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PVC removal from mixed plastics by triboelectrostatic separation

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Abstract

Ever increasing oil price and the constant growth in generation of waste plastics stimulate a research on material separation for recycling of waste plastics. At present, most waste plastics cause serious environmental problems due to the disposal by reclamation and incineration. Particularly, polyvinyl chloride (PVC) materials among waste plastics generates hazardous HCl gas, dioxins containing Cl, and so on, which lead to air pollution and shorten the life of incinerator, and it makes difficultly recycling of other plastics. Therefore, we designed a bench scale triboelectrostatic separator for PVC removal from mixed plastics (polyvinyl chloride/polyethylene terephthalate), and then carried out material separation tests. In triboelectrostatic separation, PVC and PET particles are charged negatively and positively, respectively, due to the difference of the work function of plastics in tribo charger of the fluidized-bed, and are separated by means of splitter through an opposite electric field. In this study, the charge efficiency of PVC and PET was strongly dependent on the tribo charger material (polypropylene), relative humidity (below 30%), air velocity (over 10 m/s), and mixture ratio (PET:PVC = 1:1). At the optimum conditions (electrode potential of 20 kV and splitter position of −2 cm), PVC rejection and PET recovery in PET products were 99.60 and 98.10%, respectively, and the reproducibility of optimal test was very good (±1%). In addition, as a change of splitter position, we developed the technique to recover high purity PET (over 99.99%) although PET recovery decreases by degrees.

Keywords: Waste plastics; Recycling; Triboelectrostatic; Tribo charger; PVC rejection

1. Introduction

Plastics are excellent and very useful material to replace ceramic, wood and metals because they are very functional, hygienic, light and economical. Therefore, uses of plastics are increasing more and more every year. Korea is one of the major producers of plastic in the world with total production capacity of around 11 million t/year owing to the development of oil industry [1]. USA, Europe and Japan together generate about 50 million t of post consumer waste plastics every year [2,3]. The generation of waste plastics in Korea is about 4 million tonnes every year with a small portion being recycled (<30%) [4,5]. Hence, development of material separation technique for recycling of waste plastics is a necessary situation. At present, most waste plastics are disposed by reclamation and incineration. Such a disposal of waste plastics has become a major environmental problem all over the world. Traditional waste plastic disposal, in fact, could lead to the release of hazardous substances either by weathering and natural drying or by incineration processes. Reclamation could cause the release of plastic additives such as phthalates and various dyes polluting ground water [6]. Incineration is an alternative to reclamation disposal of waste plastics, but this practice could result in the formation of unacceptable emissions of gases such as nitrous oxide, sulfur oxides, dusts, dioxins and other toxins [7].

Especially, waste plastics containing PVC pollute the environment and shorten the life of incinerator as generating hazardous HCl gas, dioxins containing Cl, etc. Also, PVC materials not only creates difficulty in recycling process, but also decreases recycling ratio of plastics, by forming compounds or deteriorating the nature of other materials even if a very small quantity of PVC is present in main a plastic [3,8–10]. Therefore, the development of material separation technique for PVC removal from waste plastics needs attention.

Waste plastics must be separated and concentrated for their reusing or recycling. Hence, many efforts to find the proper

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physical method have been attempting for a long time. In general, physical separation techniques that can recycle the mixed plastics are classified by electrostatic separation, dry and wet gravity separation, froth flotation, NIR and color sorting [2,10–13]. Gravity separation is difficult for materials of similar specific gravity, such as PVC and PET [11]. Froth flotation has the problem of waste water disposal by agents. Also, NIR and color sorting is not a perfect technique because it is difficult to separate the mixed plastics having similar properties such as same color and peak [2]. The electrostatic separation methods that can separate the mixed materials are corona discharge, induction electrostatic and triboelectrostatic. Corona discharge and induction electrostatic can separate a mixture of conductor/non conductor; whereas, triboelectrostatic method has the advantage of separating different types of materials [13–16]. Tribo charging phenomenon is utilized in numerous technical applications, such as electro-photography, electrostatic copy and printing techniques, electrostatic filtration, precipitation and coloring. Also, this separation has been used processing of valuable mineral, coal and fly ash [6,17].

