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An innovative recycling process to obtain pure polyethylene and polypropylene from household waste

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ABSTRACT

An innovative recycling process, based on magnetic density separation (MDS) and hyperspectral imaging (HSI), to obtain high quality polypropylene and polyethylene as secondary raw materials, is presented. More in details, MDS was applied to two different polyolefin mixtures coming from household waste. The quality of the two separated PP and PE streams, in terms of purity, was evaluated by a classification procedure based on HSI working in the near infrared range (1000–1700 nm). The classification model was built using known PE and PP samples as training set. The results obtained by HSI were compared with those obtained by classical density analysis carried in laboratory on the same polymers. The results obtained by MDS and the quality assessment of the plastic products by HSI showed that the combined action of these two technologies is a valid solution that can be implemented at industrial level.

1. Introduction

The constant growth of plastic consumption, in various applications, encouraged the research of new recycling procedures and the improvement of the old ones.

Europe is the second plastic producer, after China, accounting for the 20.4% of the world total production. The global production reached 288 million tonnes in 2012, recording a 2.8% increase compared with 2011 and, in general, in the last 50 years the plastic market has grown constantly and, as a consequence, the amount of polymer wastes increased as well. Every year the amount of plastics delivered to landfill is decreasing with a positive trend in the recovery of post-consumer plastics. In 2012, 61.9% of the plastics were recovered, 35.6% were used for energy recovery and 26.3% were recycled. However, the recycling rate of plastic is still at low levels (Plastic the facts, 2013).

Packaging dominates the waste generated from plastics, covering 62.2% of the total. Polyolefins (POs) account for more than 50% of the packaging production. Plastic recovery starts with the separate collection of post-consumer waste (Al-Salem et al., 2009). In the recycling plants, the different types of plastics are sorted mainly using two different technologies: the first one is based on **O**ptical **S**ensing **T**echniques (OST), the second one is based on *sink-float* processes. The OST recognizes different types of polymers comparing their spectra in the near infrared (NIR) range with a library of reference spectra. The main limitations are linked to: (i) separation efficiency, depending on the size of plastic flakes (good detection is usually achieved for particles with size >5 cm), (ii) sensing unit "blindness", depending on flakes color (dark plastics, for their low reflectance, are not classified) and, (iii) flakes surface status (the presence of labels, dirtyness or paint and coating on the plastic surface does not allow a correct recognition) (Di Maio et al., 2010). For these reasons about 50% of the input material is not correctly separated and ends up in the residues, which are usually send to incineration.

Sink-float processes separate different materials taking advantage on their difference in densities. These techniques use a process medium with an intermediate density between those of the polymers to be separated. Usually *sink-float* separation is quite simple but it becomes difficult if the materials are characterized by a slight different density. This method is often combined with flotation (Burat et al., 2009; Pongstabodee et al., 2008; Dodbiba et al., 2010).

Sink-float separation is commonly used to separate the light PO from the plastics heavier than water (i.e. PVC and PET). The resulting PO mixed product contains both polyethylene (PE) and polypropylene (PP) and can be used only for low quality recycled materials. To achieve the same physical and mechanical properties of virgin materials, a further separation of PE from PP is needed and their grade should be better than 97% (Bakker et al., 2009).

In this paper, the application of two innovative technologies for PO sorting and final pure products (PE and PP) quality control, i.e.:

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M*agnetic* **D***ensity* **S***eparation* (MDS) and **H***yper***S***pectral* **I***maging* (HSI), is presented.

MDS is a physical separation method based on the differences in density of the materials (Murariu et al., 2005). It has been already tested for the recovery of different materials: precious metals from **M***unicipal* **S***olid* **W***aste* **I***ncinerator* (MSWI), bottom ash (Bakker et al., 2007), **W***aste from* **E***lectrical and* **E***lectronic* **E***quipment* (WEEE) (Hu et al., 2011) and **P***oly***E***thylene* **T***erephthalate* (PET) (Bakker and Rem, 2006).

HSI analysis was introduced in the recycling process to monitor the quality of the two separated product streams (PP and PE). This fast and non-destructive technique is able to collect both spectral and spatial information from an object and represents an attractive solution for quality control in several industrial applications. In fact, in the last ten years the use of this technique has rapidly grown in different fields as in food and pharmaceutical sectors. Several studies have been carried out also in waste recycling sector, i.e. glass recycling (Bonifazi and Serranti, 2006), compost product quality control (Dall'Ara et al., 2012), characterization of end-of life mobile phones (Palmieri et al., 2014) and characterization of different plastics (Serranti et al., 2011, 2012; Ulrici et al., 2013; Luciani et al., 2013). Both MDS and HSI were applied to the same PO coming from Romanian and Dutch household waste (HW) to assess and validate the performances of such technologies for PO waste sorting and quality control.

