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# Triboelectric series and charging properties of plastics using the designed vertical-reciprocation charger

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A triboelectrostatic separation system consists of a tribo-charging of materials and a separation of the charged materials in an electric field. Selective charging and optimum charge density (charge-to-mass ratio: nC/g) of materials in tribo-charging are the most important parameters for separation efficiency. In this study, a new tribo-charger set was made by combining a vertical reciprocator and various charger materials, and then the triboelectric series and charging properties of the plastics was estimated. The charge density of particles was confirmed to depend on the relative humidity (<30%), the frequency (>250 Hz) and the retention time (>300s) in the vertical-reciprocation charger. In addition, the charge density of mixed samples (PMMA: PVC = 1:1) was experimentally validated to be higher than that of a single sample, because of contacting or colliding in combination with particle–particle and particle–charger surface. Triboelectric series and charging properties of plastics can be used to predict material separation for the recycling of waste plastic in triboelectrostatic separation.



## 1. Introduction

The constant generation of waste plastic and its disposal cause environmental problems along with economic loss. Particularly, mixed waste plastics are difficult to recycle or reuse because of their inferior characteristics and deteriorated qualities. Thus, many efforts have been made to recycle waste plastics and solve the concomitant environmental problems. In general, physical separation techniques that can recycle mixed plastics are classified as electrostatic separation, dry and wet gravity separation, froth flotation, near infrared rays (NIR) and color sorting [1–3]. Gravity separation is difficult for materials of similar specific gravity, such as PVC and PET. Froth flotation generates water disposal problems for the flotation agents. Also, NIR and color sorting are imperfect techniques because they are limited to smaller sizes than bottles or containers; furthermore, it is difficult to separate mixed plastics having similar properties, like the same peak and color [4,5]. The electrostatic separation methods are corona discharge, electrostatic induction and triboelectrostatic separation. Corona discharge and electrostatic induction can separate mixtures of conductors/non-conductors (metals/insulators), whereas the triboelectrostatic method has the advantage of separating various mixtures such as non-conductor/non-conductor (insulator/insulator) and conductor/non-conductor (metal/insulator) [6,7]. This technique is much cheaper and yields a much better separation efficiency than using the above-mentioned separation methods [8–10].

The charge transfer mechanism in tribo-charging is explained by three models: electron transfer, ion transfer and material transfer [11,12]. It has been reported that an electron transfer among them mainly affects the contact charging between materials [12–15], and Lowell [16] has found that surface pollution with other materials or ions does not significantly affect the charging of polymers. Furthermore, it has been reported that an electron transfer can only occur from a maximal depth of 30 nm [14,17]. On the other hand, several studies have shown that ion and material transfers can influence the charge polarity and the charge density of materials, or be involved in combination with the three mechanisms (electron transfer, ion transfer and material transfer) [11,19–21]. The most impressive reviews concentrating on the theory of tribo-charging have been made by the Lowell and Rose-Innes group in Ref. [12–18] and by the Inculet and Castle group in Ref. [22–25]. They have studied charge with respect to the Fermi level and work function, their interaction, and theoretical models of metal/metal, metal/insulator and insulator/insulator. In the process of tribo-charging, two materials brought into contact or collision can undergo a charge transfer according to their work function

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difference until the point at which their Fermi levels equalize. The final charge density will actually be the outcome of the two processes: the charge transfer that occurs during the contact and the charge backflow occurring as the materials separate [6,12].

In triboelectrostatic separation, the charged particles separate through an electric field by the particle–particle and particle–surface charging mechanisms of the tribo-charger, according to the work function difference [6,9]. This separation method can improve the separation efficiency by establishing a triboelectric series and developing a charger material, charger type and appropriate handling technique for the various charging factors. First to consider in establishing a triboelectric series, the values of the work function have been reported to depend not only on the nature or internal structure of the material, but also on its surface condition, such as oxidation or surface contamination [22]. Hence, a triboelectric series which estimates the relative charge polarity of the materials is mainly used. The charging method and charge density (nC/g) of the plastics have been reported by various researches. Commonly used devices include: an inclined rotating drum [24,26], a fluidized bed [24,27,28], a cyclone [29,30], a vibrating feeder [31,32], a honeycomb and a spiral tube charger.

