Scientific proof of high-value applications for recycled plastics

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Introduction

Within a world of growing population and welfare, the plastics industry has been strongly expanding. In 2011, 265 million tons of virgin plastics were produced worldwide, of which 57 million tons were produced in Europe. Approximately 39% of these plastics were used for packaging. The majority of plastic packaging is designed for single-use and is usually discarded after a short lifetime. Plastic packaging waste is worldwide predominantly disposed via landfill. Within Western European countries most of the plastic packaging waste was incinerated with energy recovery. Since the 1990s, part of the plastic packaging waste has been also separately collected and recycled.

In the Netherlands, many – often small – recycling companies are developing sorting and reprocessing technologies. Recycling of post-consumer plastic packaging waste is politically motivated; in general, it will generate environmental benefits and it will raise the business costs for the FMCG industry. Therefore, the interaction between recycling companies and government – either local or national – has to be intensive. Since both parties have different perspectives on plastics recycling, misconceptions occur and are based on wrong or unclear information regarding the applicability of recycled plastics. Should plastic waste be incinerated? Is the use of recycled plastics limited to thick-walled, low-value products? The aim of this document is to clarify and give relevant information about recycled plastics from a scientific and technological perspective.

Organization

The production chains of virgin and recycled plastics are different. The production of virgin plastics starts with gaseous or liquid monomers, derived from oil, being polymerized in a reactor in a polymer-producing company. Since pure, well-defined materials are used, the producers have capability to produce polymers with tailormade properties for a particular application. Then, in a second stage, either in-house or at a compounding company, grade-specific additives are incorporated to tune optical, thermal, mechanical and/or flow properties, the material is extruded and pelletized. In a third stage, the pellets are sold to converter companies, which shape it into a plastic product. Sometimes, the end product of stage two is not a pellet, but an intermediate product, such as a film or sheet. The three stages are well adjusted and producers, compounders and converters work closely together. The production waste in stage one – also called post-industrial waste – is often added to specific grades which can cope with this small difference in properties. This waste is clean, so few problems arise during reprocessing.

The recycling chain starts where the virgin chain ends. The input material is not a gas or liquid derived from oil, but household waste, which already went through the chain of virgin plastics as described above and was exposed to the environment. This chain can therefore be seen as an extension of the virgin chain.
The waste plastics are collected either at the source or afterwards. After collection, it is transferred to a sorting company, where plastics are separated from other materials, amongst others paper, metals, and organic residues. Depending on the collection scheme, this separation is less or more intensive. The plastics are separated, shredded and washed, after which the produced milled goods and agglomerates are transported to a compounder company (stage two). Here, the material, a combination of many plastics, is reprocessed with several additives, into a pellet. In a third stage, the pellets are converted to recycled products at other companies. The market of plastics waste and recycled intermediate is active and prices fluctuate continuously, whereas the price of virgin plastics is rather stable. The companies in all three stages of the recycling chain work more independently and are less connected to each other. However, since the material input is susceptible to changes in composition, it will have considerable effects on the production stages later on. Consistency, scale, and quality of material input are big issues which recycling companies have to deal with. In order to overcome these issues, companies in plastics recycling should cooperate and integrate better. When information about, for example, consistency and input quantity and quality is shared, the reprocessing process could be optimized, leading to improved product quality.

Recyclate quality
During this research, the quality of various post-consumer polyolefin samples originating from different sources was assessed. These samples were taken from rural and urban municipalities, with source separation as well as post-separation systems. Subsequently, the plastics waste (source separation) or residual waste (post-separation) was transported to various sorting facilities in the Netherlands and Germany. Here, samples were taken (big bag sized, i.e. 30-90 kg). These samples were analyzed at Wageningen UR Food & Biobased Research using manual sorting and NIR spectroscopy sorting. In a next step, the packaging waste was milled, sieved, washed, density-separated and dried. Kilogram-scale samples of the clean milled goods produced from sorted bales of PP, PE and film were taken and sent to

Eindhoven University of Technology for further analysis. Virgin plastic and post-industrial plastics waste were analyzed as well and used as a reference.

