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2段階 分離工程에 의한 3種 混合플라스틱의 摩擦荷電 靜電選別†

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Triboelectrostatic Separation of Mixed Three Kinds of Plastics by a Two-stage Separation Process†

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요 약

유사비중의 범위에 있는 PVC, PET and PMMA 3종 혼합플라스틱의 마찰하전 정전선별이 2단계 분리공정을 통하여 수행되었다. PVC, PET and PMMA의 재질분리에 있어 효과적인 하전장치의 재질은 Polypropylene(PP) 과 high-impact polystyrene(HIPS) 임을 확인하였다. PP 싸이클론 하전장치를 이용한 1단계 분리공정에서, PVC의 품위와 회수율은 공기속도 10 m/s, 전기장의 세기 200 kV/m 이상, 분리대위치 +2cm, 상대습도 30% 이하의 조건에서 각각 99.6%와 97.5%로 구하였으며, HIPS 싸이크론 하전장치를 이용한 2단계 분리공정으로부터, 공기속도 10 m/s, 전기장의 세기 250 kV/m, 분리대 위치 0cm, 상대습도 40% 이하의 조건에서 PMMA의 품위와 회수율을 각각 97.8%와 95.12%로 구하였다.

주제어 : 폐기물, 재질분리, 폐플라스틱, 마찰하전, 정전기

Abstract

Triboelectrostatic separation of mixed three kinds of plastics, PVC, PET and PMMA, in the range of similar gravity has been performed through a two-stage separation process. Polypropylene (PP) and high-impact polystyrene (HIPS) were found to be the most effective materials for a tribo-charger in the separation of PVC, PET and PMMA. In the 1st stage using the PP cyclone charger, PVC grade and recovery depended considerably on the air velocity (10 m/s), the relative humidity (<30%), the electric field (>200 kV/m) and the splitter position (+2 cm from the center) in the triboelelctrostatic separator unit. At an optimum condition a PVC grade of 99.6% and a recovery of 97.5% was achieved. In the 2nd stage using the HIPS cyclone charger, a PMMA grade of 98.3% and a recovery of 97.0% was obtained under the conditions of 10m/s air velocity, over 250 kV/m electric field, central splitter position and less than 40% relative humidity.

Key words : waste; material separation; waste plastics; tribo-charging, electrostatic

1. Introduction

Plastics are excellent and very useful material to replace ceramic, wood and metals because they are very functional, hygienic, light and economical and thus their consumption is growing at a rate of around 5% per year. About 4 million tons of plastic wastes are generated every year in Korea, but only less than 30% of them are recycled[1,2]. Plastic wastes generated from automobiles, electric, electronic and IT fields as well as packaging materials, fluid containers, clothing and household products are constantly increasing due to the industrial development and short life span of these

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Table 1. Triboelectric series of plastics

Material	PVC	COPP	HOMOPP	LDPE	HDPE	PET	RUBBER	HIPS	Calibre	ABS	PMMA
Series	+ (more positive) ←								→ (more negative) −		

equipments[3-7]. The incineration and landfill of municipal solid wastes may cause environmental problems and become more expensive. In this regard, the disposal of plastic wastes has become an important issue all over the world due to their increasing volume and decreasing landfill capacity for disposal[8-9]. Thus, the development of material separation technique that can recycle plastic wastes as well as solve disposal problems is a growing necessity.

Physical separation techniques of mixed plastics are classified as electrostatic separation, dry and wet gravity separation, froth flotation, near infrared ray (NIR) and color sorting[10-11]. Wet gravity separation and froth flotation of plastic wastes are considered costly compared to dry separation. In a wet separation process, mixed PVC, PET, PMMA, rubber and PC may raise more difficulties due to similar specific gravity and flotation agents may cause water disposal problems[12]. NIR is a difficult task due to the close similarities between the materials and it needs a further reduction of shadow contributions, and stabilization of sensor or light source to obtain reproducible measurements and color sorting is not effective separation of particles having similar properties[13,14].

