Vibro-Electrostatic Separation of Binary ABS/PS Granular Mixtures

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Abstract. This paper presents the results of experimental studies of the performance of a vibro-electrostatic plastic separator, which essentially consists of two plate electrodes undergoing translational harmonic vibrations along the horizontal plane. The principle behind the separation technique for such a separator is based on the difference between Coulomb forces acting on plastic particles after triboelectric charging. The separator has the advantages of a low-voltage field and a small structure over free-fall triboelectric separators. Separation tests were performed on binary mixtures. The effects of the feed composition of the mixtures and operating parameters, such as electric field strength, applied voltage polarity and triboelectric charging time, on separation efficiency were examined. This study was conducted to understand the effects of various parameters on separation efficiency, in order to obtain the optimum operating conditions for separators.

1. Introduction
In Japan, a new recycling law for electrical products has been enforced, which promotes accelerated recycling. Recently, most materials used in electrical products can be recycled in some firms that use excellent techniques. However, plastics cannot be recycled. This is because it is very difficult to separate mixed plastics. Thus, a technology for improved plastic separation is desired.

For the separation of mixed plastics, many experimental and analytical studies have demonstrated the effectiveness of free-fall triboelectric plastic separators for binary-component and multi component mixtures [1]-[7]. Although free-fall triboelectric separators have many advantages such as their simple construction, low energy consumption and high throughput, they require high voltages (usually 30-60kV) and large structures.

Recently, a novel vibro-triboelectric separator has been developed and its high plastic separation capability has demonstrated using plate like plastics [8]. The separator essentially consists of a vibratory conveyor equipped with two plate electrodes. The separator has the advantage of having a small structure compared with free-fall triboelectric separators. Since each plastic is separated on the inclined electrode, there is a fear that it is difficult to obtain high separation efficiency using easily rolling plastic particles. Therefore, to determine the feasibility of the vibro-triboelectric separator, it is necessary to investigate the effect of particle shape on the separation efficiency.

This paper presents the results of experimental studies of the performance of the vibro-triboelectric separator using easily rolling plastic particles. Separation tests were performed on binary plastic mixtures. The effects of the feed composition of mixtures and operating parameters, such as...
electric field strength, electrode slope and vibrating plate frequency, on separation efficiency were examined. This study was conducted to understand the effects of various parameters on separation efficiency, in order to obtain the optimum operating conditions for separators.

2. Vibro-electrostatic separation

Figure 1 shows a model of the vibro-triboelectric separator. The X-Y plane is parallel to the horizontal plane. Two inclined electrodes are fixed on the vibrating triangular plate. The slope $\theta$ of the electrodes is smaller than the angle of the static friction between each electrode and the plastics to be separated. The vibrating plate with the electrodes undergoes translational harmonic vibrations (amplitude $a$ and frequency $f$) at an angle $\alpha$ to the X-axis. The upper electrode is subjected to a constant negative voltage and the lower electrode is grounded. Suppose that particles A and B become positively and negatively charged, respectively, using the triboelectric charger. When a charged particle A is fed to the lower electrode, particle A is attracted toward the upper electrode owing to the Coulomb force and is repelled by the lower electrode. A negatively charged particle B is attracted toward the lower electrode and then conveyed along the lower electrode owing to the vibration. Therefore, particle A is separated from particle B because of the difference in their trajectories. This approach, which utilizes a vibratory electrode, makes it possible to prevent the adhesion of oppositely charged particles and to utilize a low-voltage field compared with that used in conventional triboelectric separators.

3. Experimental apparatus

This experiment was performed to verify the validity of the separation method using easily rolling
plastic particles. In this study, virgin acrylonitrile butadiene styrene (ABS) and virgin polystyrene (PS) particles were used as particles to be separated. All the plastic particles are cylinders with a radius of about 3mm and a height of about 3mm. Each plastic particle weighs about 30mg.

Figure 2 shows the rotating cylinder used for tribocharging the particles. The rotating cylinder, which is made of ABS, has an interior diameter of 80mm and a length of 100mm. Four ABS plates, each with a length of 96mm, a width of 10mm, and a thickness of 7mm, are situated on the inside surface of the cylinder. Prior to each experiment, the plastics were pretreated using a dryer for 5 minutes to ensure equilibrium conditions.

