The Long Road to a Circular Economy

Overcoming Difficulties in Plastics Recycling

Both the quantity of recycled plastics waste and of processed recyclates is continually increasing. However, there are still difficulties with the quality of the recycled plastics, which are impeding replacement of virgin material. In recent years, machinery manufacturers and plastics producers have introduced various further developments that improve the properties of recyclates as well as eliminate unpleasant odors and contaminants.

Plastics recycling is a laborious process. For the recycled material to have the necessary quality, it must first be sorted into the different plastics

Recycling and the circular economy have been key issues for the plastics industry for many years. The quantity of recycled plastics waste is continually increasing. According to the European Association of Plastics Manufacturers, PlasticsEurope, the amount of post-consumer waste recycled in the European Union (including Norway and Switzerland) doubled between 2006 and 2018. It increased from 4.7 to 9.4 million t. Since 2014, it has exceeded the amount of plastics disposed of in landfill. In 2018, 7.2 million t were sent to landfill. The majority of plastics waste in the EU, 12.4 million t, ends up in thermal recycling.

Individual countries handle their waste very differently. Whereas, for example, in Switzerland, Austria, the Netherlands, Germany and Sweden, virtually no plastics waste is sent to landfill, in Croatia, Bulgaria, Greece, Cyprus, and Malta, more than 70% is disposed of in this way. Norway, Spain, Germany, and Sweden have especially high recycling rates of just under or even over 40%.

Growing Recyclate Quantity, Stagnating Recycling Rate

In Germany, according to a study carried out by Conversio on behalf of the major plastics trade associations, the recycling rate in 2019 was 47%. Although the quantity of recycled waste rose in comparison with 2017 by 3.2% to 2.9 million t, the recycling rate did not increase during this period. The increase in the quantity of recycled waste is therefore due mainly to a higher total amount of waste, which went up from 6.2 to 6.3 million t. From the plastics used for recycling, a total of 2.0 million t of recyclates was obtained. In Germany in 2019, 1.9 million t were used for the manufacture of plastics products, of which 1.0 million t came from post-consumer waste. The proportion of total plastics

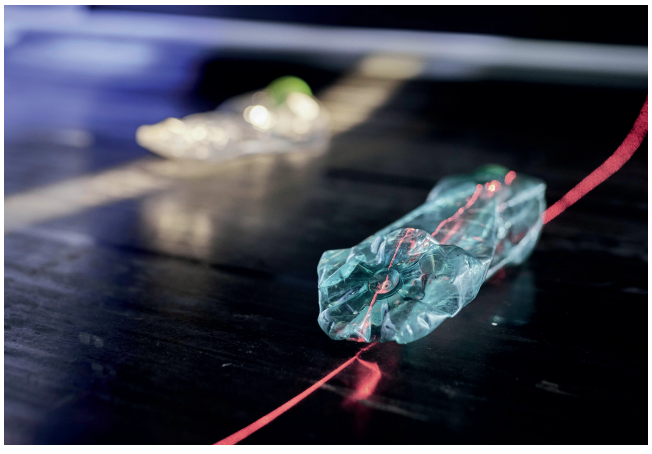

Fig. 1. NIR systems have become established as standard in sorting lines © Tomra

production accounted for by recyclates has risen since 2017 from 12.3 to 13.7 %.

The quantity of recyclates produced and processed is therefore increasing. But a significant proportion will not be upcycled. There are many reasons for this. For example, a problem arises with the sorting of plastics waste. To achieve high-quality recyclates, the plastics waste must be segregated as cleanly as possible into different types. For this purpose, sorting systems based on near-infrared light (NIR) technology are mainly used (**Fig. 1**). The wastes are irradiated with NIR. Depending on the type of material of which the waste consists, it absorbs part of the light and reflects the other wavelengths, which are evaluated by a spectrometer. On the basis of the reflections, the different materials can be detected.

