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Separation of plastics by froth flotation. The role of size, shape and density of the particles

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ABSTRACT

Over the last few years, new methods for plastic separation in mining have been developed. Froth flotation is one of these techniques, which is based on hydrophobicity differences between particles. Unlike minerals, most of the plastics are naturally hydrophobic, thus requiring the addition of chemicals that promote the selective wettability of one of its components, for a flotation separation.

The floatability of six granulated post-consumer plastic - Polystyrene (PS), Polymethyl methacrylate (PMMA), Polyethylene Terephthalate (PET-S, PET-D) and Polyvinyl Chloride (PVC-M, PVC-D) - in the presence of tannic acid (wetting agent), and the performance of the flotation separation of five bi-component plastic mixtures - PS/PMMA, PS/PET-S, PS/PET-D, PS/PVC-M and PS/PVC-D - were evaluated. Moreover, the effect of the contact angle, density, size and shape of the particles was also analysed.

Results showed that all plastics were naturally hydrophobic, with PS exhibiting the highest floatability. The contact angle and the flotation recovery of six plastics decreased with increasing tannic acid concentration, occurring depression of plastics at very low concentrations. Floatability differed also with the size and shape of plastic particles. For regular-shaped plastics (PS, PMMA and PVC-D) floatability decreased with the increase of particle size, while for lamellar-shaped particles (PET-D) floatability was slightly greater for coarser particles. Thus, plastic particles with small size, lamellar shape and low density present a greater floatability.

The quality of separation varied with the mixture type, depending not only on the plastics hydrophobicity, but also on the size, density and shape of the particles, i.e. the particle weight. Flotation separation of plastics can be enhanced by differences in hydrophobicity. In addition, flotation separation improves if the most hydrophobic plastic, that floats, has a lamellar shape and lower density and if the most hydrophilic plastic, that sinks, has a regular shape and higher density.

The results obtained show that froth flotation is a potential method for plastics separation, in particular for plastics with particle size greater than 2.0 mm.

1. Introduction

Plastic is a synthetic material and a product of excellence, with wide application and use. Plastic materials possess many advantages and are increasingly being used in several products, especially in packaging, to replace other materials, such as metal, glass, ceramic, wood and paper. Besides their lower weight, higher durability and cheaper cost, compared to many other material types, plastics could be synthesized with a wide range of properties. As a result of their increasing use, the total global production of plastics has grown from around 1.5 million tonnes in 1950 to 311 million tonnes in 2014, being the European production of 59 million tonnes, which corresponds to 20% of the global plastic production (PlasticsEurope, 2015).

The increase in plastic production and consumption has been largely responsible for the increase in municipal solid wastes (MSW). Plastic waste has become one of the major categories in MSW. In Portugal, plastics account for approximately 11% of MSW by weight, and more than 30% by volume, due to their low density. Plastic waste is an important matter in terms of environmental sustainability and solid waste management, due to their current levels of usage and disposal. There are several ways to manage plastic waste disposal, namely landfill, incineration for energy production, reuse and recycling. The disposal of plastics

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in a landfill requires wider areas and longer residence times to achieve its degradation. Energy production by plastic waste burn can also generate emissions of gases such as nitrous oxide, sulphur oxides, dusts, dioxins and other toxins, especially plastics containing PVC (Braun, 2002). Thus, recycling is one of the most important actions currently available to reduce plastic environmental impact, which has increased over the last decades, contributing to reduce oil usage, carbon dioxide emissions and the quantities of waste disposal. Despite the importance of recycling, in 2014 only 29.7% of post-consumer plastics waste in Europe was recycled and 39.5% was recovered through energy processes, with landfill use as the main form of disposal (*circa* 30.8%) (PlasticsEurope, 2015). In the same year, Portugal recycled 33% of post-consumer plastic waste and recovered 28% through energy processes, even so 39% were deposited in landfills.

Plastic recycling requires a previous separation between plastics and other constituents and also between different polymer types, in order to achieve a good recycled plastic quality, since most plastic types are not compatible with each other due to the immiscibility at the molecular level which can cause serious processing problems (Braun, 2002; Carvalho et al., 2009) and lowers the product quality (Yenial et al., 2013). Thereby, the development of plastic separation techniques is a growing necessity.

In recent years, separation technologies based on the difference in physical or chemical properties have been applied to separate mixed plastic waste. These technologies include the automatic sorting based on surface properties; X-ray detection (X-ray transmission and X-ray fluorescence) (Arvanitoyannis and Bosnea, 2001; Bezati et al., 2011); near infrared (NIR) spectroscopy (Masoumi et al., 2012) and optical sorting based on the colour (Safavi et al., 2010). When objects are large and clean and mixtures are homogeneous these sorting methods are efficient in separating plastics. However, the efficiency drops with particle size reduction and surface contamination of plastic objects.

