Method development for fast classification of waste plastic multilayer polyolefin films using near-infrared (NIR) handheld spectrometer

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The amount of packaging waste in the EU is constantly increasing. In 2020, 29.5 million tonnes of post-consumer plastic waste were collected in the EU27+3, from which 17.9 comprised packaging waste. (Plastics Europe, 2022) In Council directive 2008/98/, the EU has set a goal of achieving a recycling rate of 55% by 2030. In 2020, the European recycling rate for post-consumer plastic packaging reached 46% (under the former Packaging and Packaging Waste Directive calculation methodology), compared to 42% in 2018 – an increase of about 9.5%. The current 46% recycling rate would potentially equal 32% under the new plastics packaging recycling calculation methodology foreseen by the Packaging and Packaging Waste Directive (PPWD). (Directive (EU) 2018/852) To achieve the set goal by 2030, further improvements in the existing technologies of waste plastic separation are required.

The usage of flexible packaging films is increasing because of their lightness and versatility, while their recycling rates are still meagre. Most of the film fraction, 76wt%, are incinerated or co-incinerated, while only 24wt% are subject to mechanical recycling, which wastes valuable resources. (Eygen et al., 2017) Multilayer plastic packaging films are imposed as one of the main challenges when separating waste plastic. According to Koinig et al. (2022), in separately collected waste collected in Austria, 30 wt% are flexible 2D plastic packaging, from which 20wt% are multilayer films with a current recycling quota of 25,7%. Two-thirds of all post-consumer plastic waste are polyolefins, with a recycling level of 23% in Europe which shows the need for solutions for polyolefin waste, especially polyolefin films. (Plastics Europe, 2023) Packaging waste can be recycled using mechanical or chemical recycling technologies. Mechanical recycling is used widely in Europe. Its primary disadvantage is that the process can degrade the mechanical properties of plastic materials, which means that the plastic is 'down-cycled' into secondary and less valuable products. Also, regulations prevent mechanically recycled polyolefins from being used in food contact applications. Chemical recycling converts plastic into valuable feedstock, which can be used to produce virgin-like plastics without lowering in quality and without any restrictions on the type of application, as well as giving the possibility of recycling mixed polyolefin waste, including multilayer packaging. (Jeswani et al., 2021)

The development of chemical recycling has created complementary solutions to existing mechanical recycling for waste that would otherwise be incinerated. Chemical recycling requires high purity of input material. The quality of input material and the subsequent sorting steps significantly influence achieving a high yield from the process. (Jeswani et al., 2021) Therefore it is crucial to know the composition of input material and if it consists of any impurities, like other polymers. Currently, existing methods for verification of the purity of input material consist of diverse wet chemical methods, FTIR (Fourier transform infrared) spectroscopy, density separation, and hyperspectral imaging. The mentioned methods require time and often sample preparation. There is a need for a fast and robust method to be used as the control method for assessing the quality of input material. Near-infrared (NIR) handheld spectrometers are cost-effective, non-destructive and fast way to characterize waste plastic material and have already been proven to classify different monolayer plastic polymers successfully. (Rani et al., 2019) Moreover, since they can be used by both specialists and non-specialists, NIR handheld spectrometers imposed as the method that would fulfil the required requirements. The remaining obstacle is the characterization of multilayer polyolefin films, for which the suitability for the classification using a NIR handheld spectrometer has not yet been determined.

The tests were run to demonstrate the prospect of utilizing a NIR handheld spectrometer to classify polyolefin multilayer films and separate them from non-polyolefin multilayer films. The samples were measured with the NIR handheld spectrometer from one side of the sample, without putting a focus on which material is primary one from each side. Focus was putten on classification of material composition. All the samples of waste plastic multilayer films were first analyzed using an FTIR spectrometer as a reference method to classification with NIR handheld spectrometer. Obtained results showed the most significant representation of four plastic multilayer film fractions PP-PE, PET-PE, PA-PE and PET-PP. Given that the trial focuses on separating the polyolefin and non-polyolefin fraction, four fractions were separated into two: polyolefin fraction (PP-PE) and non- polyolefin fraction (PET-PE, PA-PE, PET-PP). Prepared samples were separated into two groups: one group of samples used as a training set consisting of 70% of the samples and another group used as a test set consisting of 30%. Measurements were made in the near-infrared region of 1600-2400 nm. Spectra were acquired using Thermo Scientific microPHAZIR.

Acquired spectra had to go through signal pre-treatment, where signal correction methods are used to remove additive and/or multiplicative effects on spectroscopic data, which often affect the performance of the chemometric analysis. (Engel et al., 2013) Several pre-processing tools were applied to the raw data, including the Savitzky-Golay second derivate procedure of five data points and a second-order polynomial followed by standard normal variate (SNV). The data were further processed using chemometric tools like PCA and classification tools using MATLAB (R2022b) with chemometric toolboxes. PCA calculation was performed over the entire spectral region using all collected spectra. The first three components accounted for over 90%, and polymers were correctly separated in clusters. After pre-processing training set data, the method was developed and tested using a test set. The results of the classification of the test set show very satisfying results with classification levels of 95-100%. Overall results show promising outcomes for the NIR handheld spectrometer to classify polyolefin multilayer waste films as a control of input material for chemical recycling.

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