The triboelectrostatic separation is a method that separates the particles charged by means of particle/particle and particle/charger charging mechanisms, due to its work function or tribo series of materials through electric field [14,18]. Table 1 shows the relative tribo charging series of common plastics [19,20]. Tribo series show the degree of work function of materials. When two materials are brought into contact or collision, charge transfer can occur between them until their fermi levels equalize by the work function difference between the two materials. Then, material with high work function and low work function are charged positively and negatively, respectively and negatively charged material is moved toward positive electrode, and positively charged material is moved toward negative electrode [10,21]. In triboelectrostatic separation, the selective charging and optimum charge density of materials are most important parameters. Therefore, this separation method can improve separation efficiency according to development of charging material and tribo charger. Triboelectrostatic separation is much cheaper and the separation efficiency is much better than that using the above mentioned classical separation methods [15–19].

The aim of this study is to remove PVC from mixed plastics (PVC/PET) using fluidized bed tribo charger (pipe line). Hence, we designed a bench scale triboelectrostatic separator unit and thus investigated the charge polarity and charge density of PET, PVC on charging materials and various factors such as charging materials, air velocity (the impact of collision or contact), mixture ratio, relative humidity effecting on charge efficiency. Also, we standardized the optimal electrode potential and splitter position effecting on the separation efficiency in triboelectrostatic separator. In addition, we confirmed a recovery possibility of high purity PET and the reproducibility of optimum test.

2. Experimental

2.1. Materials

The samples used in this study were well-defined virgin polyethylene terephthalate (PET) and polyvinyl chloride (PVC) which containing a minimum amount of additives and impurities. The samples were shredded by a cutting mill ('pulverisette 19') provided by FRITSCH GmbH, Germany and then a representative fraction of the plastics was sieved as a size fraction of $-2.0+1.6$ mm. The charged plastic particles by cutter of cutting mill neutralized the initial charges on each particle by means of air ions produced by discharger (Kasuga Denki Inc., Japan). Nine kinds of materials, namely polytetrafluoroethylene (PTFE), polyvinyl chloride (PVC), polypropylene (PP), high density polyethylene (HDPE), polystyrene (PS), polyethylene terephthalate (PET), acrylonitrile butadiene styrene (ABS) and polymethyl methacrylate (PMMA) were used as material for tribo charger in the charging material selection test.

2.2. Method

The aim of our work was focused to investigate the charging property of plastics and PVC removal from mixed plastics. Hence, it was important to use a charging unit and a separator that were able to charge and separate quantities of those substances. Fig. 1 shows a schematic diagram of triboelectrostatic separator and peripheral equipments used in this work. It is consisted of feeding zone ((6)–(9)), charging zone (1), and separation zone ((2)–(5)). A various dimensions of electrode, pipe line and splitter were the following: electrode of the screen mesh type (diameter: 1 mm, covering: 15 mm), distance between the electrodes (the upper: 50 mm, the lower: 280 mm), electrode length 450 mm, electrode width 260 mm, electrode angle to vertical axis 10°, total length of the pipe line 1660 mm, pipe line diameter 16 mm, splitter length 260 mm, splitter width 260 mm and splitter diameter 10 mm. The air-conditioning system supplies necessary an air for moving and fluidization of the plastic samples at a certain relative humidity and temperature. The plastic of 20 g is provided into pipe line with an air, and then the charged particles are deflected under the influence of the electric field between the electrodes that are connected to the high-voltage power supply (±30 kV). The charge of particles that were collected in the faraday cups are induced into faraday cup and then an electrometer measures the induced charges. The weight of particles was measured by electronic balance. Hence, the charge density was determined by charge to mass ratio (nC/g) [26]. Faraday cage (10) used in this study was MODEL of KQ-

Table 1
Tribo series of plastics

Material	PUR	PMMA	ABS	PC	PS	RUBBER	PET	HDPE	LDPE	PP	PVC	PTFE
Series	+ (more positive) ←										→ (more negative) −	

