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Review

Triboelectrostatic separation for granular plastic waste recycling: A review

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ABSTRACT

The world's plastic consumption has increased incredibly in recent decades, generating more and more plastic waste, which makes it a great public concern. Recycling is the best treatment for plastic waste since it cannot only reduce the waste but also reduce the consumption of oil for producing new virgin plastic. Mechanical recycling is recommended for plastic waste to avoid the loss of its virgin value. As a mechanical separation technology, triboelectrostatic separation utilizes the difference between surface properties of different materials to get them oppositely charged, deflected in the electric field and separately collected. It has advantages such as high efficiency, low cost, no concern of water disposal or secondary pollution and a relatively wide processing range of particle size especially suitable for the granular plastic waste. The process of triboelectrostatic separation for plastic waste is reviewed in this paper. Different devices have been developed and proven to be effective for separation of plastic waste. The influence factors are also discussed. It can be concluded that the triboelectrostatic separation of plastic waste is a promising technology. However, more research is required before it can be widely applied in industry.

1. Introduction

The past decades have witnessed an incredible and consistent growth in the consumption of plastics due to their good safety, low cost, durability, lighter weight than competing materials, and extreme versatility and ability to be tailored to meet specific technical needs (Siddique et al., 2008). It has been reported that in 2010 the global production of plastics increased to 265 million tonnes, confirming the long term trend of plastic production growth of almost 5% per year over the past 20 years (as shown in Fig. 1), while there is still room for further growth (PlasticsEurope, 2011). Each year, around 4% of global oil production represents the cost for the creation of plastic raw materials. An additional equivalent 4% of global oil production is required as energy to convert the plastic materials into prototype or finished products at the same time (EuPC, 2009).

Plastics are widely applied in packaging, building and construction, automotive and electrical and electronic equipment, with packaging being the largest segment. Although plastic products usually have excellent durability, more than half of them are discarded as waste each year. The increased demand for plastic has generated rapid growth in production as well as disposal of plastic waste. It can be concluded that plastic waste has become one of the larger categories in municipal solid waste (MSW), especially in industrial countries. For example, in the US, plastic waste found in MSW has increased from 9.5% in 1994 (USEPA, 1995) to 12.4% in 2010 (USEPA, 2011). Fig. 2 illustrates the composition of MSW in the US. Since the total amount of MSW is increasing rapidly with urban development and population growth, a constant growth of plastic waste can be expected in both developing and developed countries (Chen et al., 2011). As a consequence, the question of the disposal of plastic waste generated by industry and households has gained a growing public concern.

Plenty of toxic materials including dioxins and hydrochloric acid can be easily produced and cause huge damage to the environment if plastic waste is not managed properly (Ali and Siddiqui, 2005; Mølgaard, 1995; Simoneit et al., 2005; Wey et al., 1998). Landfill is becoming more and more expensive due to the increasing volume of waste and the decreasing landfill capacity for disposal. More significantly, landfill of plastic waste is a waste of valuable resources. It also causes a series of problems, such as additives leaching and land occupation (Lea, 1996; Oehlmann, 2009). Incineration is widely applied in energy recycling for plastic waste. Plenty of energy can be recycled during the process and be used for electricity generation, combined heat and power, or some other processes (Astrup et al., 2009b). However, incineration can also be rather risky since many toxic components are found in the fly ash and the residues in concentration that exceed the admissible limits, such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), polychlorinated dioxins (PCDs) and polychlorinated dibenzofurans (PCDFs), which may cause carcinogenesis, teratogenesis and mutagenesis (Chung, 2010; Gilpin et al., 2005; Li et al., 2001).

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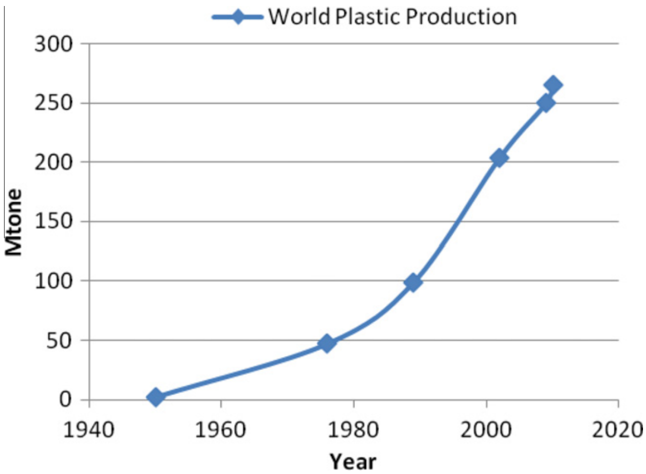

Fig. 1. World plastics production 1950–2010 (PlasticsEurope, 2011).

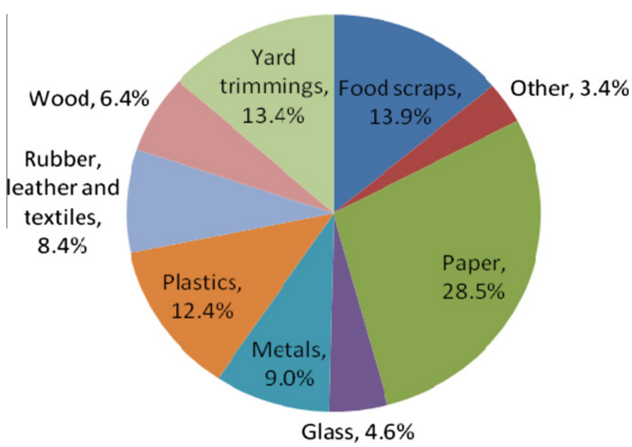

Fig. 2. The composition of MSW in the US in 2010 (USEPA, 2011).

