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A novel process for separation of hazardous poly(vinyl chloride) from mixed plastic wastes by froth flotation

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ABSTRACT

A novel method, calcium hypochlorite (CHC) treatment, was proposed for separation of hazardous poly (vinyl chloride) (PVC) plastic from mixed plastic wastes (MPWs) by froth flotation. Flotation behavior of single plastic indicates that PVC can be separated from poly(ethylene terephthalate) (PET), poly(acrylonitrile-co-butadiene-co-styrene) (ABS), polystyrene (PS), polycarbonate (PC) and poly(methyl methacrylate) (PMMA) by froth flotation combined with CHC treatment. Mechanism of CHC treatment was examined by contact angle measurement, scanning electron microscopy, Fourier transform infrared and X-ray photoelectron spectroscopy. Under the optimum conditions, separation of PVC from binary plastics with different particle sizes is achieved efficiently. The purity of PC, ABS, PMMA, PS and PET is greater than 96.8%, 98.5%, 98.8%, 97.4% and 96.3%, respectively. Separation of PVC from multi-plastics was further conducted by two-stage flotation. PVC can be separated efficiently from MPWs with residue content of 0.37%. Additionally, reusing CHC solution is practical. This work indicates that separation of hazardous PVC from MPWs is effective by froth flotation.

1. Introduction

The production of plastics has increased substantially due to the versatile properties and low price, consequently resulting in an enormous amount of waste plastics (Sawant et al., 2013). Most of waste plastics are disposed by traditional methods including landfill, incineration, which causes serious environmental problems and tremendous waste of resources. Due to the need for limiting greenhouse gases emissions and the rising prices of fossil fuels, recycling of plastic wastes is rapidly gaining significance as an alternative solution to waste management (Thanh Truc and Lee, 2016). The recycling of waste plastics, as a source of raw material, has a potential to make up for the shortage of virgin plastic production in plastic-product manufacturing and reduce the negative effects on environment. Therefore, recycling is a promising alternative and encourages the sustainable development and cleaner production of plastic industry (Alston et al., 2011).

Due to the difference in physical and chemical properties, additives and thermal properties, mixed plastic wastes (MPWs) cannot be reprocessed or recycled directly (Thanh Truc and Lee, 2016). In the case of environment, equipment and quality of recycled products, poly(vinyl chloride) (PVC) is a potential safety and hazard in the recycling process. A tiny part of PVC deteriorates the quality of other plastics. Incineration of waste plastics containing PVC generates hazardous hydrogen chloride gas and dioxins containing chlorine (Borgianni et al., 2002). In this regard, dechlorination or separation of PVC plastic receives wide attention (Yoshioka et al., 2008).

For MPWs recycling, techniques for separation of PVC are imperative. Several methods were developed for separation MPWs, such as froth flotation (Mallampati et al., 2016), density sorting (Gent et al., 2009) and triboelectric separation (Park et al., 2007). Froth flotation has been proved to be effective for separation MPWs at bench scale (Burat et al., 2009). Based on the selective attachment of air bubbles plastic surface, froth flotation can be utilized separation of plastic mixtures. The inherent hydrophobicity of most plastics poses a great challenge for separation MPWs by froth flotation, while surface hydrophobicity of plastics can be altered by some surface treatment methods. Several studies were conducted to separate PVC from binary plastics (Thanh Truc and Lee, 2016; Wang et al., 2015a, 2016). However, there exist many different types of plastics in waste stream. For example, poly(vinyl chloride) (PVC), poly(ethylene terephthalate) (PET), poly(acrylonitrile-co-butadiene-co-styrene) (ABS), polystyrene (PS), polycarbonate (PC) and poly(methyl methacrylate) (PMMA) are common plastics in MPWs. To the best of our knowledge, there is scarce report about separation PVC from multi-plastics.

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In this work, a novel method, calcium hypochlorite (CHC) treatment, was proposed to aid separation of MPWs by froth flotation. Based on the flotation behavior of single plastic, separation of PVC from MPWs was achieved by froth flotation combined with CHC treatment in binary and multi-plastic systems. Mechanism of CHC treatment was examined by contact angle measurement, scanning electron microscopy (SEM), Fourier transform infrared (FT-IR) and X-ray photoelectron spectroscopy (XPS).

2. Experimental

2.1. Materials

Samples of different kinds of waste plastics used in this study, including poly(vinyl chloride) (PVC), poly(ethylene terephthalate) (PET), poly(acrylonitrile-co-butadiene-co-styrene) (ABS), polystyrene (PS), polycarbonate (PC) and poly(methyl methacrylate) (PMMA), were purchased from Miluo plastic market (Hunan province, China). Plastic samples were obtained from waste plastics, such as bottles, water dispenser bucket, shell of household electric appliance, perspex partition. The samples of plastics were smashed with a crusher (SCP-180-2, Cixi Yinbo Plastics Machinery Co., Ltd.), washed with tap water, dried at room temperature and screened into different size fractions. The particle sizes of plastic samples used in this study were 0.9–2.0, 2.0–2.5, 2.5–3.2 and 3.2–4.0 mm. The molecular structures and pictures of plastic samples are shown in Fig. S1 (in Supporting Information).

