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Assessment of plastic packaging waste: Material origin, methods, properties

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ABSTRACT

The global plastics production has increased annually and a substantial part is used for packaging (in Europe 39%). Most plastic packages are discarded after a relatively short service life and the resulting plastic packaging waste is subsequently landfilled, incinerated or recycled. Laws of several European and Asian countries require that plastic packaging waste collected from households has to be sorted, reprocessed, compounded and reused. These recycling schemes typically produce milled goods of poly(ethylene terephthalate) (PET), poly(ethylene) (PE), isotactic poly(propylene) (PP), mixed plastics, and agglomerates from film material. The present study documents the composition and properties of post-consumer polyolefin recyclates originating from both source separation and mechanical recovery from municipal solid refuse waste (MSRW). The overall composition by Fourier transform-infrared (FT-IR) spectroscopy and differential scanning calorimetry (DSC) were determined and compared with the sorting results of the sorted fractions prior to the reprocessing into milled goods. This study shows that the collection method for the plastic packaging waste has hardly any influence on the final quality of the recyclate; however, the sorting and reprocessing steps influence the final quality of the recyclate. Although the mechanical properties of recyclate are clearly different than those of virgin polymers, changes to the sorting and reprocessing steps can improve the quality.

1. Introduction

Today, plastic waste is considered a serious social problem. The market for plastics has increased exponentially to an estimated annual production of 280 million tons in 2011 (Plastics, 2011), of which approx. 18.5 million tons, i.e. 39% of the European plastics demand, is used for packaging in Europe. After a short service life, the packaging plastics are disposed of either as landfill, incinerated or reused. The reuse can be done via chemical or mechanical recycling. In chemical recycling, the plastics are depolymerized to their respective monomers and subsequently re-polymerized (Kiran Ciliz et al., 2004) or to other valuable chemicals (Brems et al., 2012). In mechanical recycling, the plastics are sorted, melt compounded and shaped into new products. Mechanical recycling is presently the preferred treatment option for post-consumer plastic waste.

Post-consumer plastic waste can be collected via different schemes. In the Netherlands, this is done either via source separation (SS) or commingled collection (CC) with municipal solid refuse waste (MSRW) and subsequent mechanical recovery. In the SS scheme, plastic packaging waste (PPW) is separated by the consumer and offered to curbside collection services or drop-off containers. The collected PPW is subsequently transferred to sorting facilities, which yield the following fractions: poly(ethylene terephthalate) (PET), poly(ethylene) (PE), isotactic poly(propylene) (*i*-PP), film, mixed plastics (MP) and rest. The sorting facilities use near-infrared (NIR) spectroscopy sorting machines, ballistic separators, wind sifters and drum sieves. Depending on the sorting facility, plastics sorting is done in different steps or sequence. Examples of the separation procedure of the sorting facilities related to this research are depicted in Fig. 1. A more detailed description about the sorting and reprocessing procedure of the samples is given elsewhere (Jansen et al., 2012).

Sorting technologies have developed substantially in the last decade and, as a result, the sorted plastics contain only small amounts of other plastics. One intrinsic limit of the sorting efficiency is that many plastic products consist of multiple polymers used to improve their properties, e.g. the mechanical, barrier and/or optical. Examples are multilayer films and blends. Therefore, some polymer contamination will always be present that will affect the ultimate properties of the recyclates.

