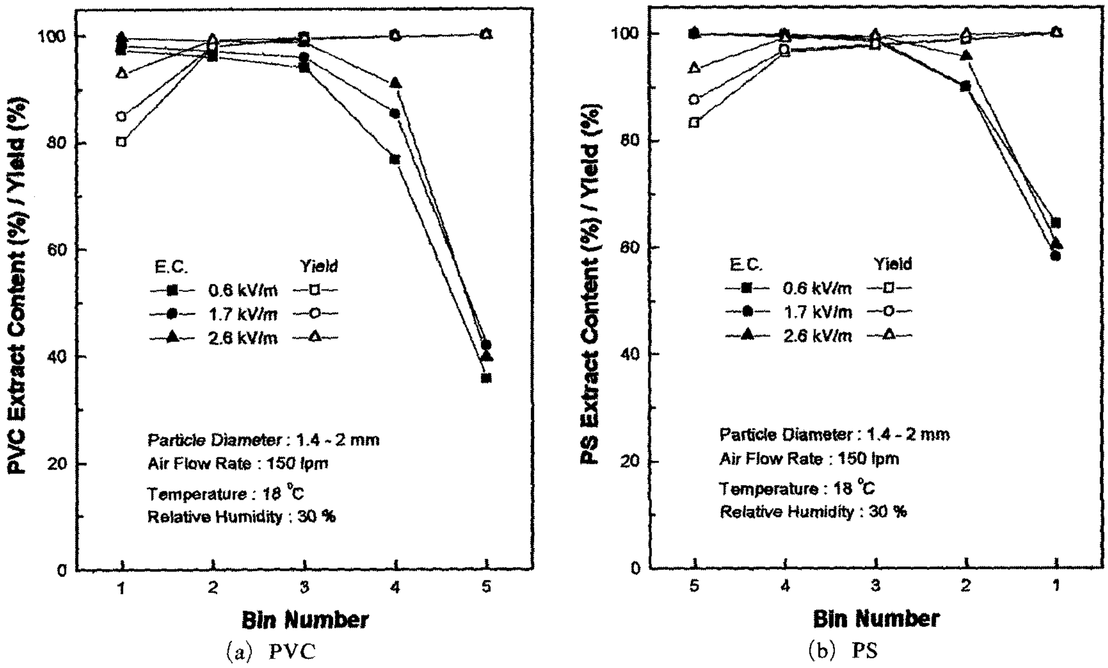


Fig. 9 Extract content and yield of PVC/PS as function of electric field strength

and polarity. In the optimal conditions with 150 lpm air flow rate and 2.6 kV/cm electric field strength, PVC material can be recovered 99.2% at the extract content of 99.1% in two bins #1 and #2, and PS material can be recovered 99.1% at the extract content of 99.7% in two bins #5 and #4 for a single stage of processing.

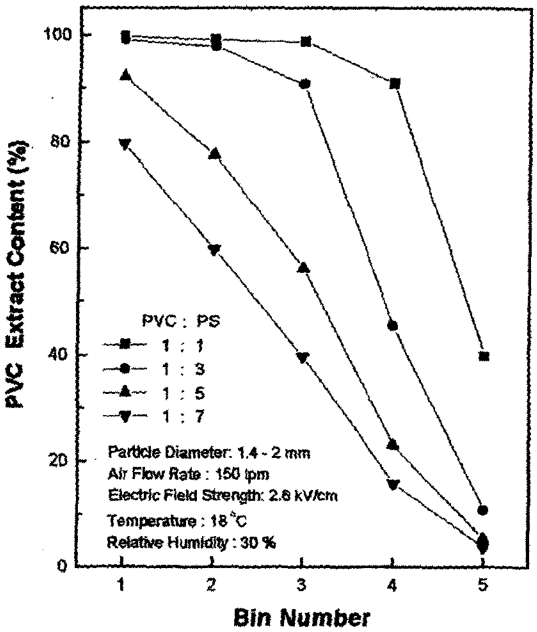
4.4 Effect of particle mixing ratio

Figure 10 shows the separation results of the cumulative extract content and yield as a function of particle mixing ratio for a mixture of PVC and PS particles measured in each of the individual collection bin #1 to #5. The mixing ratio of PS to PVC particles ranges from 1 to 7. The particle mixing ratio has an influence on the charging mechanism between particles inside the fluidized bed tribocharger. In the bins #1, #2 of the Fig. 10 (a) and (b), the yield of PVC particle is >99%, but the extract content is decreased from 99% to 60% as the particle mixing ratio is increased. And, in the bins #4, #5 of the Fig. 10(c) and (d), the extract content of PS particles is greater than 99%, but the yield is decreased from 99% to 94%. This result means that some of PS particles be come negatively charged by the triboelectrification between PS particles as the mixing ratio of PS to PVC particle is increased in the fluidized-bed tribocharger.

