Constructive Elements Regarding the Design of a Plastic Waste Shredding Machine

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Abstract

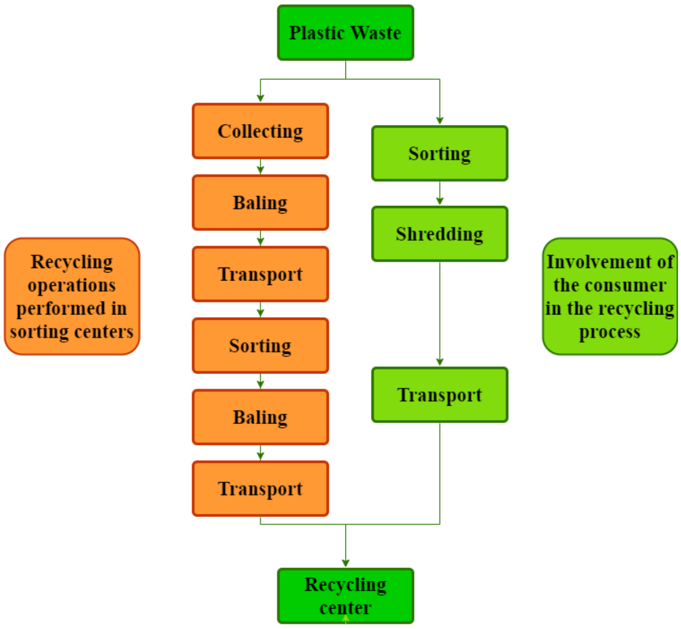
This article presents directions to improve the process of recycling plastic waste by eliminating some steps in the flow diagram of the current recycling process. The main household plastic waste materials are P.E.T., H.D.P.E. and P.P. thus this concept aims to collect, sort and shred these into flakes to reduce the space occupied before transportation to the recycling units. As these materials are visually similar but chemically very different is important to consider all the constructive elements regarding the design of a recycling machine, such as the right sensors for identifying the polymers, blades to be able to shred them, the right unit dimension, engine, and friendly interface. This machine is a big help in a world polluted by a substantial amount of plastic waste, that represents a threat to the sustainability of our planet. The main purpose of this paper is to present the first steps in the design development of such needed machine that can help reduce the amount of plastic that ends up in landfills and oceans.

Keywords: plastic waste, shredding, sorting, recycling, machine design

1. Introduction

With the main purpose of reducing the amount of household waste made of plastic, this paper follows the main features to develop a thermomechanical aggregate that shortens the stages of the technological process of recycling (collection, transport, sorting and shredding), as it can be seen in the picture below.

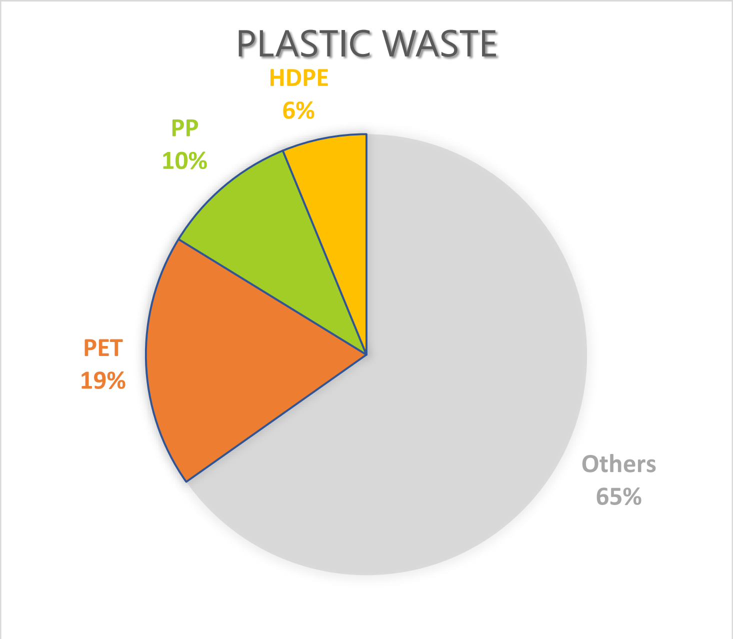
Figure 1. Diagram flow of current recycling operations vs. the developed one



We set the target waste starting from the materials that are best suited for mechanical recycling by crushing and therefore their transformation into a first stage in the form of flakes.

All 3 categories of materials P.E.T., H.D.P.E. and P.P. accounts for a quarter of all municipal plastic waste. These are especially represented in the household by plastic containers in rigid form that can be easily recycled.