Tribo-charging occurs when particles are charged with opposite polarities by particle-particle and particle-surface charging mechanisms due to their work function[15-17]. In the process of tribo-charging, two materials that are brought into contact or collision can undergo charge transfer according to their work function difference until the point at which their Fermi levels equalize. The final charge will actually be the outcome of two processes: the charge transfer occurs during the contact between materials and the charge backflow also occurs as they separate[16]. Hence, the selective charging of materials is an important parameter and the triboelectric series is widely used as an indicator of selectively charging plastics in triboelectrostatic separation. The triboelectric series which represents the order of charge polarity of a plastic material may be arranged in Table 1[18].

Yanar[19] measured the charge to mass ratio of

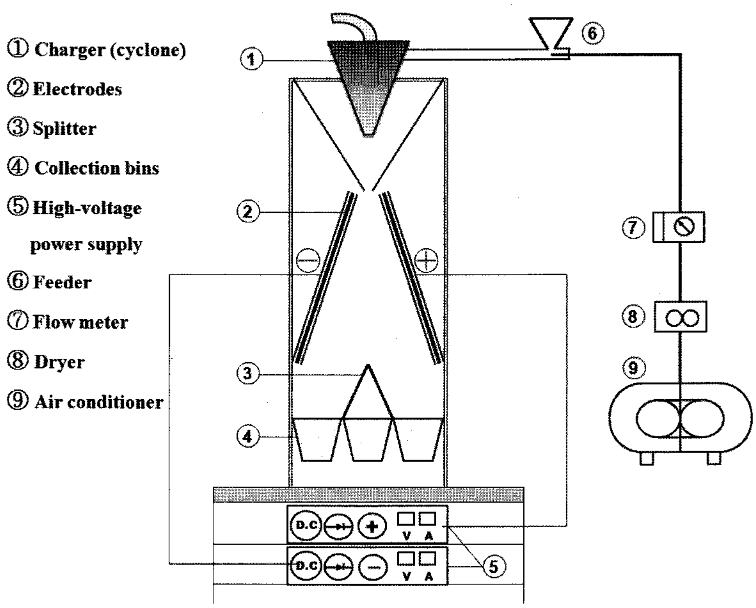

Fig. 1. Schematic diagram for a triboelectrostatic separator unit.

plastics with a copper cyclone, using a Faraday cage in consideration of air velocity and relative humidity. Inculet[20] separated PVC, Nylon, PE and acrylic using a fluidized bed and a rotating tube. Matsushita[21] separated PVC, PE, PP and PS using rotary blades. Fujita[22] and Higashiyama[23] measured the charge to mass ratio of plastics related to the material of a vibrating feeder. They reported that separation efficiency increased with decreasing relative humidity and with increasing air velocity and electric field.

This work aims at developing the effective triboelectrostatic separation technology of PVC, PET and PMMA by a two-stage separation process. Hence, we designed a laboratory scale triboelectrostatic separator unit including a fluidized bed cyclone tribo-charger and estimated a charger material affecting selective charging polarity and charge density of plastics. Furthermore, several factors such as air velocity, electrode potential, splitter position and relative humidity influencing the separation of plastics have been investigated.

2. Experimental

2.1. Materials

Polyvinyl chloride (PVC), polyethylene terephthalate (PET) and polymethyl methacrylate (PMMA) materials tested in this study were PVC pipe scrap, PET bottle and PMMA pellet obtained from a petrochemical plant, respectively. The samples were shredded using a cutting mill (pulverisette 19, Fritsch GmbH, Germany) and then a representative fraction of the plastics was

