INNOVATIVE DIGITAL WATERMARKS AND GREEN SOLVENTS FOR THE RECOVERY AND RECYCLING OF MULTI-LAYER MATERIALS

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1 Introduction

One of the main problems in any sector is that, in order to be able to recycle, the material must be well defined and separated, since, with a mixture of unwanted materials, the properties of the final product can be affected. The same is true for plastics, and this is one of the main difficulties encountered by the plastics recycling industry.

There are two options for the recycling industries. One option is for industries to directly purchase the material already separated and defined, which makes the process much easier. But in other industries it does not work in the same way as it is not possible to purchase these pure waste streams, but they have to separate it themselves. It is at this point that the problem to be addressed in the project arises.

There are numerous separation processes and different technologies to tackle this problem. This project will address some of them, studying the methods, limits and separation capacities that can be obtained in each case, focusing on multilayer/multimaterial films and pharmaceutical blister packs.

With this, the SOL-REC2 project aims to solve the problem of separating multilayer and multimaterial products in order to facilitate their recycling and thus be able to manufacture new products and give them a second useful life.

2 Mechanical recycling

Mechanical recycling is one of the first treatments for material recycling. The main objective is to achieve a reduction in the size and cleaning of the particles of the material so that subsequent treatments are easier to process, as material with impurities or of a larger size than desired can cause damage to the equipment.

This procedure consists of crushing the material so that it can then be fed into the equipment to produce recycled pellets which are then transformed by processes such as extrusion or injection moulding. Mechanical recycling can be carried out for both post-consumer products and pre-consumer materials. The ultimate goal of this process is the manufacture of new products using these recycled materials, and therefore a number of conditions must be met:

- They should not be materials that are highly degraded in the processes of transformation and/or use.
- They should be segregated by type and therefore should be collected separately.
- They should not contain impurities such as other types of materials or foreign particles that could damage processing equipment or interfere with the physical characteristics of the product.
- They should be collected in sufficient quantities for the industrial and economic viability of the process.

The main stages of mechanical recycling are cleaning, sorting, shredding, washing and obtaining pellets with or without additives to improve their properties.

Cleaning consists of conditioning the waste in order to obtain a suitable raw material, without excessive dirt or substances that could damage the equipment that will subsequently treat the waste or the final product. Sorting consists of selecting and separating the plastics. Different techniques have been developed for this, such as separation by density, air flow, electrostatic charges, infrared, etc. With shredding or grinding, mainly what is obtained is a waste size that is suitable for further processing. The waste washing stage is not always necessary, but it is recommended. The aim is to remove any type of dirt or impurities, either with water or with some type of disinfectant, depending on each material. When the washing has been carried out, the material must be dried, either by centrifugation or any other method. Once all of these processes have been carried out, the pellets are obtained by extrusion. In this process the material is mixed and homogenised by melting and then passed through a filter to remove contaminants other than plastic before the melt is moulded into filaments. It is then cooled and cut into small pieces, and we obtain what we call recycled pellets.

2.1 Methods of shredding plastic materials

The main purpose of shredding plastic materials is to reduce their size in order to facilitate further processing. Often it is not possible to introduce certain waste into the sorting equipment due to its size or morphology. It is for this reason that size reduction is carried out, as well as to facilitate the transport of waste.

In the industry, there are different types of shredding equipment, such as blade mill, cutting mills or shredding mills.

Blade shredder

This type of equipment incorporates an interchangeable screen with which the size of shredded material to be obtained can be regulated.

The operating process begins with the feed from the mouth of the shredder. Subsequently, the material passes to the rotary cutting system where the blades impact the material and cut it. Once the material has been cut, it passes through a sieve that calibrates and screens the final size of the desired product.

Figure 1. Blade Shredder

Cutting mill

Another size reduction equipment is the cutting machine for plastic materials. This type of mills is used for the shredding of textile materials, fibres or unidirectional fabrics.

This equipment has the ability to cut the input material into the desired lengths, depending on the speed of the conveyor belt transporting the material.

The material is placed on the conveyor belt and the speed is regulated depending on the desired shredding size. The material then comes into contact with the rotary cutting system, which consists of several blades. Once the material has been shredded, all the resulting material is extracted.

