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Study of the physicochemical effects on the separation of the non-metallic fraction from printed circuit boards by inverse flotation

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ABSTRACT

Recycling printed circuit boards using green technology is increasingly important due to the metals these contain and the environmental care that must be taken when separating the different materials. Inverse flotation is a process that can be considered a Green Technology, which separates metallic from non-metallic fractions. The degree of separation depends on how much material is adhered to air bubbles. The contact angle measurement allows to determine, in an easy way, whether the flotation process will occur or not and thus establish a material as hydrophobic or not. With the material directly obtained from the milling process, it was found that the contact angle of the non-metallic fraction-liquid-air system increases as temperature increases. In the same way, the increments in concentration of frother in the liquid increase the contact angle of the non-metallic fraction-liquid-air system. 10 ppm of Methyl Isobutyl Carbinol provides the highest contact angle as well as the highest material charging in the bubble.

1. Introduction

Electrical and electronic equipment production are fast growing sectors due to their increased use as well as their upgrades, and in some cases, due to the high-cost repairs, in contrast to new equipment costs as well as large amounts of obsolete equipment that generates a lot of electronic waste (e-waste), which grows at a rate three times faster than the average municipal waste (Estrada-Ruiz et al., 2016).

Recycling this type of waste is important due to the amount of plastics and metals found in them, promoting on the one hand, the reduction of e-waste generated and pollution associated with these waste, and on the other hand to the recovery of base and precious metals found in this equipment, such as Au, Ag, Pd, Pt, Cu, Sn, Fe, Al, Pb, Zn, Ni, Sb, Be, Br, Cd, Cr, etc. preserving the metallic sources (Kim et al., 2011; Mallampati et al., 2016).

E-waste recycling can be done using chemical and / or physical techniques as the use of acids and incineration of printed circuit boards (PCBs). These chemical recycling techniques are unfriendly to the environment, since the large amount of liquid generated can contaminate the soil of the surroundings. In addition, when this liquid is adsorbed underground, it can pollute groundwater reserves; as well as the low kinetic process (Kim et al., 2011). Incineration also generates poisonous gases due to the presence of some heavy metals such as lead, mercury, and bromide flame retardants. Physical techniques are less aggressive to the environment because these techniques promote the separation of the different materials that contain the PCBs by physical processes such as crushing, size separation, density separation, magnetic separation, flotation, liquid-solid fluidization, and inverse flotation, among others (Estrada-Ruiz et al., 2016; Zhao et al., 2017).

The froth flotation technique is an excessively complex physicochemical process. The chemistry behind froth flotation needs to be such that at least one particle specieś surface favors adherence to air bubbles introduced into the cell, based on the property of some materials being hydrophobic while others are hydrophilic (Estrada-Ruiz et al., 2016; He and Duan, 2017). Surface properties of bubbles are important in froth flotation of fine particles, modifying these properties by absorbing some surfactant can alter the surface of one of the phases to make it more hydrophobic

Abbreviations: e-waste, electronic waste; PCBs, printed circuit boards; CAH, Contact Angle Hysteresis; MIBC, Methyl Isobutyl Carbinol; θ_A, advancing contact angle; θ_R, resending contact angle.

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(Bueno-Tokunaga et al., 2015; Güney et al., 2015). Taking into account that more than 30% of e-waste consists of plastics that are hydrophobic in their natural state, with low surface energy, the non-metallic fraction will adhere to air bubbles, whereas the metallic fraction will not, due to the difference in wettability between these two fractions, allowing the metallic fraction to enrich in the tails before making any surface modification (Estrada-Ruiz et al., 2016; Mallampati et al., 2016; Vidyadhar and Das, 2013; Wang et al., 2015a, 2015b, 2014a, 2014b).

The addition of a type of frother produces a closed distribution of the air bubbles, it also stabilizes them, reduces their size and decreases the rate of ascent, favoring the separation of the fractions. Common flotation frother includes low molecular weight surfactants such as Methyl Isobutyl Carbinol (MIBC) (Pogorzelski et al., 2013; Tan and Finch, 2016a; Wang et al., 2014a, 2014, 2011).

Wettability is one of the most used techniques due to its simplicity to determine the adhesion properties of a material surface. The classic illustration of the three-phase contact between water, air bubble and an ideal smooth surface is shown in Fig. 1. In equilibrium, the three free-energy interfaces Υ are related by the Young-Dupré equation.

$$\gamma_{sa} - \gamma_{sw} = \gamma_{wa} cos\theta_c \tag{1}$$

where θ_c is the contact angle and γ_{sa}, γ_{sw}, and γ_{wa} the solid-air, solid-water, and water-air interfacial energies, respectively. When a large spherical bubble and a small smooth particle surface are considered, the same Eq. (1) is obtained.

