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Short Communication

Advance in Environmental Waste Management & Recycling

Styrenics, Made for Recycling

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In view of climate change, environmental pollution, population growth and the dependence on limited fossil resources, the transition from a linear economy to a closed-loop economy is both ecologically and economically necessary.

Currently, chemical recycling of plastics plays only a minor role. For example, in the year 2016, only 1.4 % of the plastic packaging wastes generated in Germany were chemically recycled, compared to 48.4% that were mechanically recycled [1]. Therefore, plastics recycling are mostly understood as mechanical recycling. Thermoplastic materials can easily be molten and reprocessed at elevated temperatures. In theory, this enables a re-use of the polymer at the end-of-life of the plastics article, whether it is a single-use item such as a packaging or cup or a more durable good. Bringing back the polymer into the same or at least a similar application is the common understanding of a circular economy.

Unfortunately, reality looks different in many cases. Often it is forgotten that plastics are not simply polymers build from their monomers, but are complex mixtures of polymers and additives to fulfill the demanding requirements of specific applications. Especially when it comes to the recycling of post-consumer waste, the results are insufficient, even with high efforts on waste sorting and cleaning. Often, only a dark grey recyclate can be offered, that lacks mechanical and optical properties compared to virgin material. This is due to mixing of different polymer types and grades and the degradation of the polymer during its use phase and during reprocessing. A second recycling of recyclates is nearly impossible, and the dark colours might prevent an efficient sorting process. The consumption of fossil feedstock is reduced a little, but in the end, the incineration of the material and thus the emission of CO_2 is inevitable. The recycling loop is not closed.

In contrast to mechanical recycling, chemical recycling processes deconstruct polymers into their building blocks. These may be purified and reused subsequently. In general, chemical recycling processes are more complex and energy-intense than simple mechanical recycling, but the products obtained by these processes are comparable to virgin materials. Therefore, chemical recycling is a supplement, where high quality mechanical recycling is hardly possible or not possible at all. In these cases, chemical recycling is the only alternative to incineration.

The idea to recycle plastics and the basic technologies that enable recycling are not new. Already in the 1990ies, when Germany introduced the Dual System to systematically collect and sort household packaging waste, first patents for several different recycling processes were granted. A few processes made it to the pilot scale [2] .One of the best-known examples is the oxy fuel pilot plant "SchwarzePumpe [3]". From the technical standpoint, most of the processes and technologies worked in a sufficient way, however, they were stopped mainly due to economic reasons or unavailability of suitable waste as an input material. The recent activities to start chemical recycling processes again almost resemble a renaissance. Many companies and initiatives strive to develop efficient processes for chemical recycling, in order to transition the linear, cradle-to-grave economy to a circular, cradle-to-cradle economy. Closing the circle between waste collection/recycling on the one hand and the polymer production/processing on the other hand can only be achieved in close cooperation with all major stakeholders along the value chain. Innovative technology providers could also play an important role, as the technologies especially for chemical recycling still have room for improvement when it comes to efficiency and selectivity. There seems to be many dynamics in an evolving market, including backward and forward integration efforts.

The various technologies for chemical recycling can be grouped into three basic categories [4-6]. The first category is gasification. Based on the well-known Fischer-Tropsch process, the plastic waste is converted under elevated temperatures and addition of hydrogen to syngas, a mixture of carbon monoxide and hydrogen, which can be further processed, e.g. to methanol.

If the polymer waste is heated to 300 to 600 °C without addition of oxygen, the technology is called pyrolysis. It can take place with or without the presence of catalysts to facilitate the conversion. There are different reactor types and settings under investigation, such as fluidized bed or rotary kiln technologies.

As a third category, dissolution and solvolysis need to be mentioned. The former refers to dissolving the waste in suitable solvents, with the aim of separating the polymer from undesired contaminants, while the polymer chain stays intact. The latter refers to a cleavage of bond within the polymer chain, for example, when polyesters are split into their building blocks.

Pyrolysis as one potential method for chemical recycling is not working for all polymer types. For example, the thermal decomposition of polyethylene and polypropylene only results in unspecific products such as waxes, light oils and gases which are not suitable for repolymerization. In contrary, some polymer grades can be broken down back into their monomers by heating above their ceiling temperature. Polystyrene (PS) and also poly methyl methacrylate (PMMA) belong to this category. They are consequently possible candidates for a circular economy by utilization of chemical recycling.

Polystyrene is a widely used, versatile material that contributes too many facets of our daily lives. Due to its high transparency, gloss and color ability it is used in applications where optical properties are important. Additionally, it is often used in applications that require highest purity and a defined composition, such as food packaging or medical devices. These demanding applications often do not allow using material from mechanical recycling, but requiring higher material quality – a quality that can be achieved by chemical recycling.

INEOS Styrolution is driving multiple projects forward to recycle post-consumer styrenics waste aimed at closing the circle towards a true circular economy for styrenics materials. The most ambitious project at INEOS Styrolution is chemical recycling of polystyrene to create material from post-consumer waste indistinguishable from virgin material and thus perfectly suitable for any application where virgin polystyrene is used today. We recently reported the successful polymerization of styrene into crystal clear polystyrene with "as-virgin" quality, which previously has been chemically recycled by de-polymerization, followed by purification. INEOS Styrolution works globally in several collaborations with research institutions as well as with recycling and sorting companies to drive chemical recycling forward by optimising processes and scaling the process for industrial use [7].

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