Figure 2. Cutting mill

Shredding mill

The operation of the shredding mill consists of exerting a shock or pressure between the material and the shredding roller. This roller has steel areas that protrude from the roller itself, which "shreds" the material. It should be noted that a mesh is placed under the rotor in order to control the particle size of the final product, which will not leave the crushing chamber until the particles do not contain sizes smaller than the holes in the mesh.

This crushing system is optimal as primary crushing, that is to say, it is a first grinding where the volume of the product is reduced in the event that the dimensions are not adequate to introduce it directly into the blade mills.

The advantages of the following shredding system are:

- It is not necessary to manually reduce the size of the material to be introduced.
- The final particle size can be controlled.
- Large crushing chamber volume.
- It is possible to introduce unwanted high resistance elements without suffering significant damage.

On the other hand, there are disadvantages to be considered:

- No metals should be introduced.
- There is little productivity in light elements or those with low density.

Figure 3. Shredding mill

3 Plastic sorting methods

3.1 Separation by near infrared spectroscopy (NIR)

Spectroscopic polymer identification is frequently used for the separation of plastics. However, the high-resolution imaging technique using X-rays is limited to the separation of PVC and PET, the speed and purity of such separation being unsatisfactory.

Current separation systems can distinguish plastics such as PP, PS, PET, EPS, PC or PVC with ease, as well as clearly identify cellulose-based materials such as paper, cardboard or wood, and natural fibres. Combinations of these materials, such as bricks or similar beverages, can also be classified. However, the materials cannot be clearly identified due to the lack of individual characteristics in their wavelength range.

Infrared spectroscopy is a fast and non-destructive technique for the automatic classification of polymers. This method has a number of advantages, such as high-speed measurements, the depth that NIR radiation can reach and the high signal-to-noise ratio. Some of the most common applications of the NIR method are the separation of packaging, plastics, electronic equipment or vehicle recycling.

The NIR equipment works by separating the detected material by blowing pressurised air through valves. The material is fed onto the belt, which moves forward and in the last third of the belt is the NIR sensor with the corresponding transmitter and receiver unit, which is aligned at right angles to the belt at the top. The emitted radiation interacts with the molecules close to the surface of the particles and is reflected, absorbed and/or transmitted, depending on the chemical composition and structure of these particles.

The scattered reflected radiation is then incident on the NIR sensor and is detected, so that it is converted into an electrical signal. This material is detected and removed by compressed air blowing, thus separating it from the remaining material stream.

In addition, it has been determined that, in order to ensure good sorting by NIR, the materials must be pre-treated.

Figure 4. NIR Equipment

3.2 Elutriation (airflow separation)

The process of material separation by air flow, also known as "zigzag", involves the separation of different materials by means of an air stream. With this separation it is possible to divide the particulate material into light and heavy fractions.

The separation is carried out on the basis of the difference in settling velocity, which is the characteristic parameter and is determined by particle properties such as size, density and morphology.

In order to determine the operation of the air flow separator, it is important to know its parts and parameters that determine its efficiency. First, the material is fed onto a vibrating belt, which disperses the materials before entering the zigzag. At this point air blows from the bottom to the top of the channel while the particles are fed approximately halfway up the channel through a feed opening. The movement of the particles is driven by gravity, airflow forces, collisions with other particles and collisions on the walls of the apparatus. Lighter particles are carried upwards by the air stream, while heavier particles settle in a collection container. The lighter particles pass into a cyclone where they are removed and, by the effect of gravity, fall into another container.

This separation system can be used to separate materials based on their different properties, such as size, density and shape.

Figure 5. Airflow separator

3.3 Triboelectric separation

One method used for the separation of materials is triboelectric separation. Triboelectric separation involves using the electrostatic properties of the materials to separate them. A prerequisite for the correct operation of this technology is that the material introduced must be rigid, to facilitate the collision of the particles.

The operation of this equipment consists of creating charges through the collision of the materials, when they come into contact with each other, causing one of them to acquire a positive charge while the other acquires a negative charge. In plastics, as they are insulating materials by nature, the charge that is generated is retained on the surface of the material interaction, so it can be measured.

At AIMPLAS, the equipment used is an electrostatic separator, which can operate in three different modes: electrostatic separation, electrostatic corona and triboelectric separation. Triboelectric separation is normally used for the separation of plastic materials. Electrostatic separation is usually used for the separation of mixtures of metal particles, such as aluminium and copper. The last method, electrostatic corona separation, is used to separate mixtures containing both plastic and metal particles. In electrostatic corona separation, electrical charges are created by the ionisation of air due to the corona discharge generated by the electrode, which is connected to a high-voltage DC supply.

