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# Upgrading of PVC rich wastes by magnetic density separation and hyperspectral imaging quality control

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ABSTRACT

Polyvinylchloride (PVC) is one of the most produced polymers in Europe, with a share of 11% in terms of mass (8 million tons) of total polymer consumption, but in 2010 only 5% of the total PVC production came from recycled materials, where other polymer recycling achieves a level of 15% on average. In order to find an innovative process to extract PVC from window frames waste, a combination of two innovative technologies was tested: magnetic density separation (MDS) and hyperspectral imaging (HSI). By its nature, MDS is a flexible high precision density separation technology that is applicable to any mixture of polymers and contaminants with non-overlapping densities. As PVC has a very distinctive high density, this technology was tested to obtain high-grade PVC pre-concentrates from window frame waste. HSI was used to perform a quality control of the products obtained by MDS showing that PVC was clearly discriminated from unwanted rubber particles of different colors. The results showed that the combined application of MDS and HSI techniques allowed to separate and to check the purity of PVC from window frame waste.



## 1. Introduction

Nowadays plastic has become essential in all human activities: in the last twenty years the resin production has increased exponentially. Polyvinyl chloride, or "PVC", is one of the most used polymers, being the third resin in terms of mass production (11%) after polyethylene (30%) and polypropylene (19%), and it is the first polymer utilized in building and construction (Plastic the facts, 2013). Due to its versatile properties, PVC has a wide range of applications: window frame profiles (28%), pipes (22%), rigid films (12%), cables (6%) and flooring (6%) with only a small percentage of the polymer production for short life usages like bottles (0.7%). According to the American Chemistry Council (2013), the market of PVC windows and doors has increased by 19% in 2012. In general the PVC demand is expected to reach 43.5 million tons in 2015, which means an average increase of 6% per year considering the 32.5 million tons demand in 2009 (PVCplusKommunikations GmbH, 2012).

For a long time PVC has been considered a health hazard material due to its high content of stabilizers that contain dangerous substances, like lead and other heavy metals, plasticizers containing phthalates, fungicides and many other deadly chemicals. In the last 10 years many progresses have been carried out to reduce the environmental impact of PVC by cutting the use of problematic plasticizer and stabilizing additives: the European plasticizer industry is committed towards the sustainability of its products shifting gradually from low to high molecular weight phthalates (less volatile); on the other hand, the lead stabilizers have been mainly substituted by calcium-based stabilizers (Vinyl, 2010). Also as a result of this effort, recycling of PVC waste has reached a level of 0.26 million tons, or 5% of PVC production in 2010. This means that 95% of PVC production is still from primary resources, which is a major environmental problem in the European Union. In conclusion, there is a lack of low-cost and efficient technical solutions for recycling of PVC in Europe.

Unfortunately, a low recycling rate of PVC is not just a waste of resources. The material also hinders the recovery of other useful compounds and energy from post-consumer wastes and generates problems and costs of cleaning off-gases.

Data from municipal solid waste incinerators (MSWI's) show that in between the regular waste, batches with PVC concentrations of 5–10%, presumably from waste treatment companies that are not able to properly recycle PVC, create high levels of HCl in the off-gas. Such high levels create costs of corrosion and limit steam temperatures and therefore power production efficiency in MSWI's. In some EU countries, large volumes of PVC-containing

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building wastes are waiting for an affordable technology to process the PVC into a resource for new PVC production.

The possibility of a combined application of two innovative technologies, the magnetic density separation (MDS) and the hyperspectral imaging (HSI), for the separation and recognition of PVC from mixed wastes was explored in this paper.

MDS is a physical separation technology that is based on the differences in density of different materials (Murariu et al., 2005). MDS has been tested already for the recovery of different materials: separation of precious metals from MSWI bottom ash (Bakker et al., 2007), recycling of WEEE (Hu et al., 2011a) and separation of several mixed plastic wastes. Great results have been achieved in the removal of contaminants from PET (Bakker and Rem, 2006) and in the sorting of secondary polyolefins from waste (Bakker et al., 2009; Hu et al., 2011b; Rem et al., 2013). The same prototype used for polyolefins separation has been set up for the recovery of PVC from different mixtures. Chiavetta et al. (2013) analyzed the Life Cycle Assessment of the PVC cable recycling with MDS comparing this scenario with the disposal of the cable waste in landfills (traditional end of life). The results showed that using this innovative technology all the environmental impacts are reduced by about 90% in comparison with the traditional landfill scenario.

PVC from window frames waste was selected for the tests, being the window frame stream the one with the largest share in total PVC waste products. An explanation for this is the large share (60%) of PVC window frames in the European window frame market. The PVC window frames have an average life cycle of 10–40 years, and with the start of the use of these frames in the 1950s, the replacement of frames started in 1980. This offers a large input for the upcoming years.

The quality of the recycled PVC depends on the characteristics of the recycling process and the quality of the input waste. A transparent relation between value and composition is required to decide if the recycling process is cost effective for a particular waste stream. Therefore, an objective and reliable quality control technique is needed in the recycling industry for the monitoring of both recycled flow streams and final products in the plant (Serranti et al., 2012; Bonifazi and Serranti, 2014). HSI is an innovative, fast and non-destructive technique able to collect both spectral and spatial information from an object. The recorded information is contained in a "hypercube", a 3D dataset characterized by spatial data (i.e. $x$ and $y$ axis, representing the pixel coordinates) and spectral data (i.e. $z$ axis, representing the wavelengths). HSI 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 industries. 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), recycled aggregates from concrete (Serranti and Bonifazi, 2014) characterization of different plastics (Serranti et al., 2011; Bonifazi et al., 2013; Hu et al., 2013; Ulrici et al., 2013).

In this paper an MDS prototype for the separation of heavy polymers has been tested for the recovery of PVC from window frames waste, the same material was analyzed by HSI working in the near infrared (NIR) range (1000–1700 nm) in order to classify different types of plastics and other materials in the PVC wastes.

## 2. Materials and methods

### 2.1. PVC from window frame waste

Selected samples were collected from a PVC recycling facility located in UK. In the processing plant, the window frames coming from building demolition are manually stripped from glass and metal parts such as hinges and handles, then they are shredded and sent to an assembly line for iron and non-ferrous materials control. At this stage, large bits of any contamination are manually removed. The remaining fraction, a mixture of PVC, rubber, foam, silicone, foil, cement residue, wood particles and fabric, is milled into granules. The granules are treated in an electrostatic separator producing the following two streams:

- main PVC fraction called "1520 quality",
- rubber fraction (45%) with PVC (55%) and residual materials called "1403 quality".

After the electrostatic separation, the PVC fraction goes through a color separator to get a product of higher purity. The purpose of the color separation is to obtain a pure white PVC flakes stream, but the main problem of this process step is that it cannot distinguish between white PVC and rubber flakes.

A 65 kg sample from PVC window frame waste was collected from the "Rubber with PVC" fraction ("1403 quality"). The maximum particles size was 10 mm. The total content of the big bag was split several times in order to obtain a representative sample of 500 g. The particles were screened in order to eliminate the fraction < 2 mm, not suitable for processing by the MDS prototype used for this study. An example of the investigated mixed plastic sample is reported in Fig. 1. The mixed sample is constituted by: white PVC particles and three different colored rubber particles (black, grey and white).

### 2.2. Density classification

The magnetic density separation is effective only if the materials which need to be separated have different densities. In order to verify this condition, the window frame waste sample was classified in different density classes by a series of sink–float processes in solutions characterized by different densities.


**Fig. 1.** Investigated sample coming from PVC window frame waste (1403 quality).