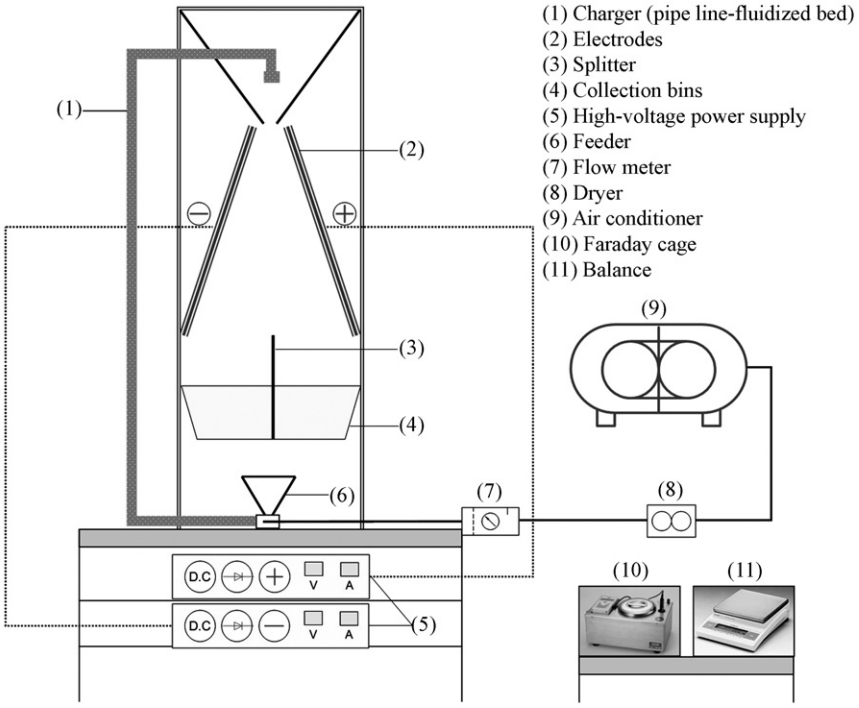

Fig. 1. Schematic diagram of triboelectrostatic separator and peripheral equipments.

1400 (Japan) and measurement range was ±1 nC ∼ ± 9999 nC (NK-1002). Electronic balance (11) was BP 2100s of SARTORIUS.

Fig. 2 shows a flowsheet used in this study for a material separation of mixed plastic. The sample was charged with moving to electrical field by air after the particle crushed to optimum size. Particles the charged by tribo charger was separated by each material when the mixed plastic pass in 20 kV field. In this study, we tested various factors, such as charging materials, relative humidity, air velocity, and mixture ratio influencing to a charge density (nC/g). In addtion, we have studied the separation efficiency of PVC, PET as a function potential difference and splitter position.

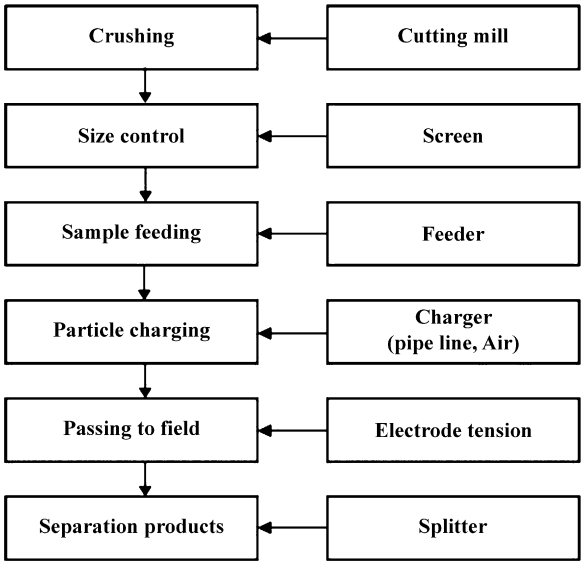

Fig. 2. Flow sheet of triboelectrostatic separation unit.

3. Results and discussion

3.1. Charging property

As discussed above, triboelectrostatic separation of plastics is important to optimize the charge density (nC/g) and selective charging on plastics. Hence, we investigated the charge polarity and charge density of plastics on charging materials and several factors. Figs. 3–5 show results of the charging property test on PET and PVC plastics. First of all, Fig. 3 shows the result of the charging material selection test on PET and PVC plastics. PET and PVC were charged in various charging materials (PTFE, PVC, PP, HDPE, Cu, PS, PET, ABS, PMMA). It was maintained at relative humidity of 30%, air velocity of 10 m/s, and then the charge polarity and charge density were measured by faraday cage. The results show, PET and PVC are charged positively and negatively, respectively, in charging materials of PVC, PP, HDPE, Cu, PS, but they are charged to the same polarity in those of PTFE, PET, ABS, PMMA. The reason is attributed to the work function of PP, HDPE, Cu and PS, which are laid between PVC and PET in the tribo-series [19,20]. Especially, in the chargers made of PP, HDPE, Cu and PS, difference of charge density of PET and PVC is the maximum in that of PP. For example, in case of PP charging material, charge density of PET and PVC was +8.0 and −15.0 nC/g, respectively, and difference of charge density of PET and PVC was 13.5 nC/g. Therefore, we selected charger made of PP for further separation test of PET and PVC.

