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Electrostatic Separation in Recovering the Food from Municipal Solid Waste

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Abstract-Food waste draws globally attention as one-third of food produced for human consumption is wasted yearly. This means the economic value from limited natural resources such as water, nutrients, land and energy are lost. Consequently the greenhouse gas emissions caused by food waste are emitted inevitably. Disposal of food potentially contributes 22% to the global warming. The waste foods are often mixed by other non-food waste, making them hard to be reused. In this country, the daily food waste has reached 7650 ton since 2002. This figure is forecasted to double up to 13500 ton in 2020, highly due to the lack of food waste recovery system. Throughout this study, we made a novel attempt to assess on recovering foods from the solid waste, which is composed of the food and non-food such as plastic and glass. An electrostatic separator was employed to separate the food from non-food, in where both wastes are prepared as multi-size granules. The recovery efficiency of food can reach 75.9% and 79.8%, from the mixture of glass and plastic, respectively. When being used for the multiple mixture separation, the separator recovers 79.3% of food, showing its feasibility in recycling the food waste and it is environmentally friendly. The study also highlights critical aspects that worth to be considered for reliability and efficiency of the electrostatic separation process, especially for the multiple mixture recovery in real environment.

Keywords- *electrostatic separation, food recovery, waste management*

I. Introduction

Waste of food appears as a global dilemma in many countries throughout the world. A study from Food and Agriculture Organization of the United Nations (FAO) reveals that 1.3 billion ton of food is wasted every year. This number is equivalent to what the whole of sub-Saharan Africa can produce [1-3]. Meanwhile, more than 20,000 children under the age of five die of hunger every day. It was estimated that almost half of the food grown is lost and wasted before the production reaches final household consumption [4]. Both the industrialized world and developing countries are suffered from this global issue (Figure 1, [5]). Rapid urbanization and industrialization in Malaysia make this country on a par as developed country. Solid waste generation increases due to rural-urban migration, per-capita income increment and high demand of quality life from the citizens [6-8]. According to the National Solid Waste Management Department, the food waste per day reached 7650 ton in 2002. This figure is forecasted to double up in 2020 [9-10]. In other word, five million ton of yearly food waste will be generated in this country if we do not concern it from now.

Throughout the food supply chain (FSC), food losses can occur during the production and post-harvesting processes. Food waste is defined as the food losses at retail and final consumption stages of the food chain, which relates to the behavior of retailers and consumers [11]. In the retail stage, the foods include vegetables and fruits will be provided to wet markets, grocers and supermarkets. Before reaching onto the shelf, about 10-15% of them will be discarded for the reasons of improper handling, e.g. insufficient cooling storage. A large portion of crops is rejected before the distribution, due to the rigorous quality standards on the size, shape and appearance [12]. Upon reaching consumption stage, wastage is once again generated from household, restaurants, hospitality sector, prisons, cafes and so on. Vegetables and fruits contribute the highest portion of food waste, if compare to cereal, roots and tubers, oilseeds and pulses, meat, fish and seafood and milk. The waste of food not only represents the waste of economic value, but also the waste of the limited natural resources such as water, nutrients, land and energy [13]. Besides, the emission of greenhouse gases such as methane and carbon dioxide, due to the waste of food, can cause the global warming [14-15].

The food waste in the consumption stage can be classified into two categories, namely pre-consumer food waste and post-consumer food waste. The pre-consumer waste gets its name for never being appeared in front of the consumer. For instance, overcooked, expired, contamination and trim waste contribute to this type of waste. Post-consumer waste, on the other hand, is mainly caused by the lack of awareness from both caterers and guests. The portion size and the behavior of guests in the self-service buffet would lead to the waste of food. Some authorities had started to put the regulations on the food waste management, before the food waste was sent for incineration or landfill. In Ireland, the Environmental

Protection Agency and the Clean Technology Centre published Waste Management (Food Waste) regulations 2009 to increase the recovery amount of food waste [16]. The food waste from the household must be source segregated, before being collected by an authorized waste collector. Source segregation refers to the waste segregation at source by the producers to avoid specified waste from being contaminated or mixed with others. In this way, the food waste can be filtered out to become animal feeds.