Figure 2. The most common 3 types of plastics from all municipal plastic waste



Plastic containers, although visually are similar, from a chemical point of view are very different, having various melting temperatures and implicitly different recycling processes.

PET short for polyethylene terephthalate, symbolized by 1 is commonly found especially in beverage containers. These can then be recycled in the form of new containers, polyester fibers, various pillow fillings or sleeping bags.

High density polyethylene, HDPE, symbolized by 2 is used for milk containers, sauces and cleaning products that can then be recycled in the form of new containers, various pipes or toys.

Polypropylene, PP for short, symbolized by 5 is found in dairy containers such as yogurt and cream and various hygiene products. These containers can then be recycled in the form of textile fibers, or various objects such as pots and speed limiters.

All these 3 types of materials are recycled according to the same steps such as crushing, washing, drying, extrusion and obtaining new granules, the main difference being the melting temperature for extrusion.

Due to their technical and economic performance, plastics today cover a wide and varied range of uses. Once they have completed their task, the objects become waste and it is therefore necessary to manage their future.

To reduce the growing volume of plastic waste, managing its treatment has become a high priority on the political, economic, and environmental agenda of all industrialized nations.

Currently, the energy recovery of plastic waste is achieved through easy options, such as incineration, which is often not cost-effective and environmentally friendly. However, it is generally difficult to recycle these materials due to their contamination with other plastics that are incompatible with each other. Therefore, it is necessary to improve technologies, such as sorting polymeric materials, so that their recycling is profitable. For cost-effective recycling of polymeric materials, plastic waste must be sorted cheaply and automatically into individual types and classes. (F. Bezati, 2010)

2. Current technology

Optical sorting technologies that are already widespread in the food industry are proving to be extremely suitable for sorting plastic waste. Compared to manual sorting, they offer significant advantages, such as better efficiency and more competitive costs. For sorting plastics, infrared processes are the appropriate optical technology, as they can quickly collect information about groups of atoms on the surface. The spectral information (derived from absorption or transmittance measurements) used in industry to differentiate plastics is largely derived from the NIR and MIR spectrum ranges.

The most popular type of sensor used in industrial waste sorting applications is a near infrared (NIR) sensor, as used where the reflective wavelength of the waste container is used to determine its type.

Using NIR technology (wavelengths: 700 - 1400nm), sorting machines capable of differentiating several types of plastics have been designed in the industry. (Lucie Jacquin, 2020)

Techniques based on optical spectroscopy, such as infrared reflection / absorption, have reached their limits. This technique has the disadvantage that it does not apply to dark plastics, cannot identify differences in the same polymer and cannot be used if the surface of the plastic waste is wet.

Nowadays, the separation of sources of recyclable waste is done through yellow bags and selective collection containers, as well as recycling campaigns, (for example, in Constanța – on city's day - were offered public transport tickets in exchange of 3 empty PET containers an event that collected 220kg of PET waste in just 10 hours - which indicates the desire and inclination of citizens to selective collection).

However, there is always the risk of misuse with these conventional methods, as the consumer may throw the waste in the wrong bag and / or incorrect part of the container.

Reverse vending machine (RVM) is a device used for the separate collection of packaging waste automatically. These devices can successfully replace human factors in the case of waste separation.

They substantially prevent human error, directly reward users, and punish abuse when necessary. The working principles of RVMs can be listed as: proximity sensors, image processing, barcode reading and radio frequency identification (RFID). But the first three techniques are inefficient in waste management applications due to the wide variety of waste, deformation conditions, shape, structure, and mass.

The use of techniques such as RFID has successfully indicated that technology is able to provide efficient waste management, it can also be a contributing factor to recycling and waste management.

Labeling all packaging materials with an RFID tag during the manufacturing phase might seem like an effective solution. However, this labeling process significantly increases costs and labels are harmful to the environment. For example, if RFID technology were to be used worldwide today, about two trillion products a year would have to be labeled. These labels may contain toxic or high-priced materials. The ability to release toxic elements into the environment, the damage they cause to separation machines and operational problems, restricts the widespread use of RFID technology. Consequently, a new efficient and inexpensive separation technique for RVMs should be developed to overcome the weaknesses of current technologies. (Korucu, Kaplan, & Büyük, 2016)

In addition, global experience has shown that rewarding is the most effective way to maintain a high level of participation in the recycling process. To ensure that the desired goals can be achieved, one of the plausible methods is by implementing a concept of reverse vending machine (RVM) in which the user will receive his reward when he recycles his corresponding item. RVM is an innovative concept that has been introduced to contribute to the efficient collection of recycled materials, stimulate recycling activities and therefore improve waste management. The RVM machine is commonly used to encourage the community to dispose of waste properly, especially for recycling materials such as plastic, paper and aluminum. (Tomari & Kadirb, 2017)

Capacitive proximity sensor is a sensor that is used to detect metallic and non-metallic objects (plastic, sheet metal, aluminum, wood, etc.). It uses the variation of the capacity between the object and the sensor.