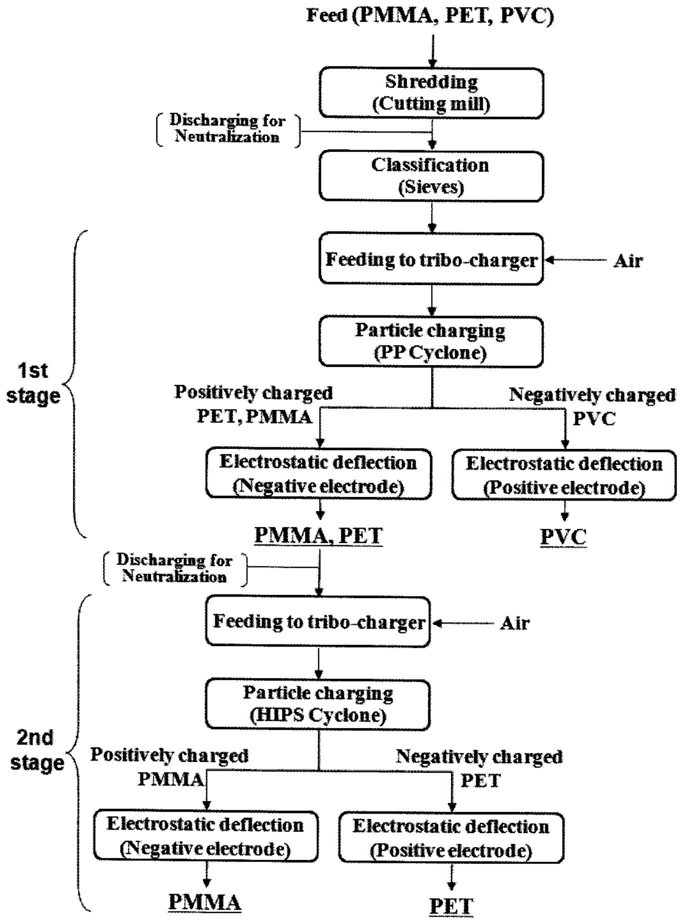

Fig. 2. Flowchart for material separation of three kinds of plastics (PVC, PET and PMMA).

sieved as –2.8+1.0 mm. Then, polypropylene (PP), high impact polystyrene (HIPS) were selected as a material of cyclone tribo-charger.

2.2. Separation Method

Triboelectrostatic separation systems were employed for the tests. Fig. 1 shows a schematic diagram of triboelectrostatic separator and peripheral equipments used in this work. It consists of feeding zone (⑥⑦⑧⑨), charging zone (①), separation zone (②③④), and collecting zone(⑤). After mixed plastics are fed into a cyclone with air, the plastics are charged with opposite polarity owing to the work function or triboelectric series in cyclone charger and then the charged particles are deflected under the influence of the electric field between the electrodes which are connected to a high-voltage power supply (±30 kV).

The charge of particles was measured with a Faraday cage. The Faraday cage used in this study was Model KQ-1400 (Kasuga Denki Inc., Japan) and a measurement range was ±1nC ~ ±9999nC. The weight of particles was measured with an electronic balance (BP 2100s, Sartorius). Hence, the charge density of particles was determined based on charge to mass ratio (nC/g). Fig. 2 shows a flow sheet for the separation of PVC, PET and PMMA in a 2-stage process. In the 1st stage, PVC was negatively charged and PET and PMMA positively charged by the charger. The negatively charged PVC particles were deflected to the positive electrode under the influence of the electric field between the electrodes and the positively charged PET and PMMA to the negative electrode. In the 2nd stage, The charged PET was deflected to the positive electrode and PMMA to the negative electrode.

Relative humidity was controlled with a dehumidifier (Model AD0502XA of Whirlpool corp., USA). Separated plastic particles were hand-picked under naked eyes and weighed. In addition, the data shown in figures are the average values from the tests repeated at least three times.

3. Results and Discussion

3.1. Selection of Charger material

The material of tribo charger is regarded as an important factor because the triboelectrification of particles is generated due to particle-particle and particle-surface charging mechanism in a tribo charger. Hence, a suitable charging material has to be selected in order that the mixed samples are charged either positively or negatively.

