Characterization and separation based on WEEE polymer particle shape.

Ana Rita Antunes Marçal

Thesis to obtain Master of Science Degree in Environmental Engineering

Instituto Superior Técnico, Tecnical University of Lisbon, Lisbon, Portugal

Abstract

The new European targets (from 2012) for Waste from Electronic and Electric Equipment (WEEE) and the fact that up to 40% of plastics from WEEE end up in the landfill are strong reasons to pursue investigation within plastics separation and apply it to WEEE. In this context, it was proposed to investigate whether the shape of identical densities plastics fragmented particles is a differentiating factor between materials. Images of ABS, HIPS and PS from WEEE treatment facilities were analyzed according to size, type of plastic and type of fragmentation (usage off different equipment). Three morphological indicators were used to describe the behavior of the particle regarding their convexity of silhouette, circularity and elongation. It was proposed as well to perform a set of tests with exploratory character to investigate whether the difference in particle shape can lead to separation of different plastics. The separation tests were conducted in gravity concentration equipment Recglass, where particle shape would be the determining factor in the separation. In these experiments a mixture of PS and ABS was used with different particle shape and color per plastic to provide quick and easy identification. In these experiments were used binary mixtures of PS and ABS with various compositions and size classes. Main results in particle shape analysis provide evidence that fragmented plastic particles is a function of size class, fragmentation equipment used and plastic type. Separation results indicate a moderate separation of both plastics, but further investigation is needed to better understand the separation potential of similar density WEEE plastics with different particle shape.

Introduction

Context

The management of Waste from Electronic and Electric Equipment (WEEE) already implemented and working in Portugal will be confronted with more demanding challenges originated from the growing diversity and quantity of WEEE has well the change of legal context for more ambitious collection and recycling targets [1].

In terms of separation WEEE is a heterogeneous flow [2], and for the small dimension WEEE, many materials can only be separated for recycling after a fragmentation process [3]. Plastics are, in weight, the second main component of WEEE [4], [5], with ABS, PS, HIPS and PP being the most common in small WEEE [6–8].

The use of optic separation, which is a typical technique for polymer separation, has limitations concerning the separation of WEEE component particles, due to their frequent dark colors [9] and small caliber [10]. Density is a propriety largely used for polymer separation, but it cannot be used in the separation of polymers with similar densities. Other techniques, such as flotation by foam have been applied with relative success in some polymer mixtures [11].

Considering that the shape of the particles is a propriety that affects most of the separation processes, it was studied if this propriety could have a more relevant role as a potential differentiation and separation factor.

On the WEEE treatment and management, there are a set of polymers, for example ABS/PS or POM/PVC, that are not separated in conventional facilities. These sets are therefore the ideal targets to discover if shape is a differentiation factor and if the fragmentation process affects the shape of the polymer.

Main goals

Considering the previous statements, the objective of this dissertation is to answer the following research question:

- Is shape a differentiation factor for different WEEE polymers with identical density, for which there is no generalized industrial solution, such as PS/ABS or HIPS/ABS?

The use of particle shape as a possible separation factor was studied searching the answer to the following question:

- "What is the separation level obtained with a gravity separation technique, considering the shape of the analyzed particles and certain operational conditions?"

Methods

Characterization

Particle size distribution

Particle size distribution study was carried in order to observe particles size class resulting of the two fragmentation processes involved and to be able to relate particle shape with size class.

Particle distribution size was performed in dry conditions with a mechanic sieving equipment, with the DIN 4188 sieving series with 11.2, 8, 5.6, 4, 2.8 and 2mm apertures.

Shape analysis

Since perception of shape is a visual experience, an image analysis technique was used to test the hypothesis. The image analysis procedure, adapted from the one developed by Pina and Lira (2009) for studying sediments [12]. It consists of the following main steps:

– Image acquisition: consists of the emplacement of particles of a given sample in a scanner surface, minimizing the overlap between particles. An image of the plastic particles is digitized in true color (RGB) at a spatial resolution of 300dpi.

– Particle identification: an algorithm based on morphological filtering (to remove small dust grains) coupled with a gradient edge detector was successfully applied to segment (or binarise) all the particles in the images.