The operation of each configuration varies slightly. In triboelectric separation, the material is introduced into the triboelectric device, where the particles of the mixture, by numerous impacts with each other and between the walls of the device, acquire different charges. Then, by means of the vibrating belt, the product is distributed across the width of the belt until it reaches the deposition electrode. In the space between the electrodes, the material is sorted by the electrostatic field forces. Depending on the sign of charge, the particles are attracted to the deposition electrode or the deflection electrode, which is connected to a power supply.

In electrostatic corona separation, the material enters directly into the vibrating belt feeder. The deposition electrode causes the product to fall into the high voltage coverage, which is created by the corona electrode. In the space between the corona and the electrode, the particles are charged with negative ions. The metallic particles, as they leave the corona discharge zone, are rapidly recharged, pick up the charge signal from the grounded deposition electrode and repel from it. The deflector electrode, which has the same potential as the corona electrode, creates an irregular field that facilitates earlier deflection of the conductive fraction from the deposition electrode, increasing the separation efficiency of conductive and non-conductive products.

Electrostatic separation works in the same way as electrostatic corona separation, except that the corona electrode is removed from the system.

Figure 6. Triboelectric separator

3.4 Separation by density difference. Washing.

The separation of different plastics according to their densities is a widely used and profitable process, as well as being one of the processes with the greatest capacity at an industrial level. These are not very difficult separations, and they are easily automated and flexible in operation, as they adapt to the densities of the different materials by varying the density of the liquid.

The separation is based on a flotation and sinking process, in which particles of different densities are introduced into a medium of intermediate density. Particles of lower density float, while those of higher density sink at a rate corresponding to their relative buoyancy in the medium under the force of gravity.

Other factors that influence the ability to effectively separate two or more plastics of different densities include: the shape, size, surface texture of the particles, density contrast with the medium, particle adhesion, agglomeration of bubbles with the particles, the hydroscopic resistance of the plastics to sinking when at an air-water interface, and the rate at which they must separate for the process to be economically viable.

As the surface area of the particles increases relative to their masses with decreasing particle size, so does their resistance to movement in the medium. Therefore, density separations are faster and more efficient for separating larger particles of slightly different densities than for smaller particles.

Figure 7. Washing equipment

4 New technology

FiliGrade Sustainable Watermarks BV (based in Eindhoven, The Netherlands) has developed an intelligent sorting solution named 'CurvCode'. CurvCode consists of a number of visible or (nearly) invisible dots placed in a mathematically-generated curve-shaped pattern. See example below:

Figure 8. Example of CurvCode

This patented code is used for applying a 'digital watermark' to plastic, fiber-based and multi-layer packaging. In its current stage of development, CurvCode is used specifically for waste sorting and recycling purposes. It does not aim to replace existing barcoding or other point-of-sale or consumer engagement techniques.

This technology allows plastic, fiber-based and multi-layer packaging to be sorted according to packaging and usage characteristics:

- Application: Food, non-food and hazardous
- Type of material: PET, PP, paper laminate, cardboard, etc.
- Colour: transparent, white, black, carbon black, other colours
- Layers: single, multilayer composition

With this technology, more than 1.000 different codes are available. Common codes are pre-assigned for sorting different package-types. Examples are:

- PET, transparent, single layer, food
- PP, other colours, single layer, food
- Carton+ALU, multilayer, food
- PE/ALU/PET, multilayer, non-food

To enable CurvCode-triggered detection in waste-sorting facilities, FiliGrade has developed a CurvCode Reading System (CRS) consisting of LED lights, standard black and white USB cameras and common PC's. Thanks to the efficient design of CurvCode and FiliGrade's custom-built detection software, the CRS uses a simple and fault-tolerant ICT architecture. When the CRS detects packaging carrying a CurvCode it sends a trigger-signal to the blow-out unit of the waste sorting line. This allows the system to operate in any sorting and/or recycling installation. The cost of a CRS is much lower than existing detection technologies such as Near Infrared (NIR).