A high amount of organic matters, particularly food waste can be found in the municipal solid waste in Malaysia. Considerable amount of food waste are being produced from hawker centers due to the "dining-out" habits of Malaysians. It is about 45% of the municipal waste are food waste, followed by other non-food waste such as plastics, papers, glass etc. [17-19]. In fact, food waste can be converted into useful materials if it is source-sorted. The National Strategic Plan (NSP) for Solid Waste Management in Malaysia has introduced policy on waste management to prioritize waste reduction through processes of reducing, reusing and recycling [20]. However, the policy does not lead to a positive result due to the low awareness of citizens [21]. Source segregation of food waste is not commonly practiced in Malaysia. Most food waste is disposed at the disposal site due to the lack of food waste recovery facilities and poor waste management in this country [22-23].

Source segregation is crucial for enabling the mentioned 45% food waste to be reused and thus protecting the environment. The recovered foods that free from plastic and glass could be consumed by animals, resulting the reduce of wastes. This study targets to investigate the feasibility of an electrostatic separator in segregating non-food particles from the recoverable foods. Electrostatic separator is capable in separating particles based on the varying conductivity of the constituent components. It is widely used to sort more conductive particles from those of relatively less conductive. A number of studies had shown the capability of the separator in treating the electronic waste [24-27]. Nevertheless, there is lack of research of electrostatic separator on the recovery of food waste documented. The author expects outcomes from the study will reduce the waste in disposal site by 10 – 20%.

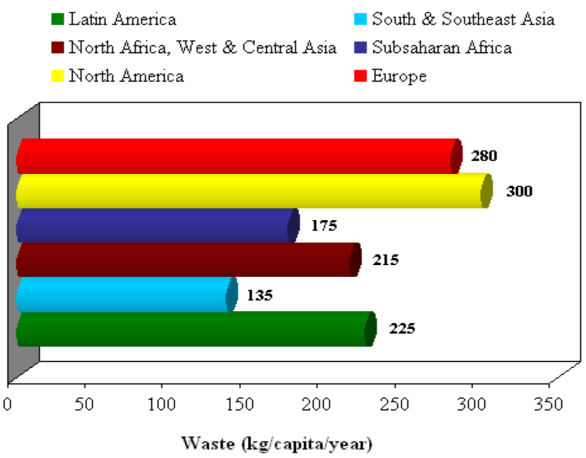

Figure 1. Food loss and waste in different regions.

II. Experimental Setup

A. Electrostatic separation

An electrostatic separator with an earth-grounded rotating drum as roller was designed and employed for the study of granular mixture separation. An ionizing electrode was connected to a high voltage power source (Trek-30kV/20mA) to generate the corona discharge of charged ions. An electrostatic electrode, formed as wide as the roller, was connected to the high voltage power source to have same voltage level as the ionizing electrode. The 10-inch diameter roller rotates at a speed of 90 rpm. A feed system located above the roller deposits the granule onto its surface. The separated products are recovered in the collecting tanks beneath the roller. The schematic shown in Figure 2 illustrates the basic principle of the high-tension electrostatic separator rotating in clockwise direction.

When the voltage is applied, a high intense corona discharge is generated to ionize the surrounding air near the ionizing electrode, forming an ionizing zone. When the roller delivers the granules through the ionizing zone, the bombardment ions electrically charge the granules and pin them onto the roller surface. The more conductive granules lose their charge rapidly, avoiding them from being pinned for a longer time than the less conductive one. With the continuous rotation from the roller, the more conductive granules are subject to a centrifuge force which is larger than the pinning force and thrown off the roller. To enhance the effectiveness of the separation, the electrostatic electrode induces an evenly distributed electric field to deviate the more conductive granules from their natural falling trajectory. This improves the effectiveness and efficiency of the separation process. The less conductive granules remain pinned to the roller due to the larger pinning force applied. Eventually they fall off at a different location than the more conductive granules as they are losing charge less rapidly or are removed from the roller with a brush.

