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# Development of a new approach based on midwave infrared spectroscopy for post-consumer black plastic waste sorting in the recycling industry

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ABSTRACT

Waste sorting is key to the process of waste recycling. Exact identification of plastic resin and wood products using Near Infrared (NIR, 1–1.7 μm) sensing is currently in use. Yet, dark targets characterized by low reflectance, such as black plastics, are hard to identify by this method. Following the recent success of Midwave Infrared (MWIR, 3–12 μm) measurements to identify coloured plastic polymers, the aim of this study was to assess whether this technique is applicable to sorting black plastic polymers and wood products. We performed infrared reflectance contact measurements of 234 plastic samples and 29 samples of wood and paper products. Plastic samples included black, coloured and transparent Polyethylene Terephthalate (PET), Polyethylene (PE), Polyvinyl Chloride (PVC), Polypropylene (PP), Polylactic acid (PLA) and Polystyrene (PS). The spectral signatures of the black and coloured plastic samples were compared with clear plastic samples and signatures documented in the literature to identify the polymer spectral features in the presence of coloured material. This information was used to determine the spectral bands that best suit the sorting of black plastic polymers. The main NIR-MWIR absorption features of wood, cardboard and paper were identified as well according to the spectral measurements. Good agreement was found between our measurements and the absorption features documented in the literature. The new approach using MWIR spectral features appears to be useful for black plastics as it overcomes some of the limitations in the NIR region to identify them. The main limitation of this technique for industrial applications is the trade-off between the signal-to-noise ratio of the sensor operating in standoff mode and the speed at which waste is moved under the sensor. This limitation can be resolved by reducing the system's spectral resolution to 16 $cm^{-1}$, which allows for faster spectra acquisition while maintaining a reasonable signal-to-noise ratio.



## 1. Introduction

Waste management is a continuous challenge given the increasing rate of waste generation by human societies worldwide. Plastics waste, in particular, has been increasingly produced since substantial manufacturing of synthetic polymers commenced more than 70 years ago. Much of this plastic waste is mismanaged, leading to its dispersal in the environment, and in some cases, its discharge into the oceans (Jambeck et al., 2015). On the other hand, collection and recycling of plastic waste is increasingly more common due to environmental agendas, but also due to decreasing space in landfills and economic considerations. Accordingly, many countries around the world have adapted legal frameworks to achieve recycling objectives for plastics. The European Union (EU), for instance, has set a target for recycling 65% of municipal waste and 75% of packaging waste by 2030, in accordance with the EU Directive of Waste (European Parliament, 2008). Subsequently, many efforts have been dedicated to the development of recycling techniques for plastics, yet, regardless of the efficiency of recycling schemes, sorting is the most important stage of the process (Al-Salem et al., 2009). Therefore, the current work focuses on the development of a method for sorting plastic waste for recycling.

In plastic waste recycling, accurate sorting by resin is crucial for producing high-quality recycled material. Infrared spectroscopy in

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the spectral range of 2–25 μm was previously performed for different polymers such as Polyethylene (PE), Polyvinyl Chloride (PVC), Polypropylene (PP) and Polystyrene (PS) (Krimm et al., 1956; Stromberg et al., 1958; Krimm, 1960; Ouroumeihei and Meldrum, 1999; Hanssen and Zhu, 2006). Although these early transmission spectral measurements showed that vibrational processes in different polymers resulted in unique transmission spectra, the technique requires the preparation of thin films or solutions for measurement and is cumbersome (e.g. Smidt et al., 2008), and therefore, cannot be used to characterize large quantities of plastic waste. Other studies used Near Infrared (NIR) reflectance spectroscopy and NIR hyperspectral imaging spectroscopy (1–1.7 μm) to classify plastic waste based on its spectral signatures (Huth-Fehre et al., 1995; Serranti et al., 2012, 2015; Ulrici et al., 2013; Amigo et al., 2015; Luciani et al., 2015), and this technology is currently operational in some waste-sorting facilities. Recently, Midwave Infrared (MWIR, 3–12 μm) reflectance spectral measurements were successfully carried out for plastic resin robust identification (Vázquez-Guardado et al., 2015). However, until such a technique reaches maturity and is implemented, it remains challenging to discriminate different families of black plastics with automated NIR sorters. This is a significant concern for recycling plants (Froelich et al., 2007). The reason for this limitation is that black targets have very low reflectance in the NIR spectral region. Accordingly, the Signal-to-Noise-Ratio (SNR) of current NIR sensors is too low for successful black polymer classification. Moreover, the absorptivity of overtones and combination bands that are observed in the NIR are much lower than those of the MWIR region.