One unique feature of CurvCode is that it separates food from non-food packaging and delivers extremely pure sorting results (no 'false positives'). This is essential to obtain approval from the European Food Safety Authority (EFSA) to recycle food packaging back to food packaging (food-safe recyclate). Also, a CRS can detect different types of multilayers as well as black plastic packaging. In certain conditions a CRS has the potential to replace existing technologies like Near Infrared.

For rigid plastic packaging nearly invisible 3D CurvCodes are 'embossed' through modifying the moulds. This method is suitable for thermoforming, injection moulding and extrusion blow moulding.

For printed packaging, visible and/or nearly invisible 2D CurvCodes are inserted into the art work, which can be incorporated in all printing techniques. Depending on the type of packaging, multiple 3D and/or 2D codes are applied (in different orientations and spread evenly across the surface) so that codes can easily be detected even when packaging is contaminated and crunched.

For demonstration and low-volume testing purposes, FiliGrade has developed a closed-loop sorting machine including a Curve Code Reading System (CRS) , a blow-out unit and a closed-loop belt. See picture below.

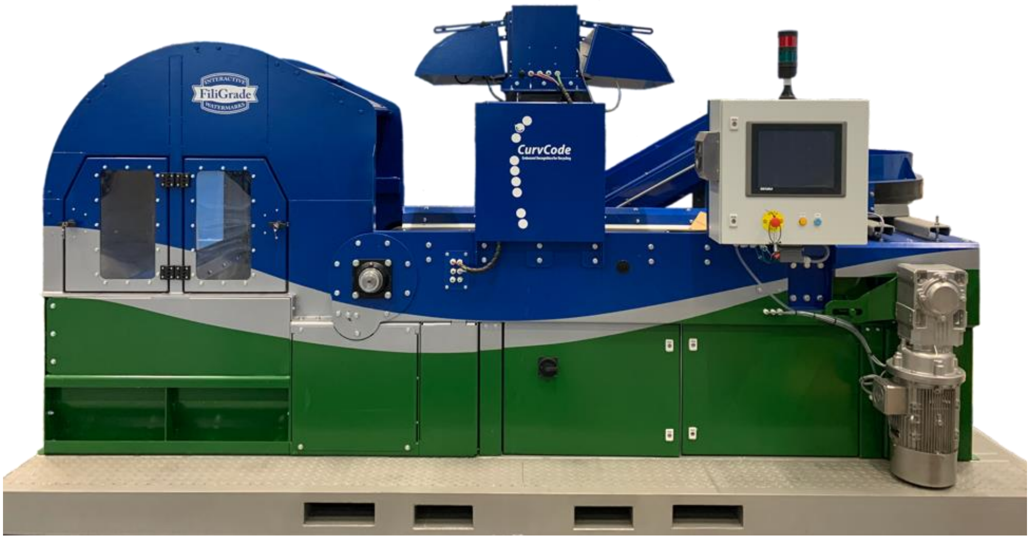

Figure 9. CurvCode detector

To enable high-volume and semi-industrial testing and demonstrations at different locations, FiliGrade has developed a mobile CurvCode Reading System (CRS) which can be fitted over any existing sorting belt up to 2 meters wide. FiliGrade can either integrate the mobile CRS with an existing blow-out unit or use software to count the number of objects carrying a CurvCode that are detected. In the latter case, interference with operational processes is minimal.

Figure 10. Hyperspectral camera

FiliGrade is a technology company. Its business model is based on licensing fees charged to brand-owners for the use of the software. Packaging producers and sorters need to sign a licensing agreement but can use the software for free. FiliGrade does not sell sorting equipment. FiliGrade supports manufacturers of industrial sorting equipment who want to add CurvCode detection technology to their products.

5 Conclusions

Depending on the nature, origin and condition of the product or waste, each material must undergo a series of treatments to facilitate subsequent processes and facilitate the recycling process.

The first treatment that is carried out is the washing of the material (if necessary) so as not to contaminate the subsequent equipment. Depending on the morphology and the material to be recycled, it will be subjected to primary shredding (shredding mill) to reduce the size, and then to a finer shredding treatment to achieve a smaller and more homogeneous shred size.

For NIR separations, there are two possibilities, to introduce the whole product or in shredded form. In the case of AIMPLAS, the equipment it has is only capable of separating final products (larger than a regrind).

In the case of the rest of the separation technologies, it will depend on each specific waste, but always in reduced sizes. Among these existing technologies at industrial level are separation by elutriation, by electrostatic charge and by density.