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Separation of mixed waste plastics via magnetic levitation

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ABSTRACT

Separation becomes a bottleneck of dealing with the enormous stream of waste plastics, as most of the extant methods can only handle binary mixtures. In this paper, a novel method that based on magnetic levitation was proposed for separating multiple mixed plastics. Six types of plastics, i.e., polypropylene (PP), acrylonitrile butadiene styrene (ABS), polyamide 6 (PA6), polycarbonate (PC), polyethylene terephthalate (PET), and polytetrafluoroethylene (PTFE), were used to simulate the mixed waste plastics. The samples were mixed and immersed into paramagnetic medium that placed into a magnetic levitation configuration with two identical NdFeB magnets with like-poles facing each other, and Fourier transform infrared (FTIR) spectroscopy was employed to verify the separation outputs. Unlike any conventional separation methods such as froth flotation and hydrocyclone, this method is not limited by particle sizes, as mixtures of different size fractions reached their respective equilibrium positions in the initial tests. The two-stage separation tests demonstrated that the plastics can be completely separated with purities reached 100%. The method has the potential to be industrialised into an economically-viable and environmentally-friendly mass production procedure, since quantitative correlations are determined, and the paramagnetic medium can be reused indefinitely.

1. Introduction

Massive global production of plastics, e.g., 322 M tonnes in 2015, has resulted in an ever-increasing stream of waste plastics (PlasticsEurope, 2016). Owning to less environmental burdens and economic feasibility, mechanical recycling of waste plastics or plastic recycling is becoming a promising practise in dealing with this particular waste stream (see Gu et al., 2014, 2016a,b, 2017a; Biganzoli et al., 2015; Wäger and Hischier, 2015; Ripa et al., 2017; Zheng et al., 2017). Recycled plastics possess comparable performance and advantageous prices to their virgin counterparts (Gu et al., 2016a), and have already been applied in the manufacturing sector (Gu et al., 2016b, 2017a). Plastic recycling is also one of the major sources of environmental benefits in waste management systems (Biganzoli et al., 2015; Wäger and Hischier, 2015; Ripa et al., 2017). However, although plastic recycling enjoys a rapid growth in recent years, most of waste plastics are still sent to landfill or incineration (PlasticsEurope, 2016). In reported cases of plastic recycling, only waste plastics of certain types and sources are recycled. For example, in the municipal solid waste (MSW) management system of Naples, only polyethylene (PE), polypropylene (PP) and polyethylene terephthalate (PET) get mechanically recycled while the mix plastics are recovered as fuels or directly end up in landfill (Ripa et al., 2017). Some Chinese plastic recycler only takes sorted waste plastics from factories or dismantling sites (Gu et al., 2017a). From a brief review of the extant literature, it can be deduced that the technology of separating mixed waste plastics is highly desirable for promoting the rate of plastic recycling, as most current practises cannot handle this particular type of MSW.

Since separation of mixed plastics poses a difficult challenge to promoting mechanical recycling of plastics, the field thereby attracts a great deal of attention from academics. Froth flotation is one intensively studied plastic separation technology (see Guney et al., 2013; Wang et al., 2014, 2015, 2017a,b; Zhao et al., 2015; Censori et al., 2016; Truc and Lee, 2016, 2017; Pita and Castilho, 2017; Salerno et al., 2018; Wang and Wang, 2017). Froth flotation exploits tiny density differences between materials (Censori et al., 2016), yet, this technology primarily focuses on separating desirable types of plastics from binary mixtures, e.g., separating polyvinyl chloride (PVC) from mixtures like PVC/polystyrene

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Nomenclature

Abbreviations

ABS	acrylonitrile butadiene styrene
CHC	calcium hypochlorite
ELV	end-of-life vehicle
HDPE	high-density polyethylene
FTIR	Fourier transform infrared
LIB	lithium-ion battery
MIBC	methyl isobutyl carbinol
MSW	municipal solid waste
NBS	national Bureau of Statistics
PA	polyamide
PC	polycarbonate
PE	polyethylene
PET	polyethylene terephthalate
PMMA	polymethylmethacrylate
PP	polypropylene
PS	polystyrene
PTFE	polytetrafluoroethylene
PVC	polyvinyl chloride
WEEE	waste electrical and electronic equipment

Symbols

g	gravitational acceleration
V	volume of the object
$\vec{B}$	magnetic flux density
χ	magnetic permeability
ρ	specific density

