SEPARACIÓN DE PLÁSTICOS RECICLADOS DE RESIDUOS DE EQUIPOS ELECTRÓNICOS COMO ALTERNATIVA PARA REAPROVECHAMIENTO DE ENERGÍA

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***Resumen* — Los residuos de equipos electrónicos se han convertido en un gran problema ambiental debido al rápido avance tecnológico y a que el plástico es uno de los residuos que más contaminan. El reciclaje de plástico es de vital importancia para la industria, pues permite un ahorro de energía al mismo tiempo que protege al medio ambiente. El descarte excesivo de plástico se ha convertido en un gran obstáculo para su disposición en rellenos sanitarios es por eso que se hace necesario emplear una técnica de separación adicional con el fin de producir plásticos con un alto valor agregado. El análisis de las características de los residuos plásticos y de las propiedades físicas del plástico han demostrado que además de las tecnologías de separación existentes se puede aplicar otras técnicas para separar los plásticos. La flotación de plástico por ser una técnica más flexible que otras puede ser útil en la separación de plásticos mezclados utilizando agentes humectantes selectivos. Existe un gran número de plásticos de ingeniería en la WEEE entre los que tenemos el acrylonitrilo-butadieno-estireno (ABS) y poliestireno de alto impacto (HIPS). El ABS y el HIPS son difíciles de separar porque tienen densidades similares y no hay atracción por agua. En lo experimento fue usado alcohol etílico en la concentración de 20% en masa cómo depresor en una célula de vitro. Los plásticos flotados fueron removidos mecánicamente y no fue necesario usar espumante. El proceso fue capaz de producir una concentración de HIPS con aproximadamente 93% de pureza y el ABS con 99% de pureza.**

***Palabras claves* — Ambiental, Energía, Flotación, Plástico, WEEE.**

***Abstract* — Waste Electrical and Electronic Equipment (WEEE) became an important environmental issue due to the constant technological evolution. Waste plastic is one of the main polluters and to recycle, it is necessary a separation step. Plastic recycling is important to the plastic industry and for energy savings. There are many kinds of plastics in extensive use at the present time and the most common in the electronic industry are the acrylonitrile-butadiene-styrene (ABS) and high impact polystyrene (HIPS). These plastics are difficult to separate because they have similar specific weights and both are repellent to water. Froth flotation may become possible by the proper use of selective wetting agents. Our experimental work tried to use ethanol to depress the plastics and was conducted in a glass cell. The floated plastics were mechanically removed and no additional frother was required. The process with 20% weight of ethanol was able to produce a concentrate of HIPS with at least of 93% purity and ABS with 99% purity.**

***Keywords* — Energy, Environmental, Flotation, Plastic, WEEE.**

I. INTRODUCTION

In the world, plastic has become a worldwide material and plays an important role in many applications. Plastic is lightweight, strong and cheap, and it can be synthesized with a great range of properties. The global production of plastic has grown exponentially over the years and correlates quite well to population growth. The increase in plastic consumption is largely responsible for the increase in waste electrical and electronic equipment (WEEE) production to WEEE recovery is challenging because of the presence of a diverse number of materials [1]; [2]. Considering only the plastic content of WEEE, it can be based on more than 15 different types of engineering plastics, including acrylonitrile-butadiene-styrene (ABS) and high impact polystyrene (HIPS) [3].

There are several methods for plastic waste disposal, landfilling, pyrolysis, incineration with energy recovery and recycling [4]. Plastics disposal

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in a landfill requires a vast area and the plastics demand a long time to be degraded. The pyrolysis methods, although the output products have a high calorific value, needs high-energy consumption and generates air pollution. Incineration with energy recovery requires a complex device to eliminate hazardous products before discharging the gases to the environment. Plastics gathered for recycling must be separated into polymer types to achieve fair recycled plastic quality. So, an effective separation of the mixed plastic waste is essential. In plastics material recycling, it is often necessary to separate mixtures of plastics into individual plastics in order to produce a useful recycling plastic product because some species are not compatible when re-melting. Outside recycling, the life circle of products just becomes a set of events without a logical solution to the resource conservation, since the potentially useful materials can hence become a hazard to environment. Other separation technologies, like gravity separation [5], electrostatic separation [6] and froth flotation [7]; [8]; [9]; [10] can be required to separate mixed plastic waste. But, it is difficult to separate mixed plastic by gravity separation due to their similar specific weights as well as to separate mixed plastic waste with small differences in charge by the electrostatic technique.