In order for froth flotation to occur, a solid-air interface must be created with the simultaneous destruction of the water-air and solid-water interfaces of the same area. Thus, to take place the adhesion of the solid particle in a bubble,

$$\gamma_{ma} - \gamma_{mw} < \gamma_{wa} \tag{2}$$

The change in physical energy $\Delta\gamma$ associated with the creation of the solid-air interface is obtained by the equation

$$\Delta\gamma = \gamma_{ma} - (\gamma_{wa} + \gamma_{wm}) \tag{3}$$

$\Delta\gamma$ is referred to as the adhesion work, or breakup coefficient. To make the froth flotation possible, i.e. in order to create a solid-air interface, the free energy change $\Delta\gamma$ given by Eq. (3) must be negative. Combining equations it gives

$$\Delta\gamma = \gamma_{wa}(cos\theta_c - 1) \tag{4}$$

This equation has been frequently used to analyze the flotation process: the more negative the value of $\Delta\gamma$, the greater the probability of adhesion between particle and bubble is and therefore, flotation as well (Kelly and Spottiswood, 1982).

Using the sessile drop method, a method based on Eq. (1), the contact angle between the surface of interest and the surrounding environment can be measured. It is a quantifiable technique with an easy procedure that allows the characterization of the wettability of surfaces. The hysteresis contact angle (CAH), i.e. the difference between the advance contact angle θ_A and the resending angle θ_R, is a measure of the surface "non-ideality" and it is closely related to the adhesion of the materials on surfaces (Pogorzelski et al., 2013).

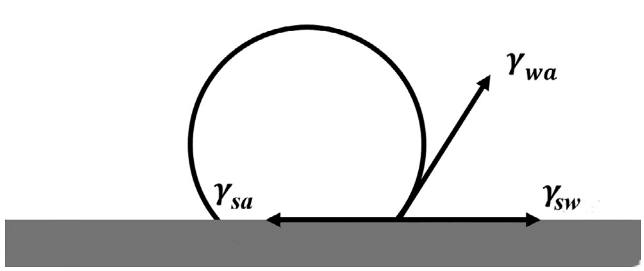

Fig. 1. Idealized representation of the three-phase equilibrium contact between air, water and solid surface.

The aim of this work is to find an approximation to the contact angle in real surfaces of the non-metallic fraction as a function of the temperature and of the amount of frother, to determine the degree of wettability of the particles obtained from the comminuting process of the PCBs and thus determine whether an inverse flotation process occurs during separation of the metallic fractions from the non-metallic fractions.

2. Experimental

2.1. Materials

Printed circuit boards (PCBs) obtained from arcade machines were the raw material for this work. The printed circuit boards were visually inspected to find and remove toxic components such as electrolytic capacitors and batteries, as well as large easy-to-handle metal parts such as a heat dissipater and screws. After this first step, the PCBs were cut with a guillotine at an average size of 15 cm per side. Finally, a crushing process employing a Craftsman crusher blade modified with a 5 HP single-phase motor with a 6 mm diameter screen was done. A grinding process was performed inside an atmospheric control chamber, so that the fine particles will be trapped within it and it can be quantified. The material generated by the grinding process was screened using a sieving mesh and a ro-tap. The particle size chosen for this experiment was 250 μm, because with this size there is a good separation of the metallic fraction from the non-metallic fraction as referred in (Estrada-Ruiz et al., 2016; Ruan and Xu, 2016). The structural characterization of the material was performed using optic microscopy in a CK40 M Olympus microscope and a Dino-Lite digital microscope.

2.2. Contact angle

Fig. 2 shows the test device for measuring the contact angle in the non-metallic fraction-liquid-air system, this consists of a rectangular glass container equipped with a flat-tipped syringe articulated with a homogeneous movement to ascend and descend vertically, which generates relatively large air bubbles (approximately 2.75 mm radius). An air bubble was generated at the flat tip of the syringe, it was held in the liquid phase to allow the system stability before it got in contact with the surface of the non-metallic fraction, then, bubble is forced against the material, it was retained between the non-metallic fraction material and the flat tip of the syringe to obtain the advancing angle. subsequently, the bubble is retracted, and just before contact with the solid is lost the receding angle is obtained. Finally, the air bubble is separated

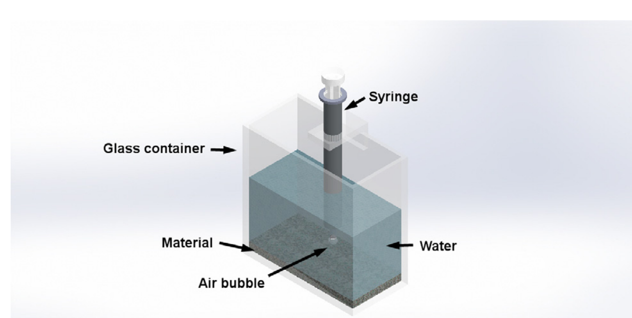

Fig. 2. Experimental apparatus used for the measurement of the contact angle.

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