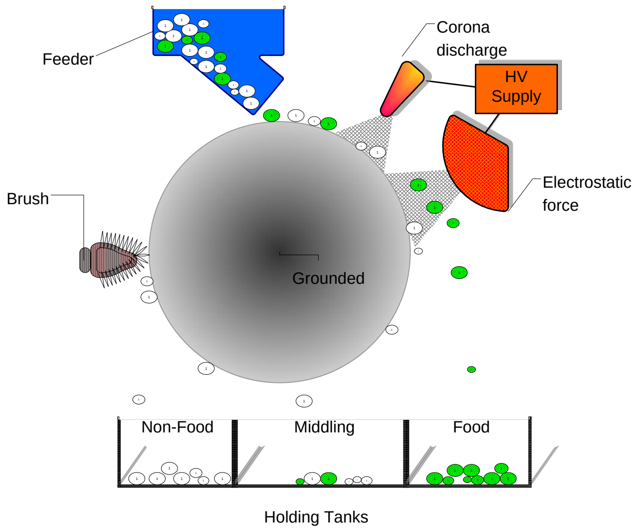

Figure 2. Schematic of the electrostatic separation process.

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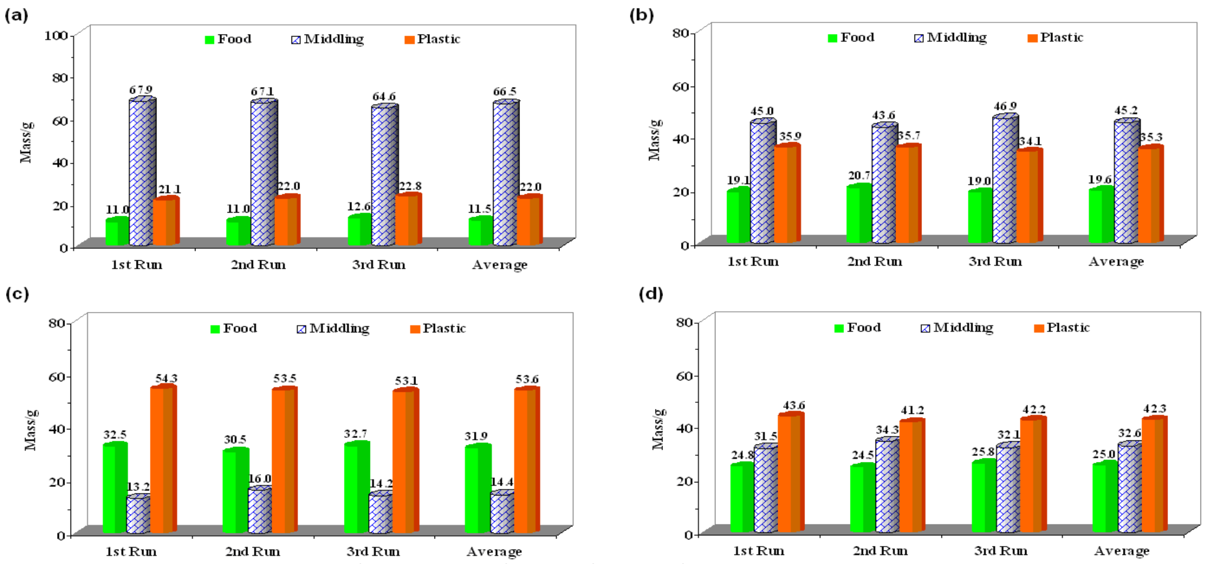

Figure 3. Food mass recovered from plastic as a function of attempts for granule size in (a) G1, (b) G2, (c) G3 and (d) G4.