For the analysis, the representativeness of the samples is assumed. This assumption is justified by the fact that triple analysis on a sample from one particular source yielded similar compositional results. The representativeness is thus not negatively influenced by sorting processes, but the composition of the input material varies. It became evident from communication with sorting facilities that a sample from a certain region varies in time and place, since consumer consumption behavior is prone to weather, season, and location. For example, in city center apartments little space exists to separate waste compared to rural areas. Therefore, little yields from separate collection are observed in cities compared to rural municipalities and the composition is also different.

If a company wants to sell recyclates - whether it is grinded, pelletized or a final product - it is important that the output quality is constant. Continuous mixing of grinded plastic in big storage tanks is preferred to reduce quality fluctuations. With regards to these fluctuations in quality, it is therefore a must to operate at a sufficiently large scale.

Figure 1: Two samples of homogeneous (left) and heterogeneous (PET contamination, right) PP from sorted household waste.

The polyolefin samples were characterized for their composition, using differential scanning calorimetry (DSC) and Fourier transform infrared (FT-IR) spectroscopy. Typically, 10% of polymer contamination is present. This percentage varies with the effort put into sorting: a sample of PE from sorted milk bottles has a higher purity compared to a sample of a PE sorted bale.

In terms of mechanical properties, there is little difference between source-separation and commingled collection. It was observed that within the recycling chain the sorting and washing processes are far more important factors for the mechanical properties than the collection method. Compared to virgin material, the mechanical properties are worse, mainly due to polymer contamination. Furthermore, the fluctuations in properties of post-industrial and post-consumer waste are similar. In general, the fluctuations within waste materials are high compared to virgin plastics, with post-industrial plastic waste having smaller fluctuations than post-consumer plastic waste.

Reduce, reuse, recycle

From an ecological point of view it is favorable to reduce the amount of plastics, thereby saving fossil resources. Despite that plastic products, including packaging materials, become thinner, the world plastics demand has been increasing yearly, making the reuse of plastic products as often as possible the most favorable option. If the plastic ends up as waste, three options are possible: landfill, energy recovery and mechanical recycling of plastics. From the ecological point of view, it is most favorable to recycle plastics. However, from an economic point of view, there are several issues that need to be considered.

The collected plastic packaging waste (both source-separated and commingled collected) is in general cheaper than virgin polymers per kg. It has to be mentioned that the price of virgin plastics is build up from raw materials and production costs, whereas the price of recyclate materials is, in addition to that, partially determined by governmental subsidies for waste collection and sorting. However, the processing costs are higher for recycled materials. Separation, sorting, washing, drying, transportation, reprocessing; it all adds up to the cost price of a recycled plastic pellet.

Application range

It is a common misconception that recycled plastics can only be used for low-value purposes or should be incinerated for energy recovery. Research in our laboratories showed that some properties of recycled polypropylene (PP) can be improved by a factor 10 using advanced processing methods. To achieve this, recycled PP pellets were filtered in the melt and subsequently tape-extruded and cooled down. Then, the tapes were drawn in the solid state in several steps, where the draw ratio and temperature were controlled. The final tapes could be produced with a smoothly operating solid-state drawing process, resulting in drawn tapes of about 0.2 mm thickness and 3 mm width. These tapes showed improved mechanical properties up to a factor 10, which is about 70% of the properties of comparable virgin tapes. Since these materials consist out of PP only, they can be recycled again after their second lifetime. These results show that the use of recyclates is not limited to low-value products and can be used in a variety of demanding applications. Although some applications require virgin plastics, the research will be continued, to discover other high-value opportunities for plastic recyclates.

Table 1: Typical issues and possible applications for different types of recyclates

Type of Recyclate	Typical issues	Typical applications
PE Rigids	Polymer purity	Injection molding
PP Rigids	Chain cleavage due to heat and weathering	Injection molding
Film	Polymer purity, inorganic impurities, melt filtration	Sheet extrusion, Film blowing
PO-Mix / MKS float	Polymer purity, hot washing, melt filtration	Thick-walled products

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