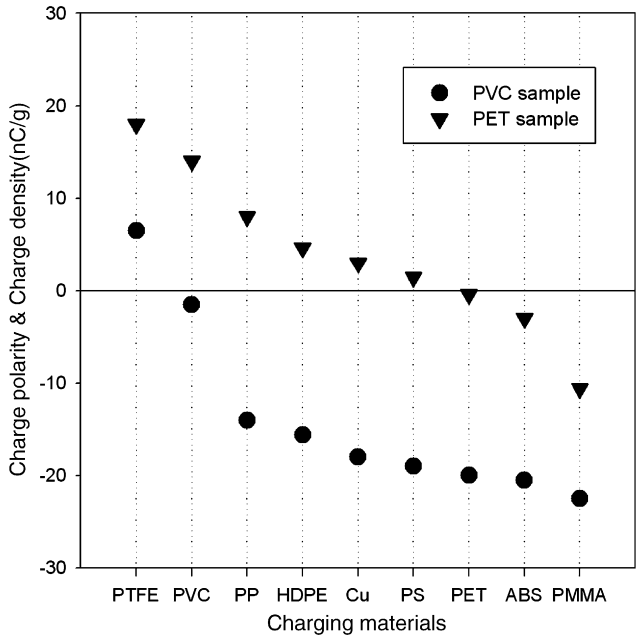

Fig. 3. The charge polarity and density of PVC and PET on charging materials.

Fig. 4 shows the effect of relative humidity on the charge density of PET and PVC in tribo charging test using PP charger. This test was carried out at the relative humidity of 20–70% and an air velocity of 10 m/s. The charge density of PVC and PET decreases as the relative humidity increases; in the opposite direction, it increases as the relative humidity decreases. The charge density of PET and PVC was over +33.0 and −32.0 nC/g, respectively, when the relative humidity was below 30%. The relative humidity influence on the charging and discharging behavior of plastics can be explained by the formation of water films onto plastic surfaces. Tribo charging test in higher relative humidity shows that water can either form adsorption layers onto plastic surfaces or swell the plastic surface. Erno Nemeth [22] reported that, water molecular in atmosphere can discharge for charged plastic as adsorbs or makes layer onto the plastic surface. Also, ions are formed by the auto-dissociation of water and impurities may be solvated and mobilized by water molecules. All ions act as charge carriers that generate a current decreasing the surface resistivity that causes to exchange and discharge effects of the charged plastic particles. Change of the charge density by relative humidity is because water disturbs surface polarization between particles or reduces the charge density discharging the charged particles, on the other hand, according to change of relative humidity can change the charge polarity. In this study, we found that the relative humidity affects absolute for the charge density and the charge polarity of PET and PVC. As expected, the separation efficiency decreases as the relative humidity increases, probably due to the discharge of the electron through the moisture attached on the surface. Therefore, it can be concluded that the relative humidity is very important factor for tribo charging and separation of the mixed samples in triboelectrostatic separation.

Fig. 5 shows the effect of air velocity on tribo charging properties of particle/charger (PET/PP charger, PVC/PP charger) and particle/particle (PET/PVC). This test was carried out injecting single PET, PVC, and mixture of PET/PVC (PET:PVC = 1:1), into PP charger at the relative humidity of 30%. In the charge density measurement of mixed sample, charged particles are separated in high voltage of over 30 kV, and then particles of a different kind in each product are rejected by sticks made of Teflon. As shown Fig. 5, the magnitude of charge density increases with increasing air velocity. The reason is, an increase of air velocity in fluidized bed causes an increase in the impact