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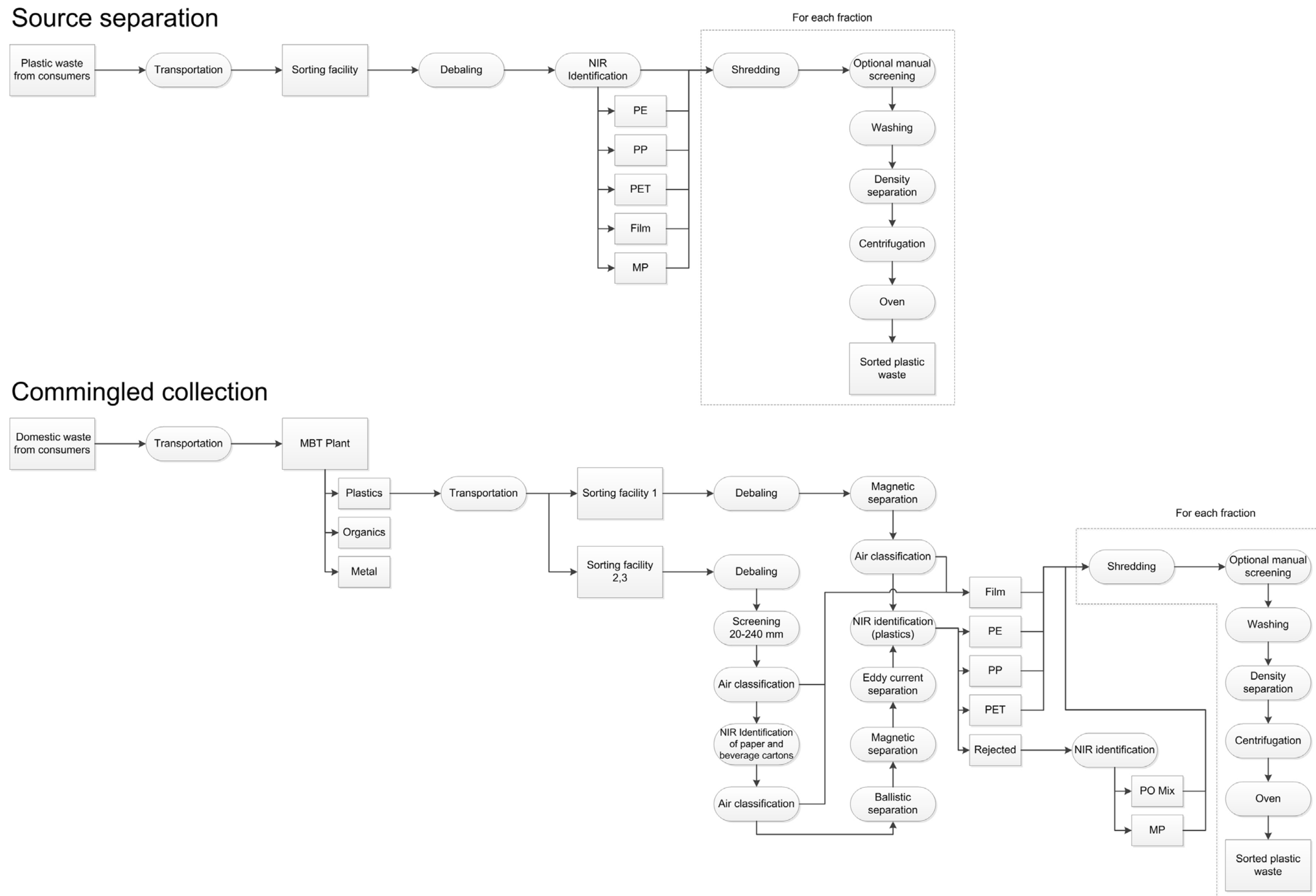

Fig. 1. Treatment of samples from source separation (SS) and commingled collection (CC) in the Netherlands.

After the sorting step, the residual fraction is incinerated, while the other fractions are reprocessed into so-called milled goods and agglomerates. The various reprocessing industries involved in this mechanical recycling typically use shredders, washing drums, flotation separators, centrifuges and tumble dryers. In the CC scheme, the PPW is collected together with the MSRW and transported to material recovery facilities, which produce a few types of plastic concentrates, i.e. so-called rigids and flexibles. Subsequently, these concentrates are sent to the abovementioned sorting facilities.

The sorting and reprocessing are two subsequent steps in the chain of material recycling and are often performed by different companies. It is unknown how the quality of recyclates depends on the different sorting and reprocessing technologies. This study aims to understand the relationship between the quality of the produced milled goods, as provided by the reprocessing industry, and the origin of the post-consumer PPW (SS vs. CC). The material quality can be assessed via an analysis of the composition and mechanical performance, which are correlated, as reviewed by Karlsson (2004). They developed (semi-)quantitative methods for the compositional analysis of polymer blends, which were obtained from recycled mixed plastic waste (Camacho and Karlsson, 2001b), by using DSC, near- and mid-infrared spectroscopy for the compositional analysis with detecting limits of approx. 1 wt%. NIR was found to be fast and precise over a large compositional range and can be used in-line. However, a drawback of NIR is that it cannot detect black materials, unlike Mid-IR. In their research, only transparent materials were used. According to the authors, attenuated total reflection (ATR) spectroscopy can be a suitable method to provide information of thick materials, but quantitative analysis of non-homogeneous materials can be difficult due to the limited penetration depth of the evanescent wave (≈2–3 μm). Therefore, good sample preparation is critical (Camacho and Karlsson, 2001b). Besides the polymers other chemical components are present, i.e. additives and contaminants, in plastic packaging waste. The quality of recyclates can also be assessed by the determination of these components via extraction techniques (Camacho and Karlsson, 2001a). A large variety of low molecular weight contaminants was identified in recycled high-density PE (HDPE) and PP, such as alcohols, esters, and ketones. The majority of these compounds were not present in the virgin plastics.

The mechanical performance of plastics is often characterized by tensile testing. Earlier studies reported on the influence of blend composition of polyolefins in relation to the mechanical properties. Teh et al. (1994) published an extensive review on PE/PP blends and the role of compatibilization and the mechanical performance in relation to the composition of post-consumer plastics, of which the majority consists of polyolefins. The morphology that governs the mechanical properties is highly dependent on the blend composition and processing/compounding conditions (Bartlett et al., 1982). Therefore, the mechanical properties of PE/PP blends are not easy to predict. Tensile specimens can be prepared via compression or injection molding. Generally, the properties from samples produced via injection molding are better, i.e. improved necking and higher strain at break (Nolley et al., 1980) in the flow direction, than via compression molding. This can be explained by the influence