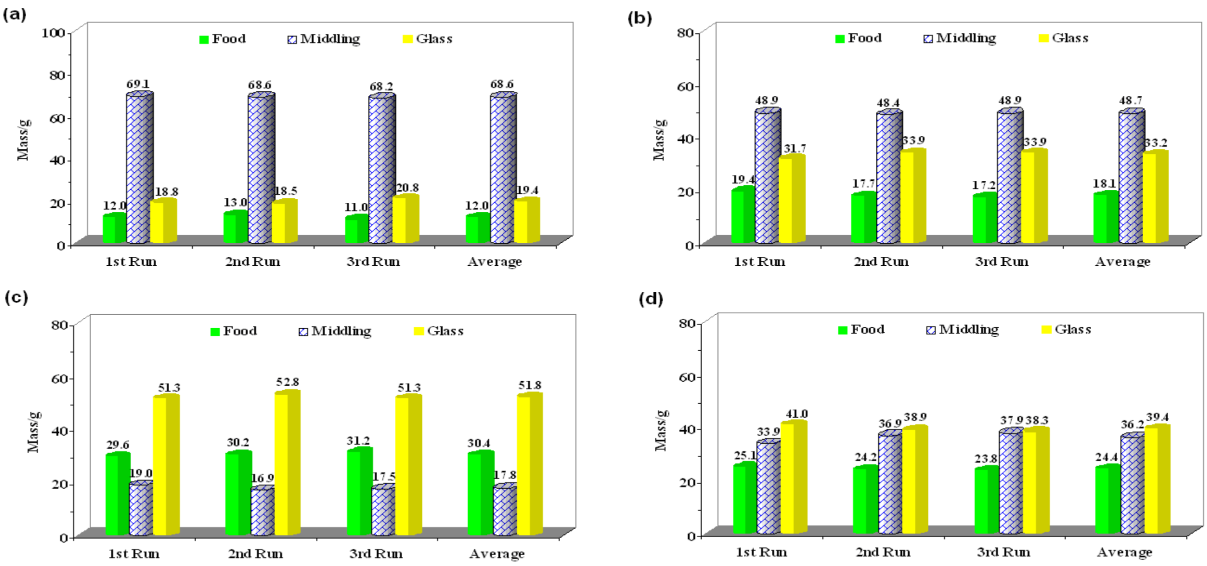

Figure 4. Food mass recovered from glass as a function of attempts for granule size in (a) G1, (b) G2, (c) G3 and (d) G4.