However, this technology reaches its limits with black products. This is primarily because carbon black is often used for black coloration. This pigment absorbs a large proportion of the NIR radiation and so prevents detection of the materials. The obvious solution is to replace carbon black with NIR-detectable black colorants. Various manufacturers such as Karl Finke GmbH & Co. KG and Lifocolor have recently launched suitable pigments and masterbatches (**Fig. 2**). Another possibility is the UniSort Blackeye sorting system developed by Steinert (**Fig. 3**). This uses a hyperspectral camera based on mid-infrared spectroscopy to detect different polymers and can also detect wastes colored with carbon black.

AI for Sorting Systems

Manufacturers are also expecting considerable improvements in NIR systems through the use of artificial intelligence (AI). "To achieve ever cleaner segregation, NIR will in the future be increasingly connected to imaging systems and artificial intelligence," says Hendrik Beel, CEO »

Fig. 2. Carbon black-free black colorants permit sorting with NIR technology. The black masterbatch from Finke can be used to color PE, PP, PS, and PET © Finke

of Steinert's subsidiary Steinert UniSort. A similar view is expressed by sorting specialist Tomra. "With the changing composition of waste streams (for example, the amount of cardboard in waste is growing significantly due to the expansion of online trade) and against a background of ever more stringent statutory requirements, the use of advanced technologies and sorting process optimization will become increasingly important. Artificial intelligence in the form of deep learning is now being increasingly employed to segregate fractions that were previously difficult to sort," explains Christoph Bach, Sales Director Europe at Tomra Sorting.

For this purpose, the company has developed a deep learning technology called Gain. With this technology, a neural network with several thousand images is trained to detect various objects and to separate these out later in the sorting process. In the first application of Gain, Tomra has trained such a neural network to detect silicone cartridges. These containers are usually made from polyethylene (PE) and after disposal still contain silicone residues. They are therefore unsuitable for reprocessing with other PE wastes but were impossible or very difficult to segregate using other sorting systems. With the Gain network, on the other hand, they can be separated. The company offers the technology as an add-on for its Autosort sorting machines (**Fig. 4**).

Robots and Digital Tools

Besides AI, Tomra expects that digitization and automation will play a very important role in sorting in the future. For example, sorting robots are being increasingly used. "Many plant operators are installing robots at the end of their sorting lines to undertake automated quality control and separate the last contaminants from the sorted waste stream. Sorting robots can complement the standard sorting system with a nozzle bar but not replace it," explains Bach.

To increase the efficiency and performance of sorting machines, digital tools can also be employed, according to Felix Flemming, Senior Vice President and Head of Digital at Tomra: "There are now tools that measure the performance of the systems and sorting machines, then process and analyze the gathered data, and turn it into valuable information. The plant operator can thus keep an eye on all the processes and performances, intervene rapidly, and initiate changes and optimization measures in order to operate the plant as efficiently as possible and obtain the best sorting results." Tomra offers such a program with its cloud-based data platform Insight (**Fig. 5**). With this program, recycling companies can collect and integrate data from their sorting machines and utilize it to advantage with the aid of monitoring tools. In this way, it is possible, for example, to identify potential faults in advance, show and compare machine performance, and then make suitable adjustments for improvement.

Elimination of Odors and Contaminants

Besides causing problems in the sorting process, contaminants and odors in plastics waste also create difficulties in recycle production. These result from prior contact with, for example, food products, detergents or cosmetics. Residues of these substances remain on the plastics and partially migrate into the polymers. To eliminate them, the comminuted plastics waste is first washed to remove coarse contaminants. In the past, this was usually done with a cold wash. However, according to Paul Niedl, Sales Manager of the Recycling Technology Business Unit at Starlinger, more and more recycling companies are now using a hot wash to clean the waste: "In the washing process, there is a trend towards high quality awareness. An increasing number of recyclers are using a modern hot wash instead of the conventional cold wash."