Infrared photoelectric sensor is a sensor that is used to detect the presence of things that are not ideal at the entrance, ie water or other liquids, stones, etc. This sensor uses standard visible LEDs that pass-through water and detects it using a 1450nm wavelength.

RVM machines sort containers in three ways: by analyzing the material of the container (for example, with an IR spectrometer), checking the shape of the container, checking the barcode. The container is scanned and identified (according to the database) and it is determined if it is compliant waste. Machines can use material recognition as well as a barcode scanner when needed, along with an online or local barcode database. This increases the price of RVM due to the IR spectrometer and barcode scanner and the accompanying electronic costs. It also makes the recognition process more complicated due to the daily synchronization of databases to process new barcodes for new container types from thousands of vendors.

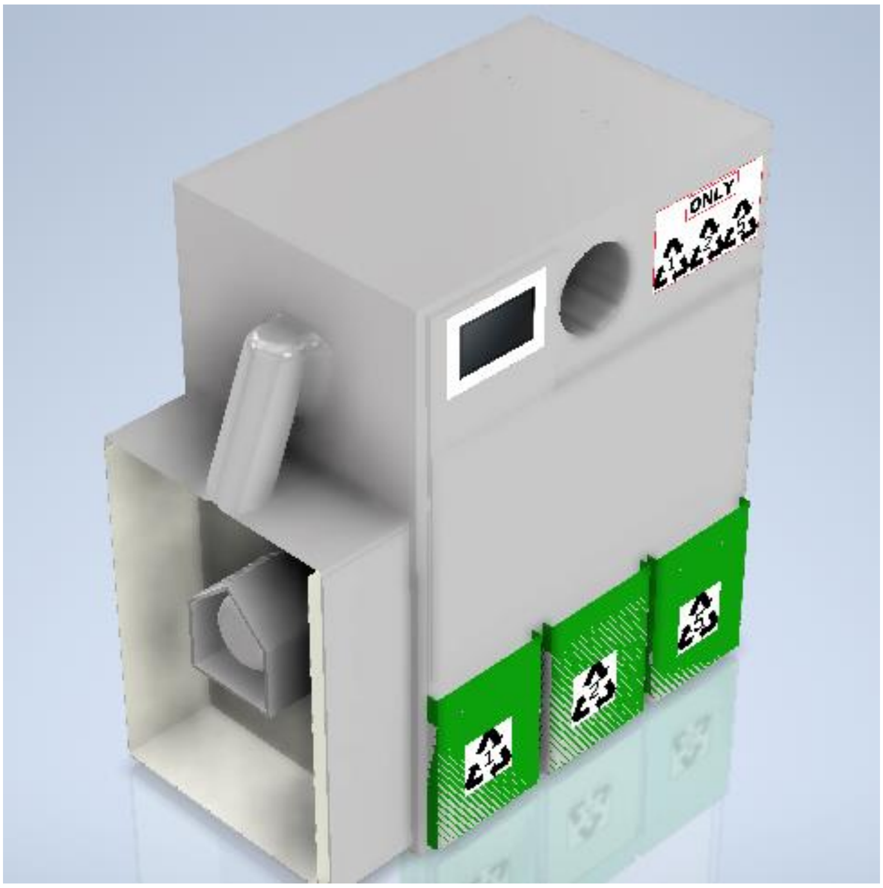
3. Constructive elements of the concept design

This report focuses on the unit developed for the separation and shredding of used plastic containers.

The main objective of this project is to: separate plastic containers according to the type of plastic they are made of; shred the containers; contribute to the collection of recyclable materials and therefore to the stimulation of recycling activities anywhere and anytime.

Plastic shredding is the process of reducing plastic waste to flakes for further processing.

Figure 3. The exterior of the concept made in Inventor



The way such a device might look can be seen in the image above. The waste would be introduced through the top, which would then be validated with sensors, collected separately on the 3 types of materials, would pass through the shredding machine, and then would be collected in the compartments where they would then be transported directly to recycling centers.