– Morphological parameters computation: for each particle, individual morphological features were extracted. These particle shape properties have been stated in terms of three complementary indexes, solidity (SL) given by Eq. (1) [13], circularity index (CI) given by Eq. (2) [13], and the shape index (SI) given by Eq. (3) [13]:

$$SL = \frac{A}{AP} \quad \textbf{[1]}$$

Where A is the particle area, AP is the convex polygon area;

$$IC = \frac{4\pi A}{p^2} \quad \textbf{[2]}$$

Where A is the particle area, P is the particle perimeter;

$$IF = \frac{l}{L} \quad \textbf{[3]}$$

Where Lmax and Lmin are the lengths of the major and minor particle axes respectively.

All particles were analyzed according to size class, original WEEE defined by color, and type of fragmentation regarding laboratorial or industrial equipment.

Separation

After the performance of shape study, two plastics with a significant difference and easy visual identification were chosen to perform the experimental trials for their separation.

Since separation through shape is not a developed area, the time was limited and the equipment used wasn’t fully available, the separation trials have an exploratory character aiming to verify mostly of concentration of one or more products occur. These trials were made using gravity separation equipment Recglass, where the particle density and size proximity provides that shape becomes the most determinant factor in particle mixture separation. The experiment was conducted in three stages, namely:

Preliminary trials – trials with mono material samples to observe the interaction equipment-particles and to select the operational variables to study in the next phase;

Operational parameters regulation – Using a binary mixture of size class +4-5,6mm, containing a random composition of ABS and PS, three operational parameters were studied in three levels to obtain the better results: inclination of the belt, belt speed and feed height.

The results in this stage were evaluated according to the maximum separation achieved in one product and both plastics concentration rate.

The full analysis of the influence of three variables in three levels requires a fractional factorial design as described in Montgomery (2001), however, due to external limitations, such design wasn't followed, conditioning the validity of the results [14].

Separation trials – with the operational parameters chosen in the previous stage, the separations trials tested a different size class and two different compositions.

Results

Characterization

Image analysis results made possible to the comparison between plastics, fragmentation processes and general particle shape behavior and show that shape is a function of the fragmentation process and plastic type.

The particles of HIPS and ABS, when fragmented in the laboratory, and within each size class, do not present a significant difference from each other in any shape index.

Regarding plastics fragmented in industrial conditions, the particles analyzed belonged to ABS and PS. ABS particles, from different original WEEE, showed no difference in solidity or circularity. However, the particles within 2,8mm – 4mm of plastic monitors and coffee machine parts are more elongated than the ones of plastic router parts. PS particles present differences in circularity and elongation when comparing different original WEEE. The most significant difference is between PS from fridge drawers (crystal) and PS from monitors (black). ABS and PS present the same type of differences but on a lower scale. PS "crystal" has the higher indexes, meaning the particles are more close to circular and less elongated.

Considering the general shape behavior, elongation is a function of the size class. Regardless of the material or fragmentation process, elongation decreases (IF increases) with the decrease of size). As for solidity, particle surface smoothness is constant throughout all size classes; however, industrial fragmented particles present slightly higher levels of surface smoothness. The circularity of the particle is a function of the fragmentation process. When observing particles fragmented in industrial context their circularity increases when size class increase; on the other hand, when considering laboratorial fragmented particles, their circularity decreases with the increase of size class. Further analysis showed that laboratorial fragmentation leads to convex irregularities in larger particles, reducing their circularity.

Separation

The mixture chosen to perform separation tests was composed by ABS from monitors (black) and PS from fridge drawers (crystal). The size classes used were above 4mm because the smaller particles adhered to the belt and didn’t fell in any separation products.

In operational parameters regulation, the one where it was observed more influence in separation was the belt angle, whereas the other parameters had little influence. The outcome of this regulation was a the choice of an angle 21º, a feed height 14cm and a belt speed of 0,075m/s.

With these parameters, recoveries around 50% to 60% for PS with grades ranging from 40% to 64% and recoveries around 60% to 70% for ABS with grades ranging 55% to 72%.

Conclusions and future work

The key issue of the shape difference between plastics with identic density - ABS / HIPS and ABS / PS - was approached with an image analysis methodology. This methodology was considered appropriate to the object of study, because although it is a two-dimensional analysis, the products analyzed had little relevance in the third dimension (very flat particles). Was also appropriate to aim for exploring the three main morphological aspects - the approach to circularity (IC), the convexity of the silhouette (SL) and the ratio of main directions (IF).