Also, several separation methods widely used in the mining industry (e.g. gravity methods, electrostatic separation and froth flotation) have been applied in the separation of plastic mixtures, each one with their advantages and limitations. Dodbiba and Fujita (2004), as well as Gent et al. (2011), reviewed all recent progresses and the potential of the available techniques, emphasizing the role of the mineral processing technologies in plastic separation.

Gravity separation methods are effective in separating materials with different specific gravity, but polymers of similar specific gravity cannot be separated using these methods. Gravity separation methods include float-sink tanks, jig, shaking table, cylindrical cyclone media separator and liquid-fluidized bed technique (Pascoe and Hou, 1999; Ferrara et al., 2000; Pascoe, 2006; Kinoshita et al., 2006; Carvalho et al., 2009; Gent et al., 2011; Kuwayama et al., 2011; Pita and Castilho, 2016).

Electrostatic separation techniques are based on differences in electric conductivity, friction charge and dielectric properties of components in a mixture, but cannot be used when there are small differences in electrostatic charge (Lungu, 2004; Tilmatine et al., 2009; Bedeković et al., 2011). As a dry method, the electrostatic separation has a clear advantage over wet methods, since it avoids the wastewater generation.

Several combination techniques are also used for the separation of mixed plastic, like air tabling and triboelectric techniques (Dodbiba et al., 2005; Li et al., 2015); sink-float separation and flotation (Pongstabodee et al., 2008); or jigging and flotation (Hori et al., 2009). In fact, Hori et al. proposed, in 2009, a new gravity separator (Hybrid-Jig), based on jigging and flotation, in which the air bubbles introduced into the particle bed during jigging modify its apparent specific gravities. Thus particles with different surface properties can be separated by jigging even if their specific gravities are similar.

Froth flotation is the most important and versatile separation method used in mining industry. Froth flotation also is a promising alternative for plastic separation, enable flotation receive increasing attention all over the world (Shen et al., 1999; Fraunholcz, 2004; Wang et al., 2015a, 2015b). The basis of froth flotation relies on the different wettability of minerals. It is a physical-chemical process based on the selective adhesion of specific particles to the air (hydrophobic particles) or the water (hydrophilic particles) in a solid/water pulp. The separation takes place in a container (flotation cell), where water and particles are put together, and then air is continuously injected giving rise to the formation of air bubbles. This pulp is previously conditioned with the controlled addition of small quantities of specific chemical reagents to promote the selective formation of aggregates between solid particles of a certain composition and air bubbles. After collision, hydrophobic particles adhere to the air bubbles, moving upwards to the top of flotation cell where they are recovered as the floated product. Hydrophilic particles settle in the pulp and become the non-floated product. Froth flotation can be adapted to a broad range of particle separations, since it is possible to use chemical treatments to selectively alter particles hydrophobicity in order to obtain the desired properties for the separation.

Plastics are hydrophobic by nature therefore, in the separation of plastic mixtures by froth flotation, the surface of one or more species should become hydrophilic, while the others are kept hydrophobic. One of the methods of selective wetting is chemical conditioning with wetting agents.

In plastic flotation, the selective adsorption of depressant molecules influences the affinity of air bubbles for different types of plastics. Many reagents have been tested as wetting agents aiming the selective flotation of plastic mixtures. Tannic acid, saponin, methyl cellulose, sodium lignin sulfonate and calcium lignin sulfonate have been used by several authors (Shibata et al., 1996; Shen et al., 1999, 2001, 2002; Marques and Tenório, 2000; Basarová et al., 2005; Takoungsakdakun and Pongstabodee, 2007; Abbasi et al., 2010; Kangal, 2010; Carvalho et al., 2010; Wang et al., 2014a). Nevertheless, plastic flotation is controlled not only by the hydrophobicity but also by the shape and size of the plastic particles (Shibata et al., 1996; Pascoe and Hou, 1999; Shen et al., 2001, 2002; Fraunholcz, 2004; Burat et al., 2009; Wang et al., 2015a, 2016).

In this work tannic acid was used to study the flotation behaviour of six plastics and to study the flotation separation of post-consumer plastic mixtures. The separation efficiency relatively to the tannic acid dosage was also evaluated by flotation recovery and contact angle measurement. Additionally, the effect of size, shape and density of the particles were analysed.

2. Materials and methods

2.1. Materials

This work used six types of granulated plastics from three recycling companies: Polystyrene (PS, black), Polymethyl methacrylate (PMMA, white), Polyethylene Terephthalate (PET-D, transparent) and Polyvinyl Chloride (PVC-D, gray) from Daniel Morais; Polyethylene Terephthalate (PET-S, blue) from Logociclo-Selenis and Polyvinyl Chloride (PVC-M, light green) from Micronipol. The plastics differed on colour and shape, which facilitated separation through manual sorting at the end of each flotation test. The density of these plastics, measured by an Ultra Pycnometer (AccuPyc 1330), ranged from 1.047 g/cm^3 (PS) to 1.372 g/cm^3 (PET-S) (Table 1).