Therefore, the aim of this study is to explore the potential of MWIR detection in plastic waste sorting. The first objective of this study was to characterize spectra of post-consumer plastic waste composed of different resins, and to determine whether MWIR reflectance spectroscopy can be used to identify different polymers in spite of black colouring. NIR spectroscopy is also applicable to characterizing paper and wood products by their spectral signatures (Tsuchikawa, 2007). However, if the MWIR is to be used to separate plastic waste, it may be useful for other types of waste, such as paper and wood products. Therefore, the second objective of the current study was to use NIR-MWIR spectroscopy for a preliminary examination of its usefulness for identification of post-consumer paper, cardboard and wood waste.

## 2. Materials and methods

Household waste samples were received from a recycling company in Sherbrooke, Quebec, Canada. The spectral measurements included 234 samples of black plastics, clear and coloured plastics, wood, paper, and cardboard (Table 1). Plastic samples included Polyethylene Terephthalate (PET), Polyethylene (PE), Polyvinyl Chloride (PVC), Polypropylene (PP), Polylactic acid (PLA) and Polystyrene (PS). No distinction was made between low-density and high-density PE since they are known to present the same spectral features (Vázquez-Guardado et al., 2015). Out of the 234 plastic samples, 81 were of a mixed or unknown resin, and 153 were of a known single resin, of which 53 were transparent, 59 were black and 41 were coloured plastic (Table 1). Samples were identified by resin identification code markings on the sample. In a minority of the samples that lacked clear markings, Differential Scanning Calorimeter (DSC) measurements were used to determine the resin. Furthermore, 29 wood and paper products were measured (two wood samples, four cardboard samples, and 23 paper samples).

Infrared reflectance contact measurements of the waste samples were performed using a pair of Full Spectrum Reflectometers (FSR, ABB Bomem Inc., Québec, QC, Canada, Puckrin et al., 2013) covering the range from 0.7 to 14 μm at 4 $cm^{-1}$ resolution. The reflectometers incorporated two detectors: an InAs detector that covers the spectral range from about 0.7 μm to 3.3 μm, and an MCT detector that covers the range from about 2.5 μm to 13.5 μm. In this paper, we present plastic measurements performed with the MCT detector (2.5–13.5 μm). These Fourier Transform Infrared (FTIR) spectrometers have an internal light source and the signal received is the fraction of light that is diffusely reflected back from the front surface of a sample into the sensor's aperture. However, unlike opaque samples, the reflectance of clear plastics is very low. Accordingly, in order to compare the absorption features of clear samples with opaque ones, the transflection spectra of clear samples was measured by placing them against an Infragold background. This enhanced the samples absorbance due to a double pass through the sample, which makes it difficult to compare directly with diffuse reflectance measurements. The FSR was set to co-add 60 measurements for our standard signature measurement procedure. Additionally, several shorter measurements of the same sample were collected to examine the effect of increased noise at a short integration time. The black and clear plastic MWIR measurements were compared to each other and to spectra of the same polymers from the literature (Krimm et al., 1956; Stromberg et al., 1958; Ouroumeihei and Meldrum, 1999; Hanssen and Zhu, 2006; Vázquez-Guardado et al., 2015) to find the common features that present themselves in the presence of black colouring.

**Table 1**
Sample breakdown by group and resin.

| Group | Resin | Number of samples |
|---|---|---|
| Mixed/unknown plastics | Mixed or unknown | 81 |
| Black plastics | PET | 7 |
| | PP | 21 |
| | PS | 18 |
| | PLA | 5 |
| | PE | 8 |
| Transparent plastics | PET | 25 |
| | PP | 3 |
| | PS | 19 |
| | PLA | 3 |
| | PVC | 3 |
| Coloured plastics | PET-blue | 1 |
| | PET-pink | 1 |
| | PE-red | 7 |
| | PE-white | 12 |
| | PE-yellow | 1 |
| | PE-blue | 2 |
| | PE-pink | 1 |
| | PP-green | 2 |
| | PP-white | 5 |
| | PP-yellow | 1 |
| | PS-brown | 1 |
| | PS-red | 4 |
| | PS-white | 3 |
| Total plastics samples | | 234 |

## 3. Results

Overall, in spite of differences in measurement techniques and instrumentation, good agreement was found between the absorption features present in the FSR measurements of plastics samples and the features documented in the literature for the same polymers (Krimm et al., 1956; Stromberg et al., 1958; Ouroumeihei & Meldrum, 1999; Hanssen and Zhu, 2006; Vázquez-Guardado et al., 2015). The locations of the main MWIR absorption features in black plastics corresponded with those of coloured samples, but the reflectance was significantly lower. The reflectance is not

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