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# Gravity packaging final waste recovery based on gravity separation and chemical imaging control

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## ABSTRACT

Plastic polymers are characterized by a high calorific value. Post-consumer plastic waste can be thus considered, in many cases, as a typical secondary solid fuels according to the European Commission directive on **End of Waste** (EoW). In Europe the practice of incineration is considered one of the solutions for waste disposal waste, for energy recovery and, as a consequence, for the reduction of waste sent to landfill. A full characterization of these products represents the first step to profitably and correctly utilize them. Several techniques have been investigated in this paper in order to separate and characterize post-consumer plastic packaging waste fulfilling the previous goals, that is: gravity separation (i.e. Reflux Classifier), FT-IR spectroscopy, NIR **HyperSpectral Imaging** (HSI) based techniques and calorimetric test. The study demonstrated as the proposed separation technique and the HyperSpectral NIR Imaging approach allow to separate and recognize the different polymers (i.e. PolyVinyl Chloride (PVC), PolyStyrene (PS), PolyEthylene (PE), PoliEtilene Tereftalato (PET), PolyPropylene (PP)) in order to maximize the removal of the PVC fraction from plastic waste and to perform the full quality control of the resulting products, can be profitably utilized to set up analytical/control strategies finalized to obtain a low content of PVC in the final **Solid Recovered Fuel** (SRF), thus enhancing SRF quality, increasing its value and reducing the “final waste”.

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## 1. Introduction

Plastic is a material that can be easily moulded and, at the same time, it is durable and inexpensive. Its production considerably increased in the last 60 years and, as a consequence, its disposal and environmental problems grew accordingly. About 4% of the world's oil and gas production, a non-renewable resource (Thompson et al., 2009), is used as a raw material for plastics and another 3–4% is exhausted to provide energy for their manufacturing. The recycling practices are the only actions able to decrease toxic emissions and the environmental impacts on the natural habitats. The recovery activities linked to plastics recycling process consist in different approaches: (i) physical and chemical processing for implementing a new product with the same properties or lower and (ii) recovery for energy production (Hopewell et al., 2009). The energy recovery of **Post-Consumer Plastics Packaging Waste** (PC-PPW) by incineration can present environmental

risks, due to the presence of chlorinated polymers generating hazardous **HydroChloric acid** (HCl) gas and dioxins. Many polymers have a high calorific value and therefore their combustion would replace the use of fossil fuels. The **PolyVinyl Chloride** (PVC), considered one of the main sources of toxic effluents, figures among the thermoplastic materials most commonly used worldwide. PVC global annual production is 35 million tons and its consumption in Western Europe amounts to 5.3 million tonnes (Shojai and Bakhshandeh, 2011; Engelmann, 1997). Polymers having close density ranges are difficult to separate using traditional density based sorting techniques, i.e. PET and PVC have similar densities, 1.38–1.40 g/cm<sup>3</sup>, respectively. The European Commission has introduced the **End of Waste** (EoW) principles and the definition of waste, recycling and recovery. The waste management concept was introduced by the 2008/98/CE directive, in particular the art. 6 establishes the cessation of the waste. This directive aims to change the waste definition and explains when it becomes secondary raw material to obtain energy. The EoW ensures the recovery of energy from waste through **Solid Recovered Fuel** (SRF). The main purpose of this directive is the reduction of harmful effects on health and environment caused by the production and management of waste, through the rational use of resources by increasing

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the practice of the reuse and recycling. Therefore a high content of chlorine considerably decreases the market value of the SRF, because it contributes to the corrosion of the incineration plant (Luciani et al., 2015). The work reported in this paper is focused on the PVC separation, performing polymer particles sorting from post-consumer wastes using a separation technique named Reflux Classifier (RC), normally utilized in the mineral processing sector. RC represents, in comparison to other separation process (i.e. flotation) a “good compromise” between cost and achievable results. Furthermore the attention was addressed to obtain a product (i.e. SRF fraction) characterized by a low PVC content and to examining the possibility to perform its full characterization by HyperSpectral Imaging (HSI) analysis. This latter goal being validated comparing the obtained results with the specific plastic waste stream characteristics determined by classical testing methods (i.e. FT-IR and calorimetric analyses).