The aim of this study is to establish the triboelectric series of plastics and to estimate charging properties that affect the charge efficiency of the plastics. Hence, we designed a vertical-reciprocation tribo-charger set that can cause tribo-charging of plastic materials using the strong impact on the upper and lower walls in charging bottle. As previous researches on impact charging, Watanabe et al. [33] and Matsusyama and Yamamoto [34] have researched impact charge of a particle against a target panel. Watanabe has measured a charge density due to a single impact of a particle against a stainless steel target as a function of impact velocity and impact angle, and Matsusyama has measured the amount of residual charge called "charge relaxation model." after the separation. It is found that impact charge increases as impact velocity and impact angle increases, and the transferred charge is a linear function of the contact area. Also, from McCown [31] study using the G-10 and Teflon-lined shaker boxes, the impact charge of polymers shows to increase with increasing the duration, frequency, and magnitude of contact. In this study, frequency and retention time affecting the impact charge in the vertical-reciprocation charger have been estimated and the triboelectric series using the relationships of the charge density and charge polarity between plastics and various charger materials has been obtained. Additionally, the charge density of a single sample versus a mixed sample was investigated with respect to the charging mechanisms.

## 2. Materials and methods

### 2.1. Materials

The plastic samples used in this study were raw, 3.8–4 mm, pellet-shaped materials containing a minimum amount of additives and impurities from a petrochemical plant. The plastic species used in most charging tests were LDPE (low-density polyethylene), HDPE (high-density polyethylene), HPVC (hard polyvinyl chloride), SPVC (soft polyvinyl chloride), COPP (co-polypropylene), HOMOPP (HOMO-polypropylene), PET (polyethylene terephthalate), rubber, Calibre, ABS (acrylonitrile, butadiene, styrene), PMMA (polymethyl methacrylate), HIPS (high-impact polystyrene), and GPPS (general purpose polystyrene). As pretreatment, the initial charges of bottle and all plastic particles were neutralized with a discharger (KASUGA DENKI INC, Japan).

### 2.2. Experimental system

Fig. 1 shows a schematic diagram of the tribo-charger of the vertical-reciprocation type designed in this study. This apparatus was designed to charge the plastics into the charging bottle at the top by a transfer from rotating motion to reciprocation by the cam axis located at the lower section. Fig. 1 (a) shows the movements of plastic particles due to artificial reciprocation of the tribo-charger. Fig. 1 (b) shows the dimension of the rotating disc; the holes in the rotating disc can control the reciprocation amplitude. Fig. 2 shows the experimental system consisting of the vertical-reciprocation charger (1), the charging bottles (2), the Faraday cage (3) and the electric balance (4). Eight kinds of materials, namely polytetrafluoroethylene (PTFE), polyvinyl chloride (PVC), polypropylene (PP), high-density polyethylene (HDPE), polyethylene terephthalate (PET), acrylonitrile butadiene styrene (ABS) and polymethyl methacrylate (PMMA) were used as materials for the tribo-charger in the triboelectric series test.

The charge density of the particles was determined by charge-to-mass ratio (nC/g). For example, the positive charge on particles induces the negative charge on the surrounding cage: the charge induced on the inner wall of the cage is equal in magnitude but opposite in sign to the introduced charge, and the charge of the

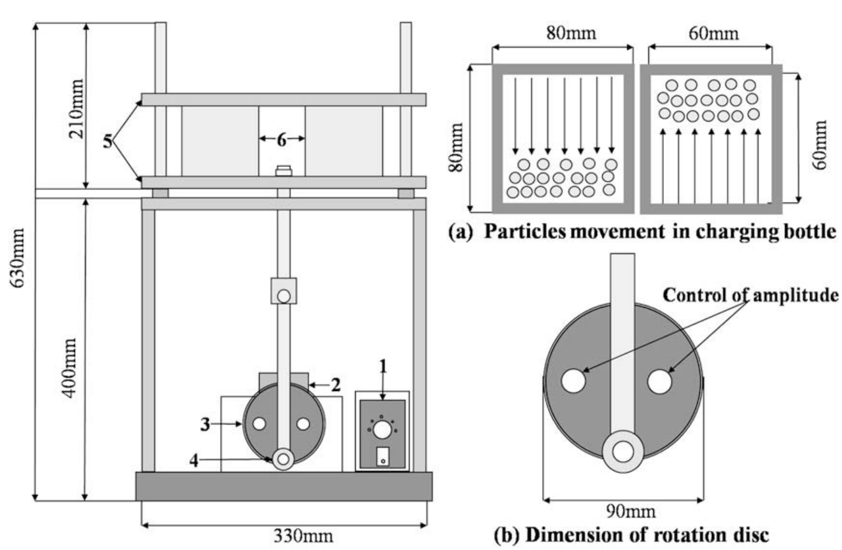


**Fig. 1.** Schematic of the vertical-reciprocation tribo-charger designed in this study (1: controller, 2: motor, 3: rotation disc, 4: cam axis, 5: vertical-reciprocation plate, and 6: charging bottles).