Froth flotation has been a broadly used technique in the raw materials processing industry for more than a century to separate the valuable components of ore from the gangue mineral [11]. Separation by froth flotation involves selective attachment of air bubbles onto the particles to be separated in a liquid medium [12]; [13]; [14]; [15]; [16]: bubbles attach to the hydrophobic particles. Since in the natural state, most plastics are hydrophobic, selective wetting of one component is necessary for their separation. This can be reached by adsorption of proper wetting agents. In froth flotation, wetting agents are related to as depressants as they suppress flotation of the wetted particles [17]. For flotation separation, it is necessary to make one of the plastics more hydrophilic than the other. This is done by selectively changing the surface wetting characteristics of specific plastics from hydrophobic to hydrophilic [18].

Plastic flotation is controlled not only by surface chemistry based on modifying wettability of the plastic but also by the shape and size of the plastic waste [19]; [20]. There are many factors affecting the efficiency of flotation operation: particle size, froth stability, number of air bubble per unit volume, conditional time, particle shape, specific gravities of the solid particles, selective depressant, agitation intensity and hydrophobicity [21].

A theoretical equation and establish the relation of floatability of plastics with surface chemical-related and gravity-related factors (ρ_p, Φ and d_p – diameter of particle) [8]. The equation shows that particle size and shape control is important for plastics flotation.

$$\rho_{bp} = \frac{1.59 d_{pe}\ \rho_p \phi}{1.59 d_{pe}\, \phi + 4K d_b}$$

ρ_{bp}=bubble and particle aggregate specific gravity
d_{pe} = diameter of particle equivalent sphere
ρ_p = specific gravity of the particle
Φ = shape parameter
K = bubble coverage percentage of the particle surface and the value is related with surface chemical related factors in plastic flotation.
d_b = diameter of bubble

Plastics particles are generally larger than the bubbles and as a result, one or more bubbles will attach to a single particle. Supposing a particle can be floated depends on its bubble-particle aggregate specific gravity, ρ_{bp}. If $\rho_{bp} > 1$ g/cm^3, the particle will not be floated, although there are some bubbles attaching onto the particle surface. The lower value of ρ_{bp}, the higher floatability the particle exhibits. From the theoretical equation, the bubble-particle aggregate specific gravity increases with the diameter of particle, suggesting that particle floatability decreases with particle size and increases with the shape parameter, meaning plate or flake, irregular and elongate particles have higher floatabilities than spherical particle since the shape parameter values of the former are lower than the final. Wetting of particle surfaces by wetting agents will cause a decrease in surface chemical-related factor and therefore an increase in bubble-particle aggregate specific weights, implying that particle floatability decreases with wetting agent additions.

Therefore, the froth flotation technique that has been investigated for the separation of ABS and HIPS from WEEE and the depressors concentration throws a significant function in the process.

II. MATERIALS AND METHODS

WEEE was gotten from a local agent in Brazil - CEDIR (Re-use Center of WEEE). The recycling unit (CEDIR) is located at the University of São Paulo, campus of São Paulo city. For the WEEE, the process also starts with dismantling on the separation of the cables, plastics, metals and glass. The procedure used to identify the plastic was based on the resin identification code (RIC) of the Society of the Plastics Industry. Along with the type and color of polymer will also be identified, although this mainly covers whether it is dark or not. The ABS and HIPS were shredded by a cutting mill (RONE FA2305) and screened into seven size fractions, +5.66; -5.66+2.83; -2.83+2.00; -2.00+1.00; -1.00+0.50; -0.50+0.30 and -0.30mm. The plastic sample was crushed and 2,00-2,83 mm size fractions used for studies. Fig. 1. represents the image of the crushed plastic sample at the -2.83+2.00 mm size fraction used for the selective flotation separation studies.