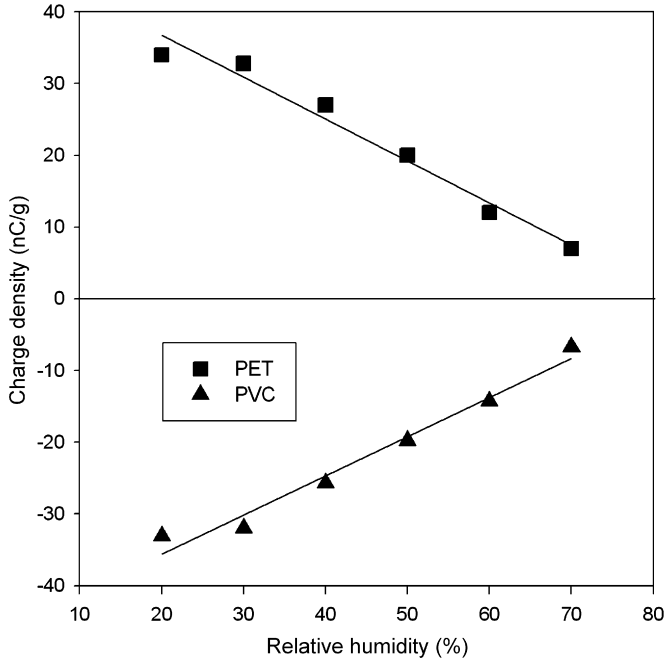

Fig. 4. The effect of relative humidity on charge polarity and density of PVC and PET.

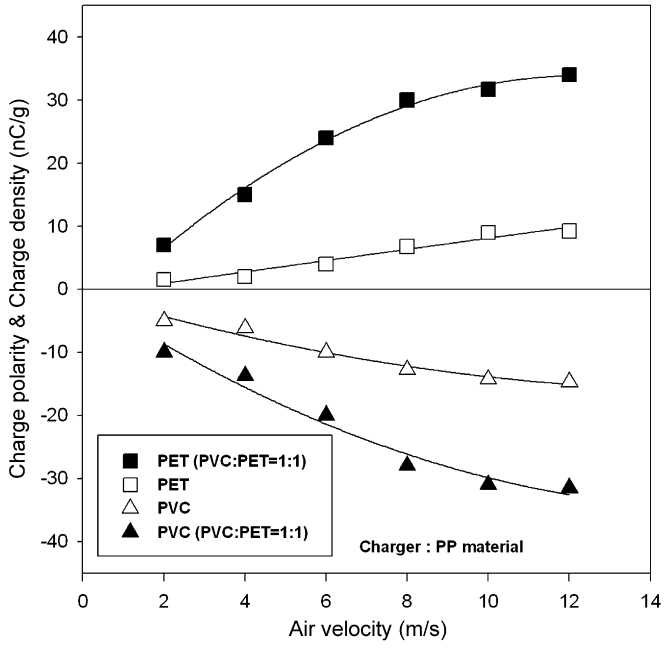

Fig. 5. The charge polarity and density of PVC and PET on single versus mixed samples.

force and frequency between the particles and their contacting surfaces [13,14,23]. More importantly, Fig. 5 proves that charging mechanism of particle/particle is more effective than that of particle/charger. Tribo charging of between mixture of PET and PVC, namely the charge density of PET and PVC by contacting or collision of particle-to-particle was +32.8 and −31.0 nC/g, respectively, at the air velocity of 10 m/s. On the other hand, in case of single PVC, PET by contacting or collision of particle-to-charger was +8.80 nC/g and −14.30 nC/g, respectively. Therefore, the charge density of PET in mixture of PET/PVC (PET:PVC = 1:1) is three times higher than single PET, and PVC in mixture of PET/PVC is two times higher than single PVC. The reason is the difference of work function value of PET and PVC is much large than that of PET and PP, PVC and PP [19,20].

3.2. Separation properties

Plastics charged in tribo charger are separated by the splitter position and the electric field of electrodes in triboelectrostatic separator. Hence, we investigated the effect of the electrode potential and splitter position for PVC rejection from mixture of PET/PVC. As previously shown in charging property tests, PET and PVC are charged positively and negatively, respectively. If the charged particle is approximated into electric field, which formed between electrodes, electrostatic force is interacted by Coulomb's law [21]. Therefore, the charged PET and PVC will be deflected toward negative and positive electrode, respectively. Fig. 6 shows PVC rejection and PET recovery as a function of the electrode potential. This test was carried out at the charger made of PP, mixture ratio of PET/PVC (PET:PVC = 1:1), air velocity of 10 m/s and relative humidity of 30%. The PVC rejection and PET recovery increase as the electrode potential increases. For example, PVC rejection and PET recovery were 89.80 and 78.50%, respectively, at 5 kV. It appears that the electrode potential of 5 kV is not strong enough to pull the charged particles toward the electrodes. The best results were obtained at 20 kV and at this time, PVC rejection and PET recovery were 99.60 and 98.10%, respectively. The results show that PET recovery and PVC rejection curves shift considerably depending on the potential of the electrodes. The charged particle and electrode potential have affinity mutually in the separation efficiency. If the charge density of particle is high, it easily can be deflected by energy of low electrode potential, relatively. If the charge density of particle is low, it can be deflected when approve by energy of high electrode potential for increasing the separation efficiency. Therefore, we confirmed that development of charger and charge technology to maximize the charge density of particle can improve the separation efficiency.