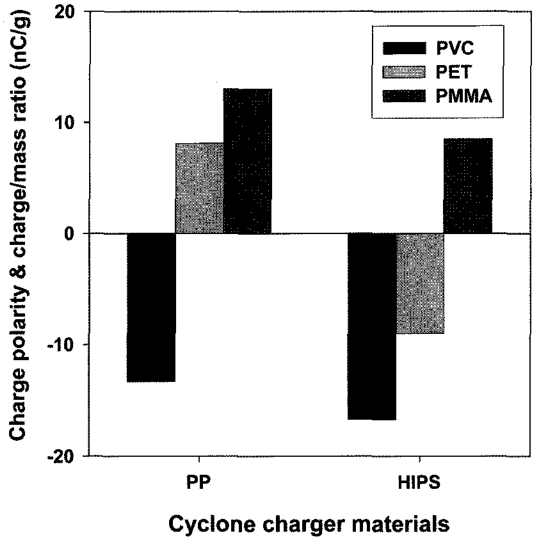

Fig. 3. Charge polarity & density of PVC, PET and PMMA as a function of charger materials (10 m/s air velocity and 30% relative humidity).

Fig. 3 shows the charge polarity and charge to mass ratio of PVC, PET and PMMA determined with the cyclone charger made of PP and HIPS materials. The charge to mass ratios of PVC, PET and PMMA in the PP charger were -13.3, +8.1 and +12.8 nC/g, and those in the HIPS charger -16.7, -9.0, and +8.5 nC/g. In case of using a PP charger, PVC is charged negatively because its work function is higher than that of PP, whereas PET and PMMA are charged positively with their work functions being lower than that of PP. This enables PVC to separate from PET and PMMA in the 1st stage. In case of using a HIPS charger, the charge polarity of PVC and PET is charged negatively because their work functions are higher than that of HIPS, whereas PMMA is charged positively with its work function being lower than that of HIPS. Thus, the PET can be separated from the PMMA in the 2nd stage.

3.2. Effect of air velocity

Fig. 4 shows the effect of air velocity on the net-

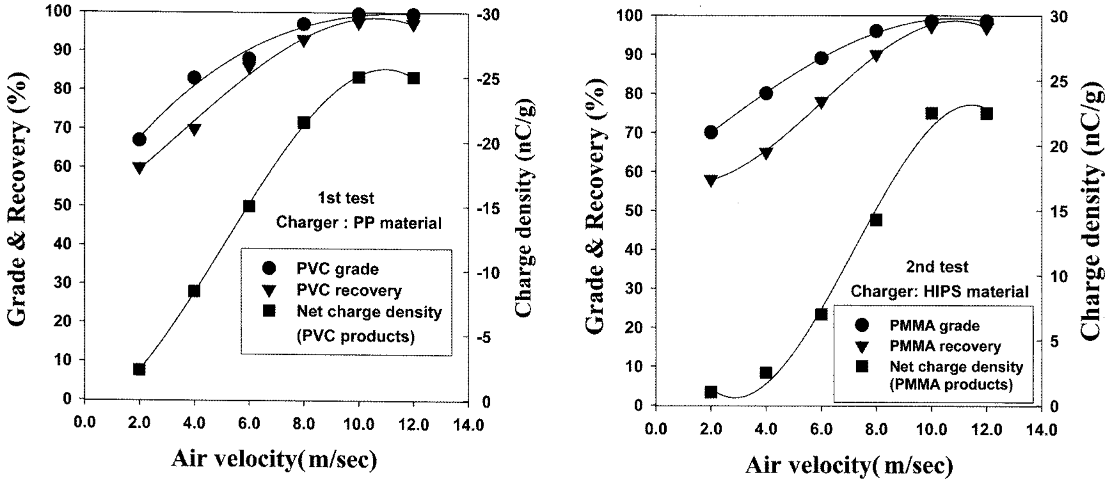

Fig. 4. Effect of the air velocity on the separation efficiency of plastics in triboelectrostatic separation unit (1 stage tests: 200 kV/m electric field, +2 cm splitter position and 30% relative humidity. 2 stage tests: 250 kV/m electric field, center(0) splitter position and 40% relative humidity).

