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Separation of plastics: The importance of kinetics knowledge in the evaluation of froth flotation

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ABSTRACT

Froth flotation is a promising technique to separate polymers of similar density. The present paper shows the need for performing kinetic tests to evaluate and optimize the process. In the experimental study, batch flotation tests were performed on samples of ABS and PS. The floated product was collected at increasing flotation time. Two variables were selected for modification: the concentration of the depressor (tannic acid) and airflow rate. The former is associated with the chemistry of the process and the latter with the transport of particles. It was shown that, like mineral flotation, plastics flotation can be adequately assumed as a first order rate process. The results of the kinetic tests showed that the kinetic parameters change with the operating conditions. When the depressing action is weak and the airflow rate is low, the kinetic is fast. Otherwise, the kinetic is slow and a variable percentage of the plastics never floats. Concomitantly, the time at which the maximum difference in the recovery of the plastics in the floated product is attained changes with the operating conditions. The prediction of flotation results, process evaluation and comparisons should be done considering the process kinetics.

1. Introduction

Polymer recycling is a reality in many countries today. In 2014, the total amount of plastics produced in the world was estimated at 311 million tonnes. In Europe (EU28+Norway and Switzerland), 59 million tonnes were produced in the same year and more than 25 million tonnes of plastic waste ended up in the waste stream, almost 30% of which were recycled (Plastics Europe, 2015).

In most cases, different polymers cannot be recycled together mainly due to their different melting temperature. Therefore, the objects composed by different materials must be fragmented for materials liberation to obtain single material particles. The particles of different materials must then be separated.

Froth flotation has been successfully used to separate plastics of similar density. Froth flotation is a promising technique, particularly in the case of small WEEE (Waste from Electrical and Electronic Equipment), where the particle size needed to free the materials may be in the millimeter range or below.

Many researchers from all over the world are researching plastic flotation from different points of view such as mechanisms, methods and reagents. The PhD thesis by Fraunholcz (1997) and the papers published by Shibata et al. (1996) and Drelich et al. (1999) were undoubtedly pioneer works. Wang et al. published a comprehensive review of the literature in this subject in 2015 (Wang et al., 2015a).

One premise of correct experimentation is reproducibility, that is, any researcher should obtain the same results under the same conditions. Nevertheless, the authors of the present paper frequently could not obtain the results published by other authors in scientific journals although the same methods and operational conditions were used. A possible reason for this was the different compositions of the plastics. In fact, some authors use virgin polymers or unused items. Yet, although the materials have the same label, there may be different additives in their composition that may affect their behavior when froth flotation is used. Furthermore, when using post-consumer polymers, the previous contact of the plastic particles with other substances and/or the grinding method may affect the surface of the particles. Another reason for the different results can be attributed to the equipment. Due to the weak forces between polymer particles and reagents, the type of equipment (flotation column or mechanical cell, for instance) may play a significant role in the recovery of the polymers in the flotation products, explaining some differences in the results.

The present paper addresses another possible reason for the lack of reproducibility – neglecting to take into account the

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flotation kinetics. In mineral flotation, the process optimization is commonly based on the evaluation of the process kinetics (see for instance some recently published works by Albijanic et al. (2015), Ni et al. (2016), and Nyabeze and McFadzean (2016)). In polymer flotation, as far as the authors know, it has not been addressed. With regard to the separation of plastic mixtures and process optimization, the common practice to evaluate separability and to discover the optimum operating conditions is to test different operational conditions at fixed flotation time (see for instance Basařová et al. (2005), Carvalho et al. (2012), Marques and Tenório (2000), Pascoe (2005), Pongstabodee et al. (2008), Shen et al. (2002a, 2002b) and Takoungsakdakun and Pongstabodee (2007)). Wang et al. (2012, 2014, 2015b) have performed kinetic flotation tests but the process kinetic parameters were not related to the operating conditions.