Fig. 7 shows PVC rejection and PET recovery as a function of the splitter position. This test was carried out at the mixture ratio of PET/PVC (PET:PVC = 1:1), air velocity of 10 m/s, relative humidity of 30% and electrode potential of 20 kV using a charger manufactured by PP material. Also, sign of (−) cm and (+) cm of the splitter position in Fig. 7 signify moving direction from center to the negative electrode and the positive, respectively. As shown in Fig. 7, PVC rejection increases as the splitter position moves to the negative electrode from center, and PET recovery increases as the splitter position moves to the positive electrode from center. The falling position of particles changes as charge density of particles charged according to charging factors (tribo series, mixture ratio, air velocity and relative humidity) under a definite gravity force, drag force and electrostatic force [14,24,25]. PVC particles which have high negative charge density are strongly deflected to positive electrode but some PVC

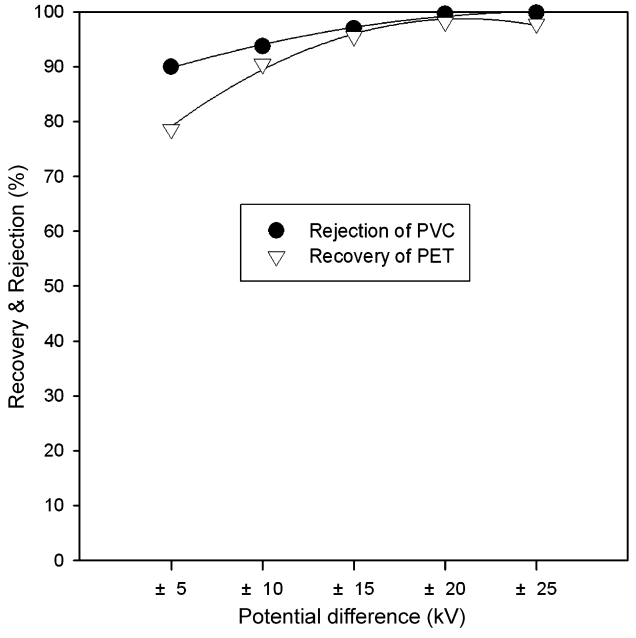

Fig. 6. The effect of the electrode potential on the separation efficiency of PET and PVC in triboelectrostatic separation unit.

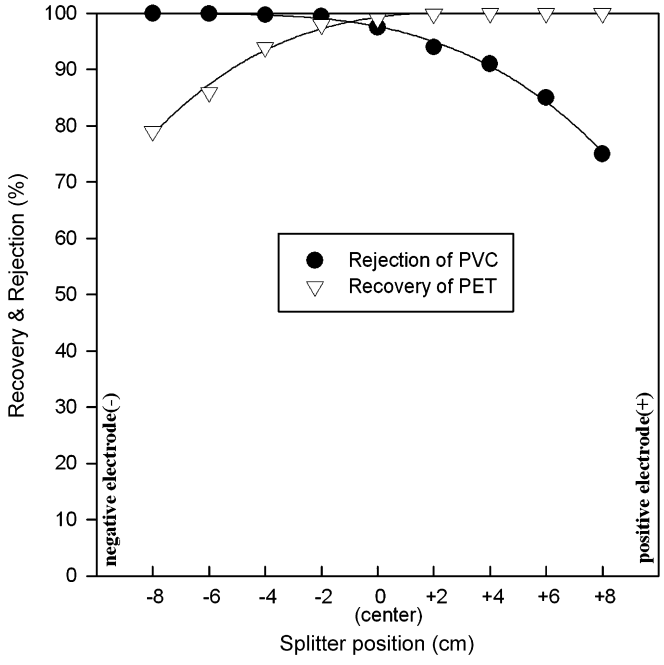

Fig. 7. The effect of the splitter position on the separation efficiency of PET and PVC in triboelectrostatic separation unit.