2. Materials and methods

2.1. Polyolefin samples from household waste

PO samples were collected, as already mentioned, in two countries: Romania and the Netherlands. The Romanian sample (RO HW) came from Valcea, a town with a population of approximately 80,000 inhabitants. A 27 kg sample, including both polyolefin and non-polyolefin polymers, as well as a small amount of other wastes, e.g. food garbage, was hand-picked from raw household wastes. Foils and polymer objects smaller than 5 cm were not selected, due to the high cost of hand-sorting from raw HW. Different from the Romanian sample, the Dutch sample was separately collected from other HW according to the Dutch PlasticHero program launched by Nedvang in 2008. In this program, the citizens are encouraged to bring their plastic wastes into a separate trash bin near their houses. The desired wastes include plastic bags, food containers, lids of jars, bottles, etc., and exclude, for instance, fast food packaging, meat packing materials or toys. The gathered polymer wastes from the trash bin are transported to a sorting plant for polymer recycling normally once a week. The investigated Dutch sample (NL HW) came from Zeeland, a province in the south of the Netherlands. Compared to the Romanian plastic waste, the Dutch sample contains not only rigid plastics, but also plastic foils.

For this study, only the blown and injected PP and PE (including both LDPE and HDPE) were selected, so the foils were removed. All the samples, in order to be processed by MDS, were shredded below 8 mm.

2.2. Magnetic density separation

2.2.1. MDS principle

MDS is a density-based sorting technology, similar to the conventional *sink-float* method; but instead of using a medium with a single cut density, it uses a liquid separation medium with a density gradient. Such liquid contains magnetic iron oxide particles with a size of about 10–20 nm suspended in water. By applying an artificial gravity, in the form of magnetic force, varying exponentially in the vertical direction, the effective density of the liquid varies in this direction as well. Plastic particles with the same density will float in the liquid at the same level: where the effective density is equal to their own density.

When magnetic liquid is placed in a magnetic field, the weight of the liquid becomes the sum of gravity and the vertical component (z) of the magnetic force. In such way, the separation medium can be artificially lighter or heavier than would be expected on the basis of its material density (ρ_l). In a gradient magnetic field (B), the total weight (F) of a volume of magnetic liquid (V_l) with magnetization M is:

$$F = \rho_1 g V_l + M V_l \nabla_z |B| = \left(\rho_1 + \frac{M \nabla_z |B|}{g}\right) g V_l \quad (1)$$

When particles made of a non-magnetic material of material density ρ_p are introduced into the liquid, their weight will be equal to their gravity minus the weight of the same volume of liquid (Archimedes' Law):

$$F = \rho_p g V_l - (\rho_1 g V_l + M V_l \nabla_z |B|) \quad (2)$$

In particular, the particles will be suspended (weightless) if

$$\rho_p = \rho_{eff} = \rho_l \pm \frac{M}{g}\frac{d|B|}{dz} \quad (3)$$

Where the gravity and the magnetic force work in opposite directions, the effective density (ρ_{eff}) becomes less than ρ_{l}:

$$\rho_{eff} = \rho_l + \frac{M}{g}\frac{d|B|}{dz} \quad (4)$$

The gradient of $|B|$ decreases in size with the distance to the magnet that produces the field. Therefore particles of different densities are suspended at different heights. In this way, the MDS can be used to sort light polymers (polymers with different densities less than that of ρ_{l}), particularly polyolefins. The ρ_{l} can be expressed as:

$$\rho_{eff} = \rho_l - \frac{\pi M B_0}{gp} e^{-\pi z/p} \quad (5)$$

in which B_0 is the magnetic strength at the magnet surface.

2.2.2. MDS setup and experiments

The MDS setup applied in this study consisted of four steps: (i) wetting, (ii) feeding, (iii) separating and (iv) collecting. Fig. 1 shows the scheme of the lab-scale MDS setup. All the components of the MDS setup are submerged under the liquid surface. The process liquid, magnetic fluid, circulates in the system: it moves from the left chamber to the right side of the MDS by the pressure difference generated by the pumps, and then flows back to the left side.

The shredded input materials (RO HW or NL HW) were first wetted with boiling water for one minute in order to make the polyolefin surface hydrophilic (Hu et al., 2010) and as well as to remove heavy plastics (>1000 kg/m^3) or other contaminants. The wetted samples are fed into a box made of stainless steel wire gauze with openings of 1 mm. Air in the feeding box was first discharged before the box was placed in position, to avoid air caused turbulence in the system. When the lid of the box is open, the polyolefin particles rose up and then flowed into the separation channel with the main flow stream, thanks to the fact that PO have a density smaller than 1000 kg/m^3. In general, a plastic flake with a thickness of 1 mm takes three seconds to reach their equilibrium height in MDS (Bakker et al., 2009; Hu, 2014), therefore the flow speed in the separation channel was set at 0.18 m/s during the tests. The separation channel was 0.6 m long, so the residence time of the particles in the channel was slightly longer than three seconds. To avoid turbulence, the upper and lower belt speed was the same as the flow speed. The magnet used in the MDS has a