Through this change, additional contaminants can be removed, which ensures higher-quality recyclates. This is also confirmed by Harald Hoffmann, Ma-

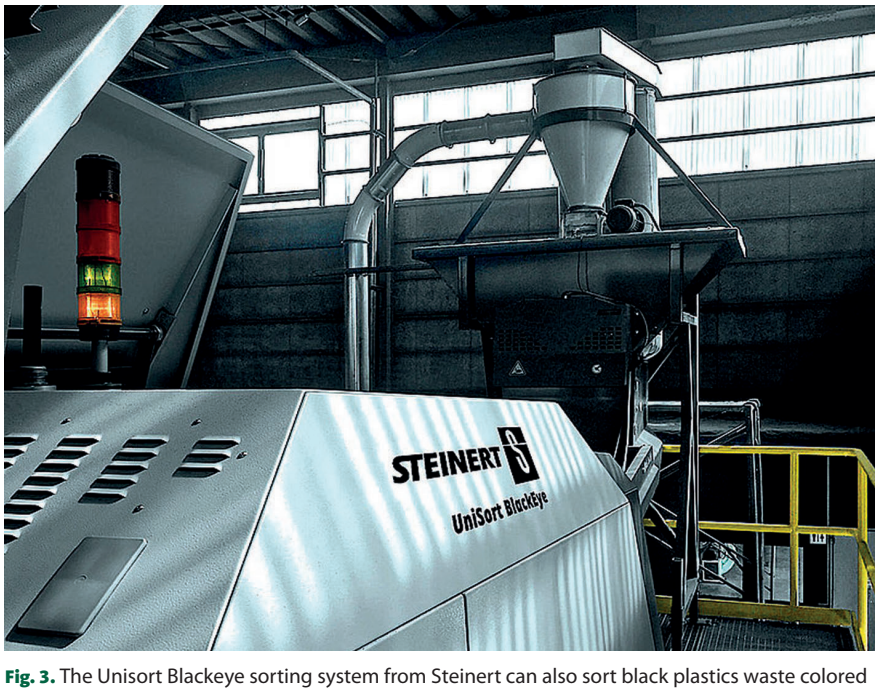

Fig. 3. The Unisort Blackeye sorting system from Steinert can also sort black plastics waste colored with carbon black © Steinert

naging Director at Lindner Washtech: "Effective cleaning and drying are essential to make plastics fit for recycling and upcycling." The company has recently introduced a hot-wash system equipped with a step dryer to dry the flakes after washing (**Fig. 6**). In the hot-wash tower, strongly adhering contaminants such as adhesives, labels, and printing ink can be removed. Drying is carried out by slowly increasing the speed of rotation in the step dryer, which, according to the company, ensures a very gentle drying process.

Successful Degassing of Recyclates

Stubborn contaminants and odors can, however, still remain in the waste even after washing. Removal of high-volatility constituents is possible by, for example, degassing during extrusion. With the ZSK twin-screw extruders from Coperion, this is achieved through constant surface renewal of the melt by the co-rotating twin screws. The high-volatility substances and odors are discharged via degassing domes and atmospheric vents. "Depending on the recycling process, a twin-screw side degassing unit can also be installed on the extruder. This can significantly improve this effect," explains Marina Matta, Team Leader Process Technology Engineering Plastics at Coperion. The extruder manufacturer has recently redesigned its ZS-EG and ZS-B side degassing units, launching the new ZS-EG easy and ZS-B easy. According to the company, these redesigned units can now be dismantled much faster from the ZSK process section and the screw shafts can be changed very easily. The time required for cleaning, e.g. with a change of formulation, is said to be sharply reduced.