charge to mass ratio and separation efficiency of plastics in a triboelectrostatic separation unit. In the 1st stage using a pp cyclone charger, the charge to mass ratio of PVC increased as the air velocity increased, having a saturation charge value of -25 nC/g at 10 m/s air velocity. An increase of air velocity in a fluidized bed may cause an increase in the impact force and frequency between particles and their contacting surfaces[24]. In case of the efficiency i.e. grade and recovery of PVC, it reached a maximum at 10 m/s air velocity and then decreased. It is plausible that the falling velocity of the particles increases with increasing the air velocity. Thus, some particles are moved toward the opposite collection bin after strongly colliding on the splitter or electrode and then both PVC grade and recovery decrease.

In the 2nd stage using a HIPS cyclone charger, the charge to mass ratio of PMMA increased with air velocity, being 22.5 nC/g at an air velocity of over 10m/s. The separation efficiency of PMMA increased as air velocity increased to 10 m/s and then PMMA grade remained constant but PMMA recovery somewhat decreased. When the charge densities in the 1st stage and 2nd stage are compared, the charge density in the 1st stage is higher than that in the 2nd stage because the work function difference between PVC and PP is larger than that of PET and HIPS.

3.3. Effect of electric field

The charged particles will be deflected primarily by electrostatic force and partly by gravity and drag force toward negative and positive electrodes and would fall with a parabolic trajectory[16,20]. Fig. 5 shows the effect of electric field on the separation efficiency of plastics in a triboelectrostatic separation unit. In the 1st stage, both of PVC grade and recovery increased as the electric field increased. At 50 kV/m electric field, the PVC grade and recovery were 77.5% and 62.1%, respectively. At 200 kV/m, 99.6% PVC grade and 97.5% PVC recovery were successfully obtained. The results show that the PVC grade and recovery increased with increasing electric field since the charged particle and electric field seem to be directly related to the separation efficiency.

In the 2nd stage, both the PMMA grade and recovery also increased as the electric field increased. At 250 kV/m, the maximum PVC grade and recovery were 98.5% and 97.3%, respectively. The results indicate that the PMMA grade and recovery curves shift considerably, depending on the electric field. The optimum PVC separation efficiency in the 1st stage was obtained at 200 kV/m, whereas that of PMMA in the 2nd stage at 250 kV/m. This is attributed to the charge to mass ratio (-25.0 nC/g) of PVC larger than that (22.5 nC/g) of PMMA as mentioned in Fig. 4.