Image analysis results indicate that the elongation of the particles is greater for smaller size class particles. Industrially fragmented particles are more close to circular shape than those fragmented in the laboratory and regarding the later, circularity decreases with increasing of size class due to convex irregularities of their silhouette. The particles of HIPS and ABS, when fragmented in the laboratory, and within each size class, do not present a significant difference from each other in any shape index. Regarding industrial fragmented material, particle circularity was the main distinguishing feature, mainly between PS particles from refrigerator drawers and PS particles from monitors.

Regarding the exploratory set of trials, it was observed that separation products were enriched with each plastic according to the difference in particle shape and the separation degree is consistent with shape difference between the two plastics. Therefore, in order to explore separation due to the shape feature, it is suggested the concretization of a sound factorial design experiment which allows a valid statistical analysis on the relationships between all process variables.

Thus, it can be concluded that particle shape relates differently to the three conditions studied (size class, type of plastic and fragmentation process). In the light of the degree of separation accomplished and the validity of these results, it is essential to continue the quantification and statistic validation of the influence of all variables, bearing in mind the goal of optimizing the separation of ABS / PS and the assessment of applicability to other difficult separation plastics such as POM/PVC.

References

[1] UE, “DIRETIVA 2012/19/UE,” no. 6. Jornal Oficial da União Europeia, pp. 38–71, 2012.

[2] DEFRA, “Trial to establish waste electrical and electronic equipment (WEEE) protocols,” London, 2007.

[3] UNEP, “E-WASTE Volume II: E-waste Management Manual,” Paris, 2007.

[4] Eionet, “Waste from electrical and electronic equipment (WEEE),” *29/10/2009*, 2009. [Online]. Available: http://scp.eionet.europa.eu/themes/waste/#6. [Accessed: 09-Jan-2013].

[5] F. O. Ongondo, I. D. Williams, and T. J. Cherrett, “How are WEEE doing? A global review of the management of electrical and electronic wastes.,” *Waste management (New York, N.Y.)*, vol. 31, no. 4, pp. 714–30, Apr. 2011.

[6] E. Dimitrakakis, A. Janz, B. Bilitewski, and E. Gidarakos, “Small WEEE: determining recyclables and hazardous substances in plastics.,” *Journal of hazardous materials*, vol. 161, no. 2–3, pp. 913–9, Jan. 2009.

[7] G. Martinho, A. Pires, L. Saraiva, and R. Ribeiro, “Composition of plastics from waste electrical and electronic equipment (WEEE) by direct sampling.,” *Waste management (New York, N.Y.)*, vol. 32, no. 6, pp. 1213–7, Jun. 2012.

[8] M. Schlummer, L. Gruber, A. Mäurer, G. Wolz, and R. van Eldik, “Characterisation of polymer fractions from waste electrical and electronic equipment (WEEE) and implications for waste management.,” *Chemosphere*, vol. 67, no. 9, pp. 1866–76, Apr. 2007.

[9] P. Chancerel and S. Rotter, “Recycling-oriented characterization of small waste electrical and electronic equipment.,” *Waste management (New York, N.Y.)*, vol. 29, no. 8, pp. 2336–52, Aug. 2009.

[10] M. R. Gent, M. Menendez, J. Toraño, and S. Torno, “Optimization of the recovery of plastics for recycling by density media separation cyclones,” *Resources, Conservation and Recycling*, vol. 55, no. 4, pp. 472–482, Feb. 2011.

[11] M. Tsunekawa, R. Kobayashi, K. Hori, H. Okada, N. Abe, N. Hiroyoshi, and M. Ito, “Newly developed discharge device for jig separation of plastics to recover higher grade bottom layer product,” *International Journal of Mineral Processing*, vol. 114–117, pp. 27–29, Nov. 2012.

[12] C. Lira and P. Pina, “Automated Grain Shape Measurements Applied to Beach Sands,” vol. 2009, no. 56, pp. 1527–1531, 2009.

[13] P. Pourghahramani and E. Forssberg, “REVIEW OF APPLIED PARTICLE SHAPE DESCRIPTORS AND PRODUCED PARTICLE SHAPES IN GRINDING ENVIRONMENTS . PART I : PARTICLE SHAPE DESCRIPTORS,” *Mineral Processing and Extractive Metallurgy Review : An International Journal*, no. May 2013, pp. 145–166, 2004.

[14] D. Montgomery, *Design and analysis of experiments*, 5th ed. John Wiley & sons, Inc., 2001.