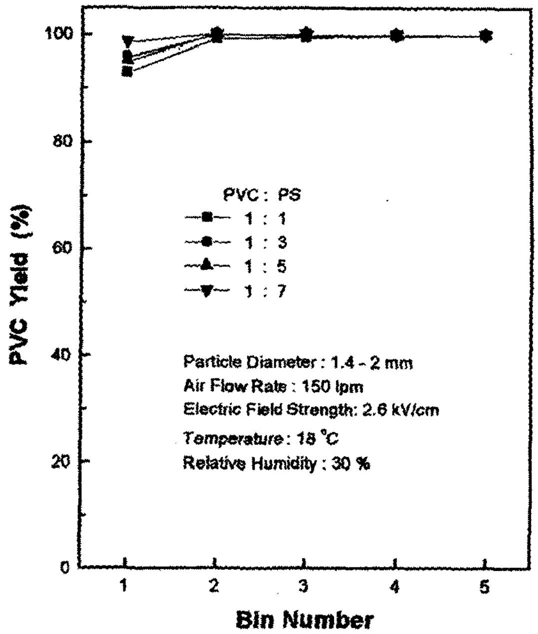
In the optimal conditions with 150 lpm air flow rate, 2.6 kV/cm electric field strength and 1 : 1 particle mixing ratio, PVC material can be recovered 99.2% at the extract content of 99.1% in two bins #1 and #2, and PS material can be recovered 99.1% at the extract content of 99.7% in two bins #5 and #4 for a single stage of processing. Therefore, in the practical application of triboelectrostatic separation system using the fluidized-bed tribocharger, the mixing ratio of the mixed plastic particles should be investigated according to the ratio of the waste plastic generation.

5. Conclusions

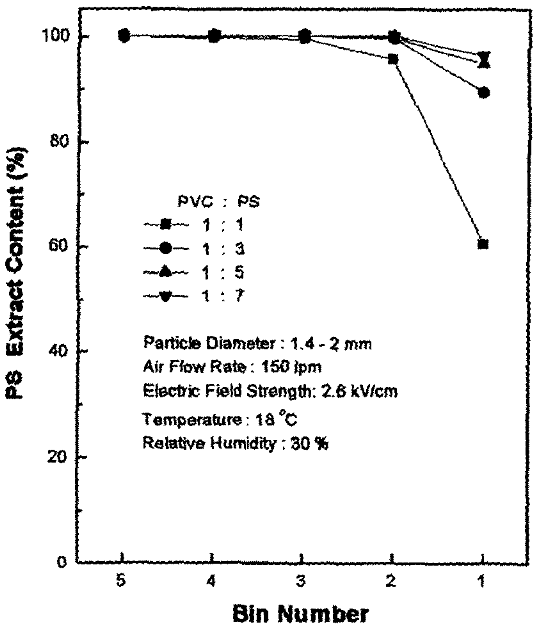
The triboelectrostatic separator using the fluidized-bed tribocharger has been investigated. Optimal conditions for maximizing the separation efficiency from the mixed PVC and PS plastics have been found experimentally. Results show



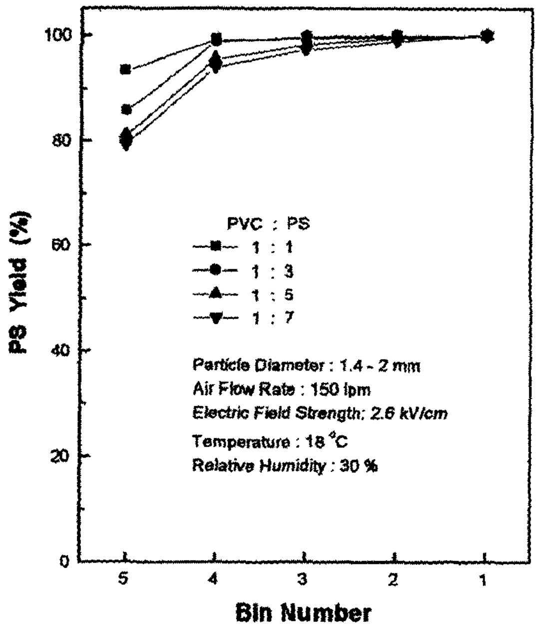
(a) PVC extract content



(b) PVC yield



(c) PS extract content



(d) PS yield

Fig. 10 Extract content and yield of PVC/PS as function of particle mixing ratio

that separation efficiency is strongly dependent on the electric field strength and particle mixing ratio. In the optimum conditions of 150 lpm air flow rate and 2.6 kV/cm electric field strength, a highly concentrated PVC (99.1%) can be recovered with a yield of about 99.2% from the mixture of PVC and PS materials for a single stage of processing. 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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