Compared to landfill and incineration, recycling of plastic waste is much more acceptable and environment friendly. Recycling is not only an approach for disposing plastic waste, but also an effective way to reduce the requirement for virgin plastics production, which can contribute to saving with respect to global warming (Astrup et al., 2009a). The terminology for plastics recycling is quite complex. Commonly it can be divided roughly into two main categories: mechanical recycling and chemical recycling. Most thermoplastics such as poly ethylene terephthalate (PET), polypropylene (PP) and polyethylene (PE) have high potential to be remelted and mechanically recycled, while for thermoset plastics, chemical recycling are more adaptable. Compared to chemical recycling, mechanical recycling is more convenient and has a low degree of pollution generation and cost. Mechanical recycling is also a better way to maintain the intrinsic value of plastic and avoid the loss of non-renewable resources. Sadat-Shojai summarized the methods of polyvinyl chloride (PVC) recycling and compared their strong and weak points as shown in Table 1. Recycling of PVC is not a representative example of polymer recycling, since PVC includes Cl in its macromolecular chains in contrast to other polyolefins (low density polyethylene (LDPE), high density polyethylene (HDPE), PP, etc.) or polyesters which include only C, H and O, but it is also useful in evaluating the processes of recycling other similar plastic waste, especially for mixed plastic waste which contain Cl or other toxic elements or compounds (Sadat-Shojai and Bakhshandeh, 2011). It shows that mechanical recycling is a promising method with low pollution, low cost and the most government support.

The most crucial challenge for mechanical recycling is that plastic waste needs to be separated effectively. Mechanical recycling is high-sensitive to the impurities. Different types of plastic are usually not compatible with each other. All of them have different physical characteristics such as melting point, density and hardness, so mixed plastics cannot present their original characteristics and the practical value descends. More significantly, the chemical immiscibility makes it desperately sensitive to the purity. For example, even small quantity of PVC in another main plastic would decrease the recycling ratio of plastics by forming compounds or deteriorating the nature of other materials (Wey et al., 1998); it is also reported that PET in a PVC recycle stream will significantly reduces the value of the recycled material by forming solid lumps of crystalline PET (Hopewell et al., 2009). Therefore, mixed plastic waste is valueless. However, it can get greatly increased value after it was separated into pure components. Nowadays households are the main source of plastic waste stream and they are still mainly collected by curbside collections, which are usually mixed of different kinds of plastic waste (Al-Salem et al., 2009; Hopewell et al., 2009), separation of high efficiency seems to be an urgent need in practical recycling. Hence, in order to improve the value and the recycling rate of plastic waste, it is really necessary to build a sound and effective separation process for plastic waste separation.

Optical sorting is used as a pre-sorting process for material (size: +40 mm −60 mm) before size reduction rather than a separation method for plastic waste scraps. Automatic devices based on optical, X-ray, and near infrared (NIR) technologies are widely used in plastic recycling facilities all over the world. However, due to the poor spectral signature obtained, black fragments in the plastic stream can hardly be processed through this way. It is also difficult to separate the mixed plastics which have similar properties such as same color and peak (Arvanitoyannis and Bosnea, 2001; Huth-Fehre et al., 1995; Scott, 1995). The diversity of different density of various plastics makes it possible to find an appropriate medium to separate the heavier plastics from lighter ones. It can be conducted either with dry particles using air tables or zigzag air classifiers or by water-based solutions or suspensions as separating medias (Dodbiba et al., 2003a; Gent et al., 2009; Hu and Calo, 2006). However, since many plastics have overlapping density ranges and similar typical densities as shown in Table 2 (Malcolm Richard et al., 2011) (for example, PVC is 1.39 g cm^{-3} and PET is 1.37 g cm^{-3}), it is not easy to separate them by density separation. Selective flotation has high recovery and purity, especially is suitable for some plastics such as PVC and polyoxymethylene (POM) which are difficult to be separated by density media separation (Shent et al., 1999). However, the maximum size of particles for flotation is no more than 500 μm (Malcolm Richard et al., 2011), and the selective flotation cannot be achieved without changing surface properties for the plastics with similar surface properties, such as PVC and PET (Burat et al., 2009). For wet density separation or flotation, water is needed in the whole process, which causes a concern about secondary pollution. Dewatering or drying the mixture after separation cannot be avoided.

As a dry technique, electrostatic separation utilizing corona charging has been successfully applied to separate metal/non-metal mixtures (Gente et al., 2003; Hou et al., 2010; Li et al., 2007). However, such technologies are only suitable for separating conductors from dielectrics, but not able to separate a mixture of different dielectrics such as mixed plastics. As a consequence, triboelectrostatic separation has been studied for materials separation especially for separation of insulators.

Triboelectrostatic separation is definitely one of the most important and promising materials-processing techniques. In the