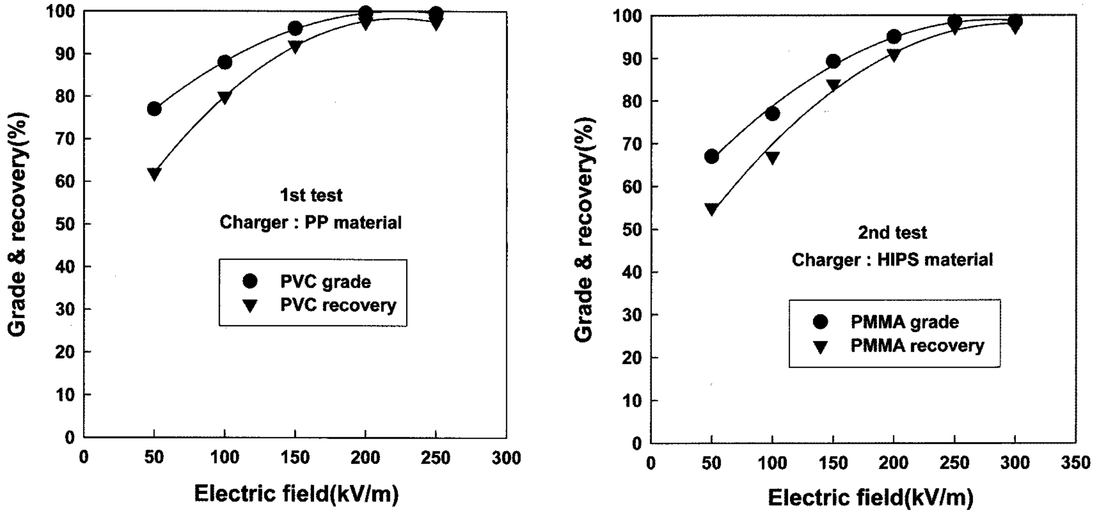

Fig. 5. Effect of the electric field on the separation efficiency of plastics in triboelectrostatic separation unit (1 stage tests: 10 m/s air velocity, +2 cm splitter position and 30% relative humidity. 2 stage tests: 10 m/s air velocity, center(0) splitter position and 40% relative humidity).

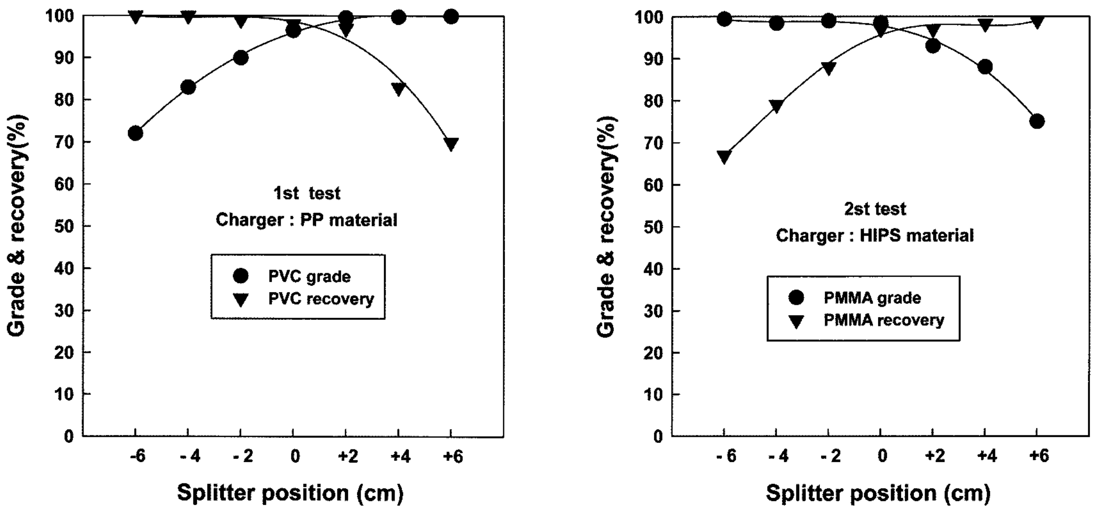

Fig. 6. Effect of the splitter position on the separation efficiency of plastics in triboelectrostatic separation unit(1 stage tests: 10 m/s air velocity, 200 kV/m electric field and 30% relative humidity. 2 stage tests: 10 m/s air velocity, 250 kV/m electric field and 40% relative humidity).

3.4. Effect of splitter position

Fig. 6 shows the effect of splitter position on the separation efficiency of plastics in a triboelectrostatic separation unit. As shown in the 1st stage, PVC grade increased as the splitter position was moved from the negative electrode to the positive one, and PVC recovery increased as the splitter position was moved from the positive electrode to the negative one. The falling position of particles can vary, depending on charging factors such as the work function, charger material, mixture ratio, air velocity and relative humidity under a definite gravity force, drag force and electrostatic force[19-24].