Odor Removal after Extrusion

To remove low-volatility substances from recyclates, Erema offers a system known as Refresher that can be connected to its Intarema-TVEplus extruder (**Fig. 7**). While the extruder takes care of high-volatility substances, the low-volatility constituents are removed in the downstream Refresher. The Refresher works without a vacuum, which, according to Erema, reduces the complexity of the system and operating costs. The company also claims that energy consumption is low, since Refresher mainly draws on the system's own energy from the pellets that are preheated during the extrusion process to maintain the required temperature. With this combination, recycled HDPE (high-density polyethylene) can also be used for packaging that comes into direct contact with food. The company has obtained approval for this from the US Food and Drug Administration (FDA). "With this recycling system, it is possible to process not only all HDPE beverage containers but also HDPE closures for PE, PP, and PET beverage bottles. The recyclate can be used in ratios of up to 100 % in the production of containers coming into direct contact with foods of all kinds," explains Manfred Hackl, CEO of Erema.

Coperion also offers systems for odor removal after extrusion. In these deodorization systems, the pellets are continually degassed. "Depending on the »

Fig. 4. Deep learning in operation: for its Autosort sorting machines, Tomra offers the neural network Gain, which makes it possible to sort silicone cartridges, for example © Tomra

plant design, our Bulk-X-Change heat exchanger can be used to further improve the process," adds Team Leader Marina Matta. With this heat exchanger, the pellets are heated to accelerate odor reduction.

Another problem is the fact that during use plastics are exposed to wear and tear. This happens, for example, through environmental effects such as heat and UV radiation or through contact with certain substances and can lead to depolymerization, chain scission, and the consumption and escape of additives. The recycling process itself can also cause polymer degradation, for example through remelting. To prevent this, recycling must be carried out as gently as possible. "Basically, a moderate temperature level and the shortest possible residence time in the recycling process achieve the best recyclate quality. This must be taken into account in designing machinery and equipment for the recycling process. Ideally, it should then be possible to avoid thermally prestressing the recyclates, e.g. by predrying or vacuum heating. This brings advantages in terms of both end product quality and energy requirement," explains Dr. Stephan Gneuss, CEO of Gneuss Kunststofftechnik.

Gentle Recycling Process

For the gentlest possible recycling process, Erema e.g. offers the Intarema TVEplus RegrindPro system. In this system, at the start of recycling the material is heated and dried in a preconditioning unit. As a result, it arrives preheated in the extruder, which enables melting to be carried out with a short extruder screw. This reduces shear stress on the melt. The melt is then filtered, homogenized, and degassed. "This method of processing has proved successful with thick-walled regrind, such as PE, PP, ABS, and PS," explains Erema CEO Manfred Hackl. The company, together with Corema, also offers a system that combines recycling and compounding of the recyclate in one process step. "The system converts recycled raw material input into filtered melt. This melt is fed directly to a co-rotating twin-screw extruder. With this system, it is possible to admix not only a wide variety of additives but also fillers and reinforcing materials in higher quantities," reports Hackl. In this way, the recycled plastics can be customized for their intended application and necessary additives introduced. The twin-screw extruders used are manufactured by Coperion.

Additives Increase Recyclate Quality

To increase the quality of recyclates and compensate for any degradation, recyclates can be modified by additives that improve, for example, their mechanical properties and processability. Various plastics and additive manufacturers have introduced products for this purpose. "With PA, the use of reactive chain modifiers that react with the end groups is helpful. In this way, relative viscosity can be precisely adjusted, enabling PA scrap to be upcycled into high-quality injection molding material. In addition, heat stabilizers help extend the lifetime of the recyclate for the further product lifecycle," explains Dr. Kristina Frädrich, Product Manager for Polymer Additives at additive manufacturer Brüggemann. The company has developed the two reactive chain modifiers Brüggolen M1417 and M1251/M1253 for PA and Brüggolen TP-R2090 and R8895 for upcycling polyolefins.