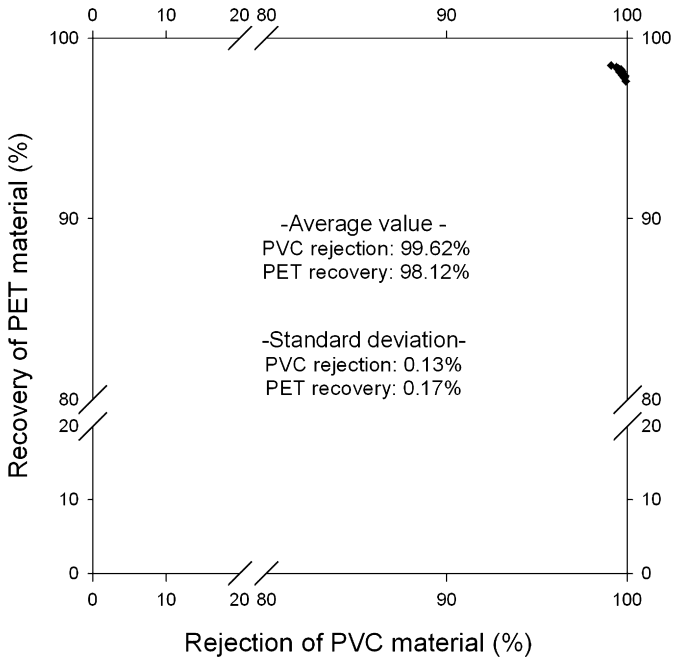

Fig. 8. Results of the reproducibility tests at optimum condition in triboelectrostatic separation unit.

particles which have low or neutral charge density fall freely or to the opposite side. Also, in case of PET, some PET particles are not deflected to negative electrode and behave similarly to PVC. Such behavior of particles deteriorates the separation efficiency of PVC/PET. Therefore, controlling the splitter position can improve the separation efficiency. Considering the results, in this study, the optimum splitter position was determined which moved 2 cm to negative electrode from center. At this condition, PVC rejection and PET recovery were 99.60 and 98.10%, respectively. As a change of splitter position, we recovered high purity PET (PVC rejection of over 99.99% in PET products) from position of −4 cm. The reason is because PET purity is differently demanded per recycling products. For example, PET bottle is demanded the purity of over 99.99%.

Fig. 8 shows the reproducibility on optimum test in triboelectrostatic separation for PVC removal from mixture of PET/PVC. These tests were carried out over 50 times at the mixture ratio of PET/PVC (PET:PVC = 1:1), air velocity of 10 m/s, relative humidity of 30%, electrode potential of 20 kV and splitter position of −2 cm using a tribo charger manufactured by PP material. The test results show that, the deviation between the measurements was negligible and the reproducibility was very good (±1%). Therefore, we obtained the base date for PVC removal from PET/PVC waste plastic.

4. Conclusion

For PVC removal from mixture of PET/PVC, we have designed a bench scale triboelectrostatic separator. The effects of several factors (charging materials, relative humidity, air velocity, the mixture ratio) on the charge polarity and charge density of plastics in tirbo charger and the effects of the electrode potential and splitter position on the separation efficiency have been studied.

In the charging properties, it was found that the charge polarity and charge density of PET and PVC were very effective at the tirbo charger made of PP, with the decrease of relative humidity, and with the increase of air velocity. The dominant charging mechanism in tribo charger was particle/particle (PET:PVC = 1:1) which is more efficient than particle/charger (PET/PP charger and PVC/PP charger) owing to tribo series. Hence, we confirmed that the charge polarity and charge density of PET and PVC can be improved by controlling these factors.

The separation efficiency of PET and PVC in triboelectrostatic separation unit increases as electrode potential increases and the splitter position moves to negative electrode from center. PET recovery and PVC rejection considerably depend on the electrode potential, which the optimal values of PVC rejection and PET recovery are achieved at 20 kV. As a change of splitter position, we developed the technique to recover high purity PET or to control the purity of products required when recycling of waste plastics.

The reproducibility of this study was very good. In future research, base on the systematic approach presented in this article, we will extend to various plastics separation processes.

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