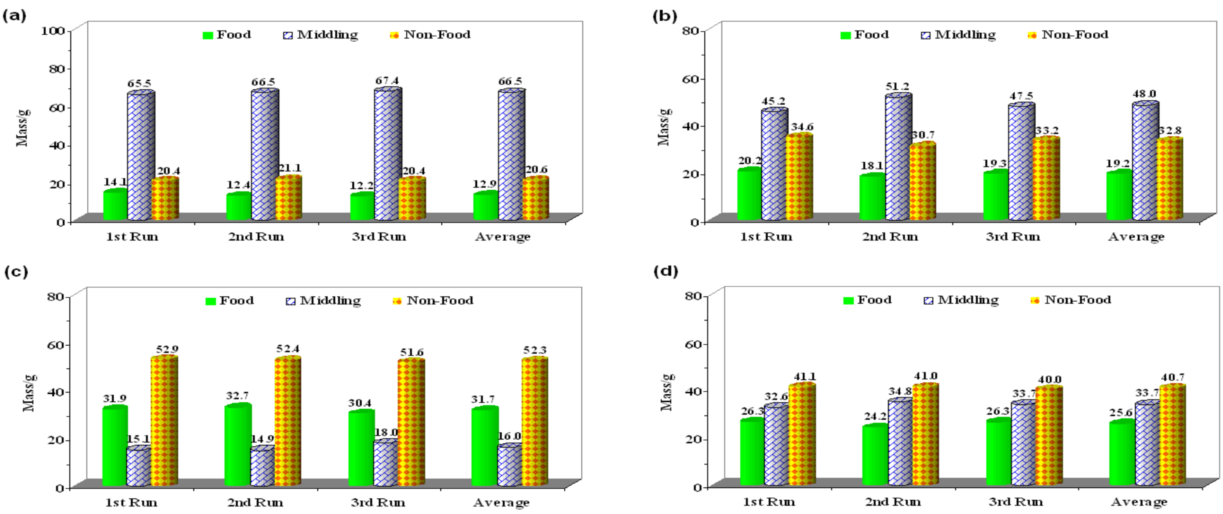

Figure 5. Food mass recovered from glass as a function of attempts for granule size in (a) G1, (b) G2, (c) G3 and (d) G4.

B. Materials and method

The granule mixtures of food (carrot skin) and non-food (plastic, glass) were prepared in portion of 40% and 60% respectively. Sizes of the granules were sampled into four groups, namely G1 (< 0.5 mm), G2 (0.5 – 1.5 mm), G3 (1.5–3.0 mm) and G4 (3.0 – 5.0 mm). Weight of the separation results collected from the holding tanks were measured by a precision balance with resolution of 0.1 g. The ambient was recorded as 24 – 28□C with relative humidity of 20 – 30%. Water content in the food is between 5 – 10% to maintain its conductivity [28-29]. The samples are synthetically prepared.

III. RESULTS AND DISCUSSION

A. Separation of Food and Plastic

Mixture samples consist of 40 g of food and 60 g of plastic are prepared. As shown in Figure 3(a), the recovery performance is poor when the sample size is too small (< 0.5 mm). Electrostatic separation process relies on the charge properties of food (which is more conductive) and plastic (non-conductive). The roller delivers these granules to pass through ionizing zone formed by the corona electrode..Charges are induced on them especially non-conductive plastic material. The induced force, ionizing force, Fi relates negatively to the size of the granules and is defined as

$$F_i = Q^2 / 4\pi\varepsilon d^2 \quad (1)$$

where Q is charge, is electric permeability and d is diagonal length. Larger food granules subject to a lighter pinning force are not much restricted to detach from roller [30]. Fine particles of foods, on the other hand, have significant larger pinned magnitude if compared to other groups [31]. Thus the recovery efficiency in G1 appears as the lowest, which is only 29%.

When the granules in G2 are used, the average recovery efficiency increases to 49% due to the size increment. The efficiency improves for the increasing size of granules, and reaches the highest record at 80% when the granular size is ranging from 1.5 to 3.0 mm (G3). Meanwhile, the average mass of middling remains as the lowest at 14 g. When the granules pass the ionizing zone, more conductive particles loss charge more rapidly and subject to relatively larger centrifuge force. Centrifuge force, Fct is proportional to the particle mass, m:

$$F_{ct} = mR\omega^2 \quad (2)$$

where R is roller radius and ω is angular velocity. Larger particles in G3 subject to larger centrifuge force which detaches them from roller effectively. Moreover, the electrostatic force Fe, expressed as

$$F_e = QE \quad (3)$$

where E is electric field strength, acts as a lifting force to attract the conductive particles to fall to the food tank. Electrostatic force is proportional to the particle surface area that exposes to the charge. The largest granular size in G4, however, does not improve the separation results if compared to G3. The efficiency is only 63% and in contrast with the previous discussion of size increment. This may highly due to the increment of gravity force overwhelms electrostatic force. This reveals size of granules shall be appropriate determined for the separation process, nether too large or too small.