Subscripts

G	gravitation
f	buoyancy
m	paramagnetic medium
s	sample

(PS) (Salerno et al., 2018), PVC/PET (Guney et al., 2013), PVC/acrylonitrile butadiene styrene (ABS) (Wang et al., 2017b; Wang and Wang, 2017), PVC/polycarbonate (PC) or PVC/polymethylmethacrylate (PMMA) (Wang et al., 2017a), or separating PS from PS/PMMA, PS/PET, and PS/PVC (Pita and Castilho, 2017). Introduction of frothers such as methyl isobutyl carbinol (MIBC) (Truc and Lee, 2016; Salerno et al., 2018; Wang et al., 2017a) or terpineol (Wang et al., 2015) significantly improves selective floatability of target materials, but also would bring extra costs and environmental burdens of these processes. Surface treatments like boiling treatment (Wang et al., 2014), calcium hypochlorite (CHC) treatment (Wang et al., 2017a), Fenton treatment (Wang et al., 2017b; Wang and Wang, 2017), microwave and/or mild-heat treatment (Truc and Lee, 2016, 2017) have been proved to be effective in promoting recovery rates and purity, and shortening process time. However, considering the massive stream of waste plastics which shows no sign of stopping increasing, these pre-treatments might not be practicably and economically feasible. The sizes of plastics play important roles in froth floatation (Wang et al., 2014, 2017a; Pita and Castilho, 2017). To achieve such narrow size distribution as that used in the extant works (Truc and Lee, 2016; Salerno et al., 2018) could lead to huge energy consumption, and shredding poses significant environmental impacts to the overall lifecycle performance of mechanical recycling of waste plastics (Gu et al., 2017a). Similarly, hydrocyclone is only competent of separating binary plastics, and uses plenty of density medium which has a density in between the two types of plastics (Manidool, 1997; Richard et al., 2011; Yuan et al., 2015). Using a specific designed channel, hydraulic separation is a promising alternative in plastic separation (Lupo et al., 2016; Moroni et al., 2017). Still, this process can only handle binary plastic mixtures, and is also affected by particle sizes.

In this study, a technology denoted as "magnetic levitation" or "MagLev", which is based on a simple configuration of two identical square magnets are at precise alignment with like-poles facing each other, is applied and investigated for separating mixed waste plastics. Combining with the conventional Archimedes method, the magnetic levitation employs a much simpler, cheaper and more convenient configuration than the magneto-Archimedes levitation which uses delicate and expensive superconducting magnets of high magnetic flux density, which is up to 12 T (Ando et al., 2015) or 17 T (Liu et al., 2014a,b). Owning to the capacity of distinguishing minor differences in densities, that is, up to 0.0002 g cm^{-3} (Mirica et al., 2009), a level that can reflect the changes in molecular structures (Atkinson et al., 2013), this technology has been applied in density-based applications such as density measurement (see Mirica et al., 2010; Nemiroski et al., 2016a,b; Xie et al., 2016; Xia et al., 2017), forensic analysis (see Lockett et al., 2013), particle manipulation (see Mirica et al., 2011; Subramaniam et al., 2014), and quality control (see Hennek et al., 2015). However, according to the brief review, there is no reported application of this technology can be found in the arena of environmental engineering, or more precisely in waste management. Furthermore, very limited attention has been paid on applying the magnetic levitation method on particle separation, and the only relevant publication is about extracting desirable type from binary mixtures (Atkinson et al., 2013). To address the conundrum of separating mixed waste plastics more than two types, this work can extend the literature of applying magnetic levitation to solve engineering problems. Multiple commonly-used thermoplastics were used to simulate the mixed waste plastics more than binary, and were then applied to the proposed separation methods. The contribution of this study is threefold. First, the application of the magnetic levitation, a process is still in its early development, has been extended to the field of waste management, for separating and recycling resources from multiple mixtures. Second, a novel plastic separation process that based on magnetic levitation is developed, in which is multiple plastics can be separated based on their tiny density differences and without constrained by the particle sizes or in need of any exterior energy supply, as froth floatation and hydrocyclone do. Third, mathematical correlation between magnetic field, material density and levitated height is discussed for scaling up the experimental configuration. Currently, all the reported MagLev methods are employing standards for curve fitting (see Mirica et al., 2010; Nemiroski et al., 2016a,b; Xie et al., 2016; Xia et al., 2017), and the absence of such correlation could limit the further development of this process. Clarification of this mathematical correlation would provide tremendous implications for future research and potential industrialisation of the magnetic levitation technology.

The paper is organised as follows. Section 2 describes the device configuration, experimental design and procedure that used in this study. In Section 3, results of a series of experiments are presented and discussed, in which effects of sizes are studied and different plastic separation methods are compared. The conclusive marks and directions of future works are given in Section 4.