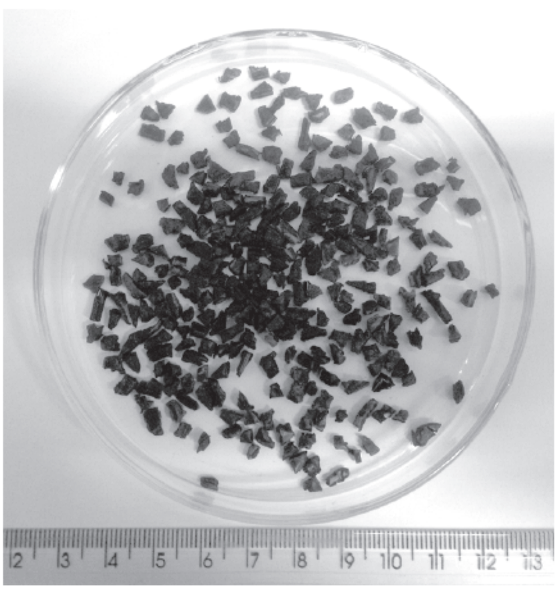

Fig 1. Image of HIPS -2.83+2.00mm size

The specific weights of the HIPS and ABS were measured in a pycnometer. The depressant was added as a solution of ethanol P.A. (99,5% purity, supplied by CAAL) at different concentrations. The experiments were conducted in a glass cell, 105 cm high and 8 cm in diameter with a volumetric capacity of 3 dm^3. A ceramic porous sparger plate (pore diameter of 10^{-16} μm) at the base of the cell was used to produce gas bubbles with compressed air (3.0 dm^3/min). The flotability tests were carried out with the wetting agent in the cell and were made gas bubble into contact with the plastic particles. Approximately 10g of each of the plastic samples were taken for test. No additional frother was required a conditioning time of 5 minutes was used. The sufficient conditioning time was allowed for proper mixing of the plastics. The floated plastics were mechanically removed for a 10 minutes flotation period. The recovery of individual materials was determined by counting the particles and identified by color and collected in the concentrate.

III. RESULTS AND DISCUSSION

In the plastics recycling process, cutting mill shredders products of plastics are the feed materials to the flotation process and the particles are not uniform in size and shape. According the principle of the effects of particle size and shape on plastics floatability, it is necessary to control particle size and or shape to achieve a higher selectivity for plastics flotation [18]. The ABS and HIPS are difficult to separate because they have similar specific weights and both are repellent to water. The specific weights of these plastics are summarized in TABLE I.

TABLE I
TYPE AND SPECIFIC GRAVITY OF THE INVESTIGATED PLASTICS

Plastic Type	Specific Weights (kg/m3) from WEEE	Specific Weights (kg/m3) by Fraunholcz (1997) [18]
HIPS	1,080	1,070
ABS	1,040	1,050

Flotation tests were conducted with -2.83+2.00 mm particles size fraction, following a conditioning time of 5 min. No additional frother was required. Fig. 2. shows values of flotation recovery as a function of reagent concentration. The percent flotation recovery of individual plastic from a mixture of two in the presence of ethanol (20% wt.) was observed in a Fig. 2. and the results was 99% for HIPS and 90% for ABS

According to TABLE II, flotation recoveries measured at concentration of flotation agent shown that the wettability decreases additionally at higher concentrations. The wetting agent, ethanol, decreases the flotation recovery with the optimal concentration was in 20% wt. and increased the wettability of ABS.

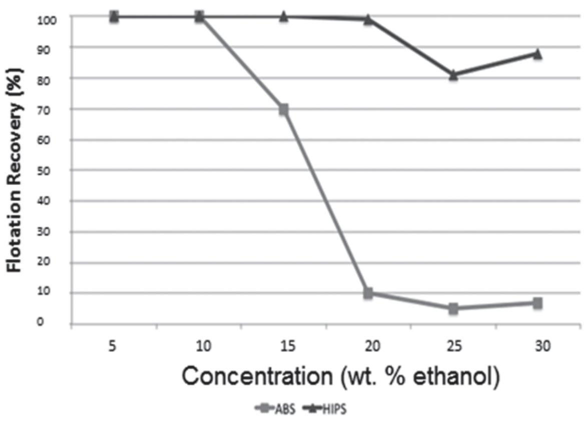

Fig. 2. Flotation response of ABS and HIPS as a function of ethanol concentration

TABLE II
FLOTATION EXPERIMENT USING ETHANOL P.A.

Reagent	ABS Recove ry (%)	ABS Purity (%)	HIPS Recovery (%)	HIPS Purity (%)
Ethanol P.A. (20% wt.)	90	99	99	93

In the presence of air bubbles the behavior of the plastic particles is significantly influenced by the wettability of the plastics. The experimental work tried to use the ethanol to depress the ABS and got good results, the process with 20% weight of ethanol was able to produce a concentrate of HIPS with least of 99% recovery and 93% purity, ABS with 90% of recovery and 99% purity.

IV. CONCLUSION

The experimental work tried to use ethanol with P.A. grade chemical to depress the plastics and got good results. The process with 20% weight of ethanol P.A. grade chemical was able to produce a concentrate with at least of 93% purity for HIPS and 99% purity for ABS.

Froth flotation is flexible and useful to separate mixtures of plastics. It is possible to separate ABS and HIPS by flotation from WEEE with the use of proper wetting agents and by adjusting experimental conditions to induce selective flotation.

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