Fig. 5. With digital tools such as the cloud-based platform Insight from Tomra, the performance of the whole plant and of individual machines can be monitored. This makes it possible to implement optimizations as the plant is running and carry out predictive maintenance © Tomra

Fig. 6. The hot-wash system from Lindner combines hot washing and drying of the plastics flakes © Lindner-Recyclingtech

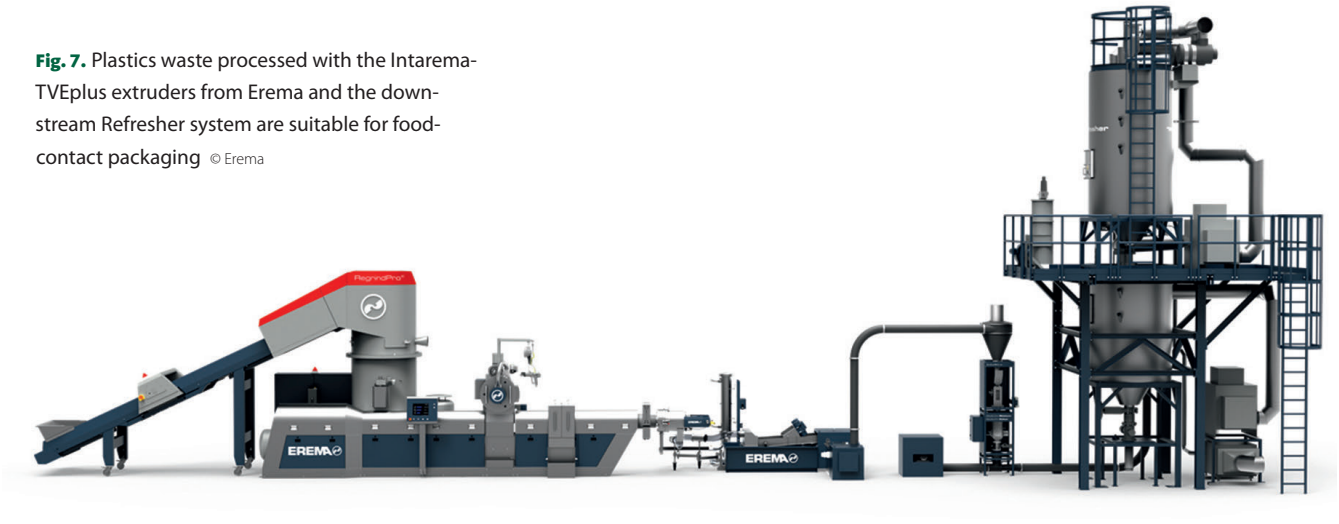

Fig. 7. Plastics waste processed with the Intarema-TVEplus extruders from Erema and the downstream Refresher system are suitable for food-contact packaging © Erema

The two companies APK and Mitsui have collaborated in a research project to improve recyclate quality. In this project, the additive requirement of recyclates produced by the solvent-based recycling process Newcycling from APK was determined and suitable stabilizer systems developed. The project also identified appropriate analytical methods for monitoring the input stream. It was found that the Yellowness Index (YI) and Oxidation Induction Time (OIT) were particularly suitable. According to the companies, the results of the studies can also be applied to other recycling processes.

Guidelines for Recycling Design

Technical improvements alone, however, are not sufficient to implement the circular economy. Suitable waste collection systems and significant changes in product design are also necessary. In future, recyclability must play an important role in product development right from the start. The mantra here is: design for recycling. "The key success factor in design for recycling is as far as possible to use just one polymer for a product. Copolymers often make economically and environmentally viable recycling impossible. In addition, polymers differ in their suitability for recycling and due account should be taken of this in material selection," says Stephan Gneuss.

The main focus of design for recycling is often to reduce the complexity of a product and the number of materials and constituents it contains. "Basically, design for recycling follows the approach of less is more. Ideally, only one material should be used, even for multi-part products. Colorants and other additives also have a negative influence on the sorting and recycling process," concludes Christoph Bach from Tomra. Both the organization Plastics Recyclers Europe and plastics manufacturer Borealis have developed guidelines for recycling-friendly product design. What is also needed in design for recycling, according to Paul Niedl from Starlinger, is a rethink of consumer behavior: "The total convenience trend of recent decades has led to ever more complex packaging – often with problematic recyclability. Plastics packaging is important to prolong the shelf life of food but it has seriously overshot the mark." ■

Florian Streifinger, editor

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