Figure 3 shows the experimental apparatus used for separating the plastic particles. The separation unit equipped with two plate electrodes is attached to a vibrating shaker, which is inclined to the horizontal plane at an angle $\alpha$. The distance between the two electrodes is 20mm. The collection system, which consists of eleven collection trays, is also attached to the separation unit, as shown in Figure 4.

Figure 3. Experimental apparatus

Figure 4. Collection trays

The procedure for separation is described. Known quantities of feed materials (30 grams of each) were placed into the ABS cylinder for triboelectric charging, as shown in Figure 2. Charged particles were then fed into the separation unit, as shown in Figure 3. After collecting the plastic particles that fell into each collection tray, the plastic particles in each collection tray were weighed. All experiments were carried out at room temperature and relative humidity less than 41%.
4. Experimental results
Separation efficiency can be evaluated on the basis of purity and recovery rate. These terms are defined as follows.

For ABS in tray A

\[ \text{Purity} = \frac{\text{Mass of ABS in tray A}}{\text{Total mass in tray A}} \]  \hspace{1cm} (1)  

\[ \text{Recovery rate} = \frac{\text{Mass of ABS in tray A}}{\text{Total mass of feed material ABS}} \]  \hspace{1cm} (2)  

For PS, purity and recovery rate were calculated by replacing ABS with PS in Equations (1) and (2).

Figure 5 shows typical examples of the amounts of ABS and PS recovered from each of the collection trays. \( T_c \) and \( \omega \) are the triboelectric charging time and rotation speed of the cylinder for triboelectric charging, respectively, as shown in Figure 2. Most ABS particles were collected in trays
1-5 and most PS particles were collected in tray 11. It is clear, therefore, that ABS particles can be separated from the ABS and PS mixture.

Figures 6 (a) and (b) show the effects of voltage on the amounts of ABS and PS recovered from each collection tray. As shown in Figure 6 (a), for 7kV, the largest amount of ABS is collected in tray 5. At voltages larger than 7kV, the largest amount of ABS is collected in tray 2. This is because the Coulomb force acting on the ABS particles increases with increasing voltage. In the range of voltages used, the amount of PS in each collection tray is independent of voltage. The reason for this is that the slope $\theta$ of the lower electrode is smaller than the angle of static friction between PS and the lower electrode.

Figures 7 show the effect of the slope $\theta$ on the amounts of ABS and PS recovered from each collection tray. The amounts of ABS recovered from trays 1-4 are smaller at $\theta = 8^\circ$ than at $\theta = 10^\circ$. The phenomenon occurs because the normal force $R$ acting on ABS particles decreases with increasing $\theta$. The amount of PS recovered from tray 11 is smaller at $\theta = 8^\circ$ than at $\theta = 10^\circ$. The reason for this is that some PS particles adhered to the lower electrode at $\theta = 8^\circ$.

Figures 8 show the effects of the separator vibration frequency on the amounts of ABS and PS recovered from each collection tray. The amounts of ABS recovered from trays 3-5 are smaller at 30Hz than at 36Hz. This is because it is easy for the ABS particles to be conveyed at high frequencies. The amount of PS recovered from tray 11 is larger at 36Hz than at 30Hz. The reason for this is that some PS particles adhered to the lower electrode at 30Hz.
Figure 9 shows the effects of the feed composition of the plastic mixtures on the amounts of ABS and PS recovered from each collection tray. In the range of the feed compositions of the mixtures used, the amounts of ABS and PS in each collection tray are independent of the feed composition. It is expected, therefore, that for the feed composition used, the new separation method makes it possible to obtain high separation efficiency.

After considering numerous experimental results, trays 1-5 and 10-11 were designated for the collection of ABS and PS, respectively.

Table 1. Optimum experimental result

| Purity (%) | Recovery rate (%) |
|------------|------------------|
| ABS        | 99.1             | 96.2           |
| PS         | 99.6             | 91.0           |

Table 1 shows the optimum result obtained in the experiment. It is possible to obtain high purities and recovery rates of ABS and PS for a low-voltage field.

5. Conclusions

The triboelectric separation of a binary plastic mixture was investigated experimentally using a vibro-triboelectric separator. It is possible to obtain a high purity and a high recovery rate using easily rolling plastic particles. It was found that the separator has the advantage of a low voltage field compared with conventional triboelectric separators, and that the separation efficiency of this separator depends on electrostatic field strength and other operating parameters.

To develop a practical separator, it is necessary to test the various shredder residues.

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