Calcium hypochlorite, as treatment agent, was obtained from Sinopharm Chemical Reagent Co., Ltd. The frother, methyl isobutyl carbinol (MIBC), was obtained from Sinopharm Chemical Reagent Co., Ltd. Chemical reagents used in this study including calcium hypochlorite and MIBC were of analytical purity and used as received. Tap water was used as flotation medium throughout the flotation experiments.

2.2. CHC treatment

Plastic particles were treated with CHC solution (100 mL) in a thermostat-controlled water bath (JJ-4A-B, Chang Zhou Ao Hua Instruments Co., LTD, China). After CHC treatment, filtration was conducted to separate plastic particles and CHC solution. The particles were rinsed with tap water before flotation experiments. As to flotation behavior of single plastic, plastics with particles size of 2.0–2.5 mm were used as an example, and the fraction of plastic particles in CHC solution was 10 wt%. For separation of binary plastics, the fraction of plastic particles was 20 wt%. For separation of multi-plastics, PMMA, PVC, PET, ABS, PC and PS waste plastics (2.0–2.5 mm) were mixed with mass ratio of 1:1:1:1:1:1 and subjected to CHC treatment with fraction of 24 wt%.

2.3. Flotation experiments

The flotation experiments were conducted using a self-designed flotation column with a height of 170 mm and a diameter of 30 mm (Wang et al., 2015b). Air was passed through the sand core to produce gas bubbles, and an adjustable air-pump (Guangdong Hailea Group Co., Ltd) with maximum airflow rate of 7.2 ml min^{-1} was employed. Methyl isobutyl carbinol (52.8 mg L^{-1}) serving as frother was added into the flotation column during the flotation experiments. At the end of the flotation test, the float and non-floated plastic particles were collected, rinsed with tap water, dried in atmosphere, and weighed. The separated products were manually sorted according to the difference in color, and the flotation recovery and purity of each plastic in the floated and non-floated products were calculated based on mass balance Eqs. (1) and (2).

$$\varphi_{iF} = \frac{m_{iF}}{m_{iF} + m_{iS}} \times 100\% \quad (1)$$

$$\eta_{iF} = \frac{m_{iF}}{m_{iF} + m_{jF}} \times 100\% \quad (2)$$

where φ_{iF} and η_{jF} are the recovery and purity of component i in float product, respectively, %; m_{iF} and m_{iS} are the mass of component i in float and sink product, respectively, g; m_{jF} is the mass of component j in float product, g.

2.4. Reusing CHC solution

PVC and PET plastics were selected as an example to investigate the feasibility of reusing CHC solution. PVC and PET (2.0–2.5 mm) were treated with CHC solution under optimum conditions. After filtration, plastic particles were subjected to froth flotation for separating PVC/PET. The CHC solution was reused for treatment of PVC/PET plastics. Due to the loss of CHC solution, 5% CHC solution with higher concentration (3.0 g L^{-1}) was replenished. The flowsheet of reusing CHC solution was demonstrated in Fig. S2 (in Supporting Information).

2.5. Measurements

The wettability of plastic samples was evaluated by contact angle measurements using a contact angle measuring instrument (DSA20, KRUSS). Surface morphology was determined by a scanning electron microscopy equipped with energy dispersive spectrometer (Quanta FEG 250) with an accelerating voltage of 10 kV. FTIR spectra were determined using a Nicolet Avatar 360 FTIR spectrometer (Nicolet Magua Corporation, USA) in the wave region between 4000 and 400 cm^{-1}, resolution 4 cm^{-1}. XPS was determined by an X–ray photoelectron spectroscopy (ESCALAB 250Xi, Thermo Fisher Scientific).

3. Results and discussion

3.1. CHC treatment of simple plastic

Preliminary experiments indicate that CHC treatment affects the floatability of waste plastics. The factors of CHC treatment including CHC concentration, treatment time and temperature were investigated by single factor experiment. Fig. 1 shows the flotation recovery of single plastic as a function of experimental factors. It can be observed that PVC, PC, ABS, PS, PMMA and PET plastics possess inherent floatability. The flotation recovery of untreated samples is 100%, indicating that it is difficult for direct separation of PVC from other plastics by froth flotation.

CHC treatment affects significantly the flotation recovery of PVC, PC, ABS, PS, PMMA and PET plastics. The flotation recovery of PC, ABS and PVC drops sharply with an increase of CHC concentration (below 0.4 g L^{-1}). However, the flotation recovery of PMMA, PS and PET remains nearly 100% at CHC concentration below 0.7 g L^{-1} and drops with further increasing of CHC concentration. The proper CHC concentration for separation of PVC/PC, PVC/ABS, PVC/PMMA, PVC/PS and PVC/PET is chosen as 0.1, 0.2, 0.7, 0.7 and 0.7 g L^{-1}, respectively.

Treatment time and temperature were further optimized at the chosen CHC concentration. Plastics show different response to treatment time and temperature under experimental conditions. For PVC/PC, the flotation recovery of PVC decreases with an increase of treatment time and temperature, and the optimum conditions are 50 min and 70 °C. As to PVC/ABS, the flotation recovery of ABS decreases with an increase of treatment time and temperature, and the optimum conditions are 50 min and 70 °C. As to