The appliance must be provided with a method of rapid disposal of improper waste that is introduced, but also with an easy-to-use interface as well as certain warnings or warnings

To reduce as much as possible, the vibrations and noise from it, the electric motor, and the transmission from it to the shredder shaft are located in an isolated room which in turn is located at the top of the very large space for non-compliant waste.

The most important step was to study the basics of the shredder. This included the machine. The main component of a plastic container shredder is the blade. Thus, the attention is directed to the study of an appropriate design of the blade to serve the desired purpose.

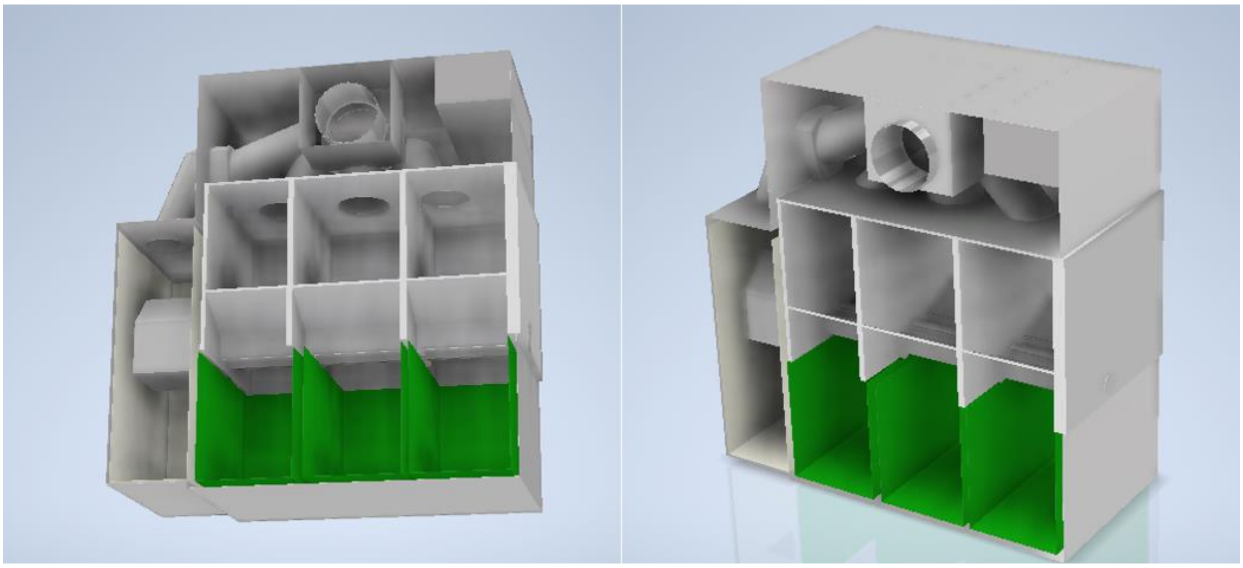
The purpose of the shredding mechanism is to shred as many plastic bottles as possible, at once. The size of the device is 200mm x 150mm x 100mm. The shredder has many cutting knives in the form of blades with curved edges, which are arranged in a "V" -shaped design as shown in Fig. 5. The shaft is hexagonal and is made of stainless steel. The knives are assembled on a single shaft with a spacer between them.

After determining the type of blade, the second important thing is the design of the machine. The design is done in INVENTOR. The various components required along the blade are frame/ support, shaft, washers, gears, etc. Thus, the design phase is briefly classified as machine construction, cutting system and transmission system while the main design aspect is the occupation of space. The main goal is to create a machine as compact as possible so that the space needed to be occupied is easy to find in neighborhoods.

The larger the thickness of the plastic container, the thicker and larger the size of the plastic pieces after it has been shredded.

Once the CAD modeling is done, the next step is to select the material. For example, the material for the blade and frame is steel and the gears are made of steel, but there are many other aspects in terms of the characteristics of the materials that will have to be considered.

Figure 4. The interior of the waste recycling concept made in Inventor



The aim is to identify four possible categories: PET, HDPE, P.P., or fraud (any waste that does not correspond for various reasons).