PVC particles which have high negative charge to

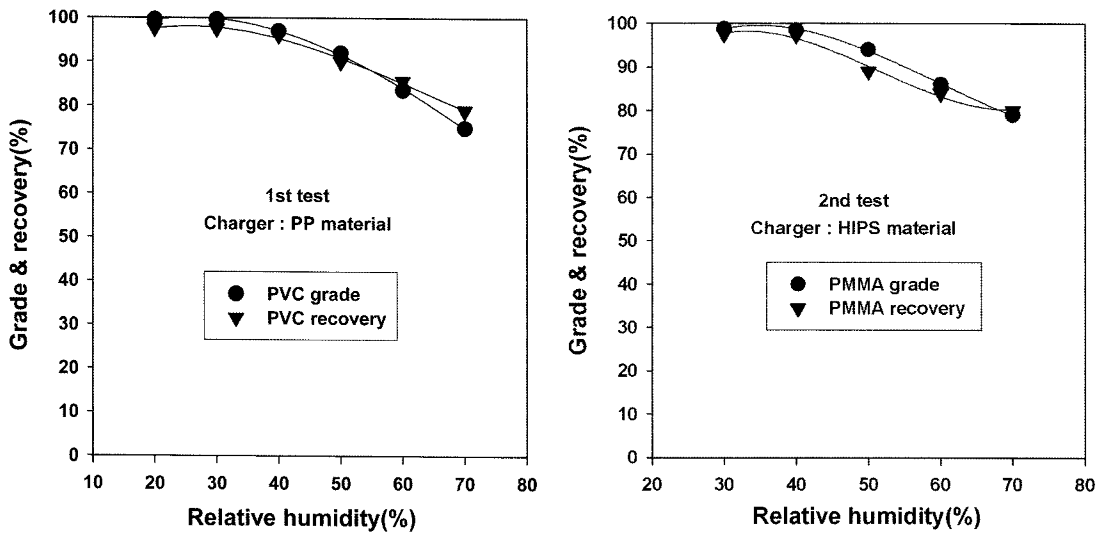

Fig. 7. Effect of the relative humidiy on the separation efficiency of plastics in triboelectrostatic separation unit (1 stage tests: 10 m/s air velocity, 200 kV/m electric field and +2cm splitter position. 2 stage tests: 10 m/s air velocity, 250 kV/m electric field and center(0) splitter position).

mass ratio are strongly deflected to the positive electrode but some PVC particles which have neutral charge to mass ratio fall freely. Also, in case of PET and PMMA, some PET and PMMA particles were not deflected to the negative electrode and behaved similarly to PVC. Such behavior of particles deteriorated the separation efficiency. Considering the results, a PVC grade of 99.6% and a recovery of 97.5% were obtained at the splitter position +2cm from the center to the positive electrode, which seems to be the optimum position. However, A PVC purity of 99.9% could be obtained at the splitter position between +6cm and the positive electrode although the PVC recovery con-siderably decreased by 29.5%.

In the 2nd stage, the highest PMMA grade and recovery each of 98.5% and 97.1% were obtained at the central splitter position. Also, a PMMA grade of 99.4% was obtained at the splitter position between -6 cm and the positive electrode although the PMMA recovery was comparatively decreased by 33.2%.

3.5. Effect of relative humidity

Fig. 7 shows the effect of relative humidity on the separation efficiency of plastics. In the 1st stage, the acceptable separation efficiency of PVC could be obtained as long as the relative humidity was less than 30%. Furthermore, the 2nd stage tests show that the separation efficiency of PMMA remained constant when the relative humidity was less than 40%. With increasing relative humidity, water films are formed onto plastic surface[15] and it disturbs the surface polarization between particles when contacting or colliding particles. Also, the surface charge of charged particles decreases probably due to the discharge of the electron through the moisture layer attached on the surface.

4. Conclusion

The separation of mixed three kinds of plastics, PVC, PET and PMMA, in the range of similar gravity has been performed through a two-stage separation process. The separation efficiency of particles con-siderably depended on the air velocity, the relative humidity, the electrode potential and the splitter position in the triboelelctrostatic separator unit. In the 1st stage using the pp cyclone charger, a PVC grade of 99.6% and a recovery of 97.5% have been achieved. Also, in the 2nd stage using the HIPS cyclone charger, a PMMA grade of 98.3% and a recovery of 97.0% could be obtained. In order to obtain 99.9% PVC grade and 99.5% PMMA grade, their recoveries should be sacrificed by 29.5% and 33.2%, respectively with moving the splitter from the center to +6cm and -6cm position.

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