The flotation of mineral particles is commonly assumed as a first-order rate process (Xu, 1998). The recovery of the particles, R, at time t, can usually be approximated by using Eq. (1)

$$R(t) = R_{\infty}(1 - e^{-kt}) \quad (1)$$

where k is the flotation rate constant and R_{∞} is the flotation recovery at infinite time. Different particles correspond to different values of the equation parameters at any given set of chemical and physical operating conditions. Because of the presence of middling particles, it is common for sets of particles to be defined in mineral flotation, e.g. fast and slow floating particles.

In mineral processing this is a common tool to evaluate flotation performance and to optimize the process. With regard to polymer flotation, the kinetics has not been addressed mainly because the flotation concerns liberated particles in close particle size intervals. Furthermore, the flotation speed is quite high.

In the present work, an experimental study was carried out to evaluate the need for performing kinetic tests in the flotation of plastics. The plastics used were PS and ABS. These polymers are difficult to separate by simple and cheap methods such as density separation. The samples used came from post-consumer electrical appliances. Two operating conditions, depressor concentration and airflow rate, were modified to evaluate whether changing those conditions had an effect on the operating conditions of the process kinetics. The wetting agent used to depress ABS was tannic acid, which has been used with success by different authors in the separation of polymers (Wang et al., 2015a).

2. Materials and methods

2.1. Sample

The ABS and PS samples were collected in a Portuguese shredder facility. In this plant, the WEEE are first manually dismantled and then shredded. The samples were collected in the plant prior to shredding. The ABS sample was collected from vacuum cleaners and the PS was collected from printers. To ease the evaluation of test results, the plastics selected were of different colors; the former was orange while the latter was gray. The measured density of the plastics was, respectively, 1.03 and 1.04 ± 0.01 g/cm^3.

The sample preparation started with the shredding using a Retsch SM 2000 cutting mill equipped with a 10 mm sieve. The particles obtained after shredding were classified by particle size, using a Fritsch Analysette vibrating sieve apparatus.

The size fraction selected for the experimental work was 2–4 mm. The experimental tests were performed with samples with 10 g of each polymer, i.e., equal proportion of both polymers.

2.2. Experimental methodology

The flotation tests were carried out in a Leeds laboratory flotation cell (see Fig. 1) with 5 L of volume. This cell is mechanically agitated by a rotating impeller located at the bottom of the cell. This feature allows air bubbles/particles aggregates to form in a uniform manner, leaving the surface undisturbed by the presence of an impeller shaft. A grid is located at mid-height to prevent exaggerated turbulence. These features are especially important in the flotation of plastics due to the low density and to the weak forces between particles and air bubbles, which make them more sensitive to turbulence than mineral particles.

Compressed air is introduced in the bottom of the cell at the center of the impeller blades. Fraunholcz (1997) showed that the depression of plastics must be made in the presence of cations, hence tap water was used. The flotation was carried out at natural pH, meaning that no manipulation of pH was made. Nevertheless, the pH and temperature of the tap water were measured in all tests. The respective values obtained were a pH of 8 and 24 °C, with negligible variations.

Fig. 2 illustrates the experimental procedure used. Before each flotation test, the sample was mixed with tap water for 10 min

Fig. 1. Leeds flotation cell used in the study.

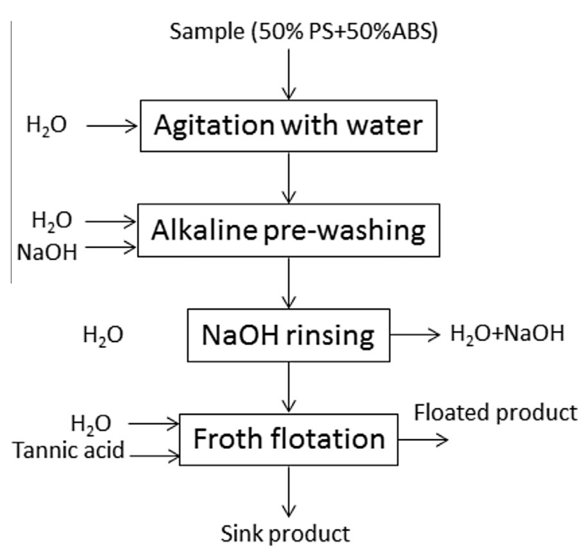

Fig. 2. Experimental procedure diagram.