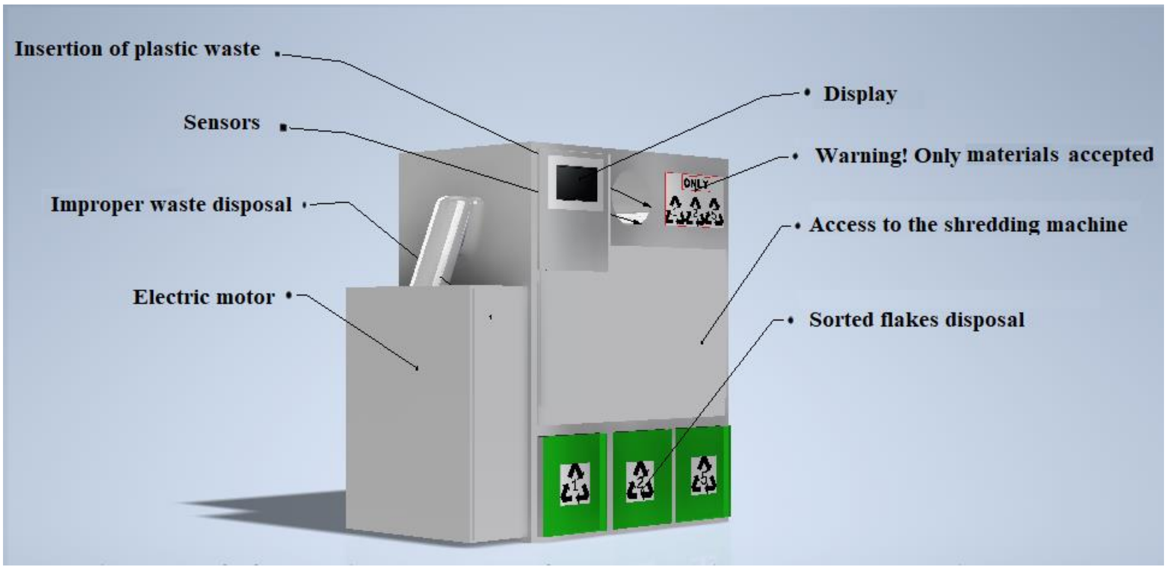
The flow starts by receiving the input, which is the plastic container. The sensor then detects the type of plastic. If the sensor does not detect any plastic, the object is removed, and the flow stops. If the sensor detects a plastic, the sensor sends plastic to the next sensor for unwanted liquid detection (Aditya Gaur, 2018)

As an RVM is not just a standalone box, but rather a smart machine that requires interaction with users, waste collectors, the IT support and maintenance team, and suppliers that provide space to locate the device, the developed system should clearly describe all components and the relationships between them, ie to be user friendly.

The person who recycles places the empty container in the reception opening; the horizontal feeding system allows the user to insert containers in turn, while also having a large capacity to collect the containers.

Before being shredded, the device collects containers separately until enough is accumulated so as not to waste and justify the electricity used.

Figure 5. Main elements of the recycling unit



The design concept of the machine is presented in Fig. 6. and consists of certain major subassemblies. The aggregate also presented in the 3D model, is designed in a rectangular shape, divided into three main subsystems: collection, separation and shredding with the distribution of flakes in 3 categories.

It is equipped with LCD display, two sensor units, a crushing unit, driven by an electric motor. After being checked by the sensors, each container will be sent with the help of air nozzles in the corresponding compartment, and then it will be shredded inside the chopping unit located at the bottom of the machine.

4. Conclusion

In conclusion, the development of this device can be a solution to increase the volume of waste recycling by the contribution of all consumers who want to be actively involved in this process.

I consider that a first stage in the recycling of this waste, namely the crushing can be done by the consumer with the help of this aggregate, thus eliminating the stages of sorting, baling and transport to sorting centers and then to recycling centers. So that the 3 types of plastic can reach the recycling centers directly sorted according to the material and in the form of flakes.

Regarding further developments, much remains to be established and clarified, starting with the types of sensors required for all material type and material storage operations, operating parameters, power required for the electric motor of the shredding machine, the number of knives used, the reduction of noise produced, the construction and purchase price and so on.

The research concludes that the aggregate's ability to fade and dry flakes is not cost-effective. Such operations would involve additional costs, both by increasing the size by introducing a tank, connecting the unit to the water and sewerage network but also by using too much water, thus not being economical as this operation can be done in recycling centers for a much larger amount of flakes with much lower consumption of water, and electricity.

Research has also been done on the ability of the device to store certain waste by color so that after crushing it can be stored in separate compartments in the form of flakes. Thus, once the flakes are collected from several such devices, they do not require color sorting in the recycling center where they arrive, but with a much smaller capacity than the recycling centers, the operation would be a waste of energy and would also generate and a high price in terms of the types of additional sensors needed. It is necessary to sort by colors because if the colors remain mixed, once the flakes melt, the melt could have a single color, a shade of dark gray, dirty, the operation of pigmentation of polymeric materials being irreversible. So, I add as a conclusion that the operations of washing, drying and sorting flakes by color can be done at impressive speeds in recycling centers much more energy efficient and economical.

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