B. Separation of Food and Glass

The experiment was conducted with a mixture of 40 g of food and 60 g of glass. The roller was cleaned and air-dried to prevent any substances from the previous experiment from adhering. Separation results in Figure 4 reveal the similar finding which the best efficiency is achieved by using the G3 particles. However, more granules fall as middling instead of being food or non-food, if compared to the food-plastic separation. Though having the same sizing 1390 kg/m3) [32]. In other word, larger number of plastic granules contributes the same weight of 60 g for each experiment, regardless of the density. The glass granules are subject to larger gravity force consequently. Under the same operating conditions, the pinning force on glass granules is comparatively lighter, resulting in the increases of middling.

C. Separation of Food, Plastic and Glass

The feasibility of food recovery by electrostatic separation is apparent in previous sections. In order to reflect the real environment, mixture of 40 g of food and 60 g of non-food mixed by glass (30 g) and plastic (30 g) is made ready. Separation results are shown in Figure 5. The food recovery efficiencies are 32%, 48%, 79% and 64% for samples of G1, G2, G3 and G4, respectively. Our previous discussion on particle sizes can be applied in this experiment. Highest efficiency is again recorded when the size ranging from 1.5 to 3.0 mm is employed. This suggests the size parameter for our future research to investigate other variables, e.g. charge density, variable high voltage supply, angular velocity for further improving the separation results. Results of the three separation processes are summarized and compared in Fig. 6.

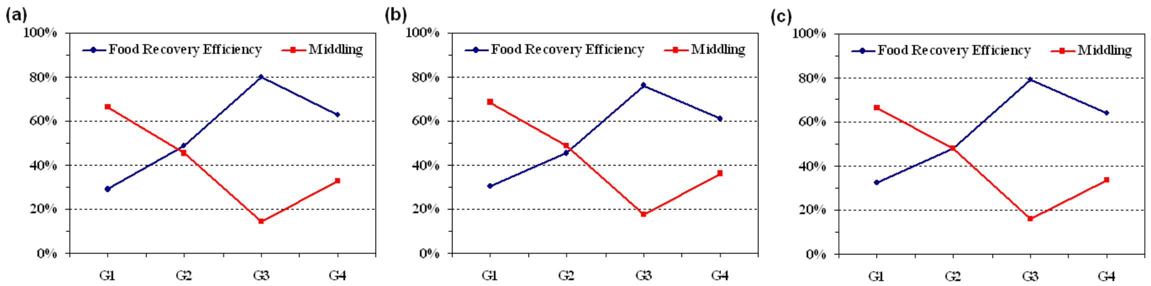

Figure 6. Recovery efficiency and middling percentage for (a) food-plastic, (b) food-glass and (c) food-plastic-glass separation.

D. Considerations in separation process

The A granular particle, regardless more conductive or less conductive, passes through the pinning zone is subject to a pinning force generated by the corona electrode. Magnitude of the pinning force relates to the particle size. The electrostatic electrode located downstream the corona electrode induces a lifting force on it thereafter. The lifting force strength relies on the supplying electric field. A gravity force acts on the mass of the granule. A centrifuge force applies on the granule due to the clockwise angular rotation by the roller and the granule mass. An air friction, or air drag force in an opposite direction of gravity, depends on the velocity and the size of granule [33]. These significant forces are illustrated in Figure 7. The equilibrium state for the granule can be achieved when

$$(F_g - F_d)\sin\gamma = F_{ct} + F_e - F_i \quad (4)$$

where air drag force is represented as F_d.

To improve the food separation efficiency, mass of middling granules in the middling holding tank shall be minimized. According to Figure 6, food recovery efficiency increases with the decreases of middling in every process. Food may wrongly be classified as middling products during the processing process. Reducing the middling implies higher possibilities of recovering the food from non-food [34].