## 2. Materials and methods

### 2.1. The sample

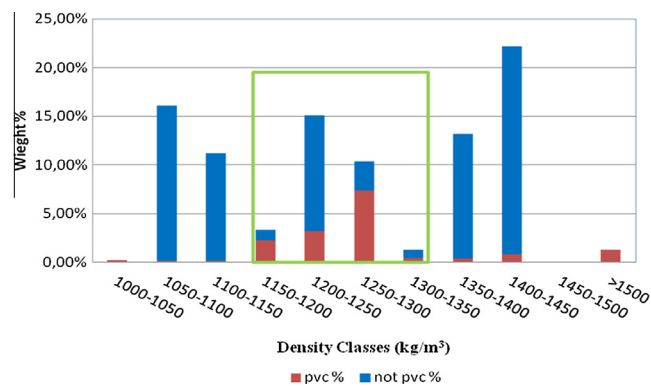
The analyzed sample is representative of the residual fraction resulting from a plastic waste sorting plant, more in detail it is the heavy fraction (i.e. sink product) coming from sedimentation tanks. In order to reduce the presence and to contemporary realize a further PVC recovery, a laboratory scale separation was carried out. A reference sample of about 700 g was utilized for testing. In a previous study (Bonifazi et al., 2014) a reference sample of the same material was analyzed, to characterize and to quantitatively assess the presence of chlorine contained in the residue fraction. The typical composition of this product is reported in Table 1. The characterization of the material was developed by different analytical approaches, that is: (i) density characterization (Fig. 1) and (ii) Fourier Transform Infrared Spectroscopy (FT-IR) (Table 2). The density distribution of the sample (Fig. 1) clearly shows as most of the chlorinated particles are characterized by a density ranging between 1150 kg/m<sup>3</sup> and 1300 kg/m<sup>3</sup>: about 80% of the total chlorinated particles are in this range.

### 2.2. The separation process

The sink fraction (i.e. plastic packaging plastic waste) as resulting from plastic packaging processing, was preliminary milled by a blade mill and was separated utilizing the RC. The RC is a fluidized bed separator (Zhou et al., 2006), allowing to separate particles according to their size and density (Nguyentranlam and Galvin, 2001). It is typically used in the mining sector for the separation of coal from “ashes” (i.e. the gangue, that is the heavy fraction) (Galvin et al., 2002) and is an innovative device offering advantages in both particle size classification and gravity separation. The device thanks to its architecture (i.e. channels inclined walls) increases the degree of segregation of the particles, which

**Table 1**  
Typical composition of a PC-PPW sample (Bonifazi et al., 2014).

Waste	% w/w
PoliEtilene Tereftalato (PET)	26.80
PolyVinyl Chloride (PVC)	24.90
Rubber	3.10
PolyStyrene/Acrylonitrile Butadiene Styrene (PS/ABS)	9.60
PolyAmide/PolyButylene terephthalate (PA/PBT) and other polymers	5.40
PolyEthylene/PolyPropylene (PE/PP) (added)	11.90
PE/PP	5.50
PAPER/FIBER	4.20
METAL/INERTS	8.60



**Fig. 1.** Density distribution of the coarse product selected from the sink fraction resulting from laboratory sink-float separation of the heavy fraction as resulted from the industrial processing. The distribution of the PVC particles/aggregates is displayed in red. The blue distribution is referred to particles/aggregates not containing PVC. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

**Table 2**  
Results of FT-IR analysis carried out on a representative set of particles coming from the sink fraction as resulting from laboratory test.

PET	PE	PP	PS	PVC	Other
% w/w					
51.7	5.1	2.9	7.5	16.0	16.8

precipitate in the area below the fluidized bed, therefore this movement generates an improvement in the separation performance (Nguyentranlam and Galvin, 2001). The kinematic approach of Ponder (1925) and Nakamura and Kuroda (1937) attributes the increase in the rate of particle segregation to the increase in the horizontal projected area of the inclined surfaces. For this study, the instrument has been modified and adapted for the material processed.

The sink fraction was previously milled to make the material more homogeneous and to increase “particles aggregates” liberation (i.e. plastic, paper, fibers and metals). The laboratory RC is shown in Fig. 2. The device was modified in order to facilitate particles disaggregation, to reach this goal a turbulent area was specifically created in the feeding zone. As result of the processing 3 products have been obtained: (i) SRF fraction (i.e. natural fibers, paper and PVC), (ii) float material (i.e. mainly polyolefin films, and (iii) “heavy” fraction (i.e. mainly plastics flakes and metals). After separation, FT-IR analysis was applied to realize a complete identification of the different polymers and to quantitatively assess their presence. Non plastics particles were manually sorted and the samples with the higher content of paper and fibers have been tested by calorimetric analysis to determine the emission of chlorine. Each particle was then analyzed by HSI in order to identify its spectral signature in the VIS-NIR (1000–1700 nm) wavelength range and to build an ad hoc spectra reference library to be utilized for the further HSI based classification.

### 2.3. Products sample collection and processing

#### 2.3.1. FT-IR analysis

Sink fraction was dried and about 300 coarse particles were selected to perform FT-IR analysis. The particles were acquired and analyzed one by one. A Perkin Elmer FT-IR Spectrum™ 100 was utilized.

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