Force model in Figure 7 discloses the granule size may affect the separation results. This is in a general agreement with the empirical results obtained in this study. Meanwhile, the recovery efficiency could be influenced by the random arrangement of the multi-size granules on the roller surface (Figure 8). If the granules form a multi-layer, the food can be misclassified as non-food and vice versa. The granule deposit speed from the feeder to roller shall be controlled to form a mono-layer, however, it may result in longer processing time. Uniform sizing of granules is hard to achieve due to the constraint of mechanical hardware. To encounter this problem, the variant of granule sizes shall be limited to minimize the possibilities of misclassification. This study suggests the granules with size ranging from 1.5 to 3.0 mm shall be used in the recovery process.

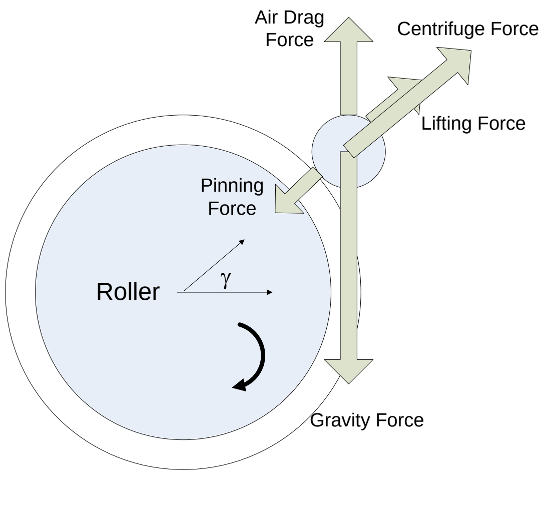

Figure 7. Analysis of forces on the granule.

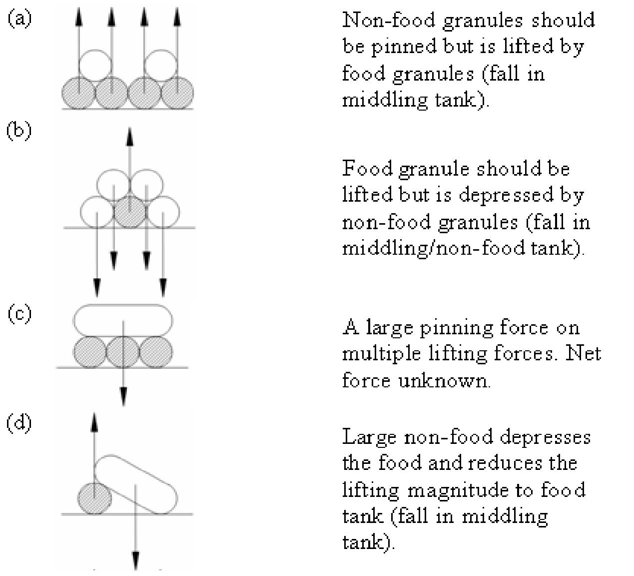

Figure 8. Schematic of the possible misclassifications.

IV. CONCLUSIONS

Food is more conductive, relatively to plastic and glass in the electrostatic separation. Most the granules, both food and plastic are subject to a strong induction field (or electric image force) when they pass the ionizing zone. Less conductive particles are electrically charged due to the ion bombardment from the corona electrode, enabling them to be pinned to the roller. The more conductive particles, i.e. foods, tend to lose their charge faster through the grounded metal roller than the non-conductive granules. They are free from, or less bounded by the image force. Larger food granules have more tendencies to escape from being pinned than fine granules. These particles will be detached from, or thrown away by the centrifuge force of roller in an induced trajectory to the food tank. The electrostatic electrode, located downstream of the corona electrode, provides an evenly distributed electric field (or lifting force) to further attract the foods to the desired tank.

Electrostatic separation is feasible in recovering the food from multi-size mixture. The food recovery efficiencies are at 75.9%, 79.8% and 79.3% respectively from glass, plastic and glass-plastic mixture. Optimization and robust design of separation process shall be further studied for efficiency enhancement. A comprehensive study of forces act on granule body is worth to be studied to understand the interactions between relevant parameters.

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