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Design and Development of a Mobile Collection Unit for Plastic Waste Recycling - REC.ECO.PLAST-

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Abstract

In this project, we designed and developed a mobile unit - **REC.ECO.PLAST** - for the collection of Polyethylene Terephtalate (PET) wastes. The objective is to offer a simple and efficient collection system to help the local community to get rid of the large quantities of plastics that invade our daily lives. The **REC.ECO.PLAST** unit performs the first three operations of the recycling cycle, including the collection, sorting and crushing of bottles or flasks into petals or grains. Then put it in a bag ready to transport to the processing plant.

The challenge of this project is to develop such a collection system, with low cost, which allows a simple and large implantation in all the massive gathering of citizens.

The types of plastics considered during the concept phase of this project include the PET, the HDPE, the LDPE and the PP; their known technical charactestics and their massive presence in our daily lives guided this choice.

REC.ECO.PLAST is made up of five subsystems of the collection unit including the mechanical system, the optical system, the sorting system, the solar system and the control system. The resolution of the technical and financial challenges linked to the development of these different subsystems is a major step in this project. Enabling community engagement, this project will certainly improve people's lives and contribute to a sustainable environment.

Keywords: Collection, recycling, plastic, waste, conception, environment.

1. Introduction

Faced with the global challenges of protecting the environment, the idea of recycling has become more than relevant in the political and economic sphere, as stated in the 21st Conference of the Parties [1].

In recent years, Algeria has seen a significant increase in the production of solid wastes ; the ratio per capita in an urban area has reached 0.7 kg / d / h, or nearly 9 million tons per year, of which more than 10% is represented by plastic [2].

Plastic has emerged as a symbol of modernity whose expansion of use has allowed the emergence of the culture of disposable. Its growing is due, in large part, to its characteristics: light, malleable, waterproof, adaptable to many type of products. In the particular case of Algeria, the imports of these materials, from Italy alone, saw an increase of more than 25% in the year 2004 compared to the year 2003. Unfortunately, the use of plastics, which is rooted in our daily life, is a real challenge in promoting sustainable development. In fact, these plastics not only reduce the natural resources but also destroy the environment through their non-biodegradable waste.

Among more than 2 million tons of plastic packaging, produced in Algeria by 192 industrial units alone, only 4000 tons are recycled (ie 0.0002%); whereas the recycling capacity of plastic is 130 000 tons per year [3]. This unsatisfactory recycling performance comes from the fact that the population is not sufficiently engaged in the recycling process and only the large industry is acting in this field. Changing the people's mindset should be the main strategy to limit the negative impact of plastics on our lives and on the lives of the future generations.

This project is a contribution that should positively affect the involvement of the population in the recycling process. Specifically, we design and build a modular collection unit so that it is accessible to as many people as possible.

2. Plastic Materials

This section will define the plastic materials and provide information on the volume of produced plastic, the volume of plastic waste and its recycling rate.

2.1. Definition of plastic

Plastic is defined as a polymeric substance of organic or semi-organic origin, containing a large number of atoms (or groups) of carbon, oxygen, hydrogen or nitrogen. There are several varieties of plastics, which can be grouped into three main categories: thermoplastics, thermosets, and elastomers.

Plastics are made from natural materials such as oil and its derivatives and natural gas. Thermoplastics melt under the effect of heat and solidify under the effect of cooling. For thermosets, the transformation is irreversible; once formed, the plastic no longer deforms.

2.2. Global production of plastic

According to the Federation of Plastic Producers, an estimated 311 million tons of plastic was produced worldwide in 2014, an equivalent of 10,000 kilos of plastic per second. This production consumed about 8% of the global oil production. China is the largest plastic producer in the world, with 26% of the world's total, followed by Europe with 20%. In contrast, Africa and the Middle East produce only 7% while Latin America produces 5% only. Germany leads in plastic consumption by 24.9% followed by Italy 14.3% and France by 9.6%.

2.3. Plastic waste thrown into the sea and oceans

In 2014, plastic waste was estimated at 25 million tons annually in Europe, with 6.5 to 8 million tons being dumped into the oceans, which end up in micro-particles ingested by marine fauna.

The seas and oceans receive daily about 8 million tons of plastic waste, of which 5 million tons (63%) are solid waste, fallen or thrown from the boats [4]. In the Mediterranean Sea, 250 billion micro-fragments of plastic float on the sea, according to the "Mediterranean in Danger" expedition conducted off European coast in July 2010. Pieces of plastic, invisible to the naked eye, are contained in beach sediments, shoals and sand, according to researchers at the University of Plymouth.

We are currently witnessing a massive pollution caused by the plastic bags. It will take between a century and 1000 years for this plastic to degrade and break up into microscopic waste that could pass through the food chain with consequences that are still poorly evaluated. At present, marine fauna is the most affected because of the daily hazardous waste it receives; it is estimated that there will be 50 million non-biodegradable wastes in the short term.

Fig.1. Plastic wasted amped in the nature

2.4. Plastic recycling rate

- In Algeria, only 25% of the plastic wastes are recycled!
- In France, the French Environment and Energy Management Agency (ADEME) estimated plastic waste at 2.5 Million tons a year in 2009. These plastics are poorly recycled; out of 3 million tons of waste, 1.4 million tons are land filled (45%), 506 000 tons are recycled (17%) and 1.1 million tons are recovered as fuel (37%).
- On the other hand, in Switzerland the plastic discharge is forbidden and the recovery rate is almost 100%.

3. Recycling, Types and Processes

This section presents a general overview on recycling, its types and its different processes and their evolution over time. A particular focus is given to the recycling of plastic waste and its methods, its advantages and its contribution to the industrial development and to the protection of the environment.

3.1. Definition

Recycling is a process that allows the transformation of a product at the end of the cycle to a reusable resource for the same industry or for another sector of activity.

3.2. History

Recycling is used since the Bronze Age. At that time, used metal objects are melted in order to recover their metal for the manufacture of new objects. In all civilizations, the art of "doing something new with the old" exists. For example, old rags, then paper and cardboard, are recovered to make paper pulp. The situation changes with the gradual and massive development of the industry and the huge increase in consumption.

The management of raw materials and waste is becoming increasingly difficult, the first becoming too rare and the second too invasive. Recycling plays a big role in safeguarding the environment.

During the Second World War and few years after the war, any dress shirt at the end of life was recycled by individuals: the buttons are carefully recovered for later sewing work, the sleeves separated to protect the arms in dirty work or to polish the shoes and the rest reused as rags to clean windows. These rags were also traded to rag pickers, who collected them for paper making.

In 1970, recycling was revived by the supporters of the environment, who launched the current logo to identify the recyclables products and the products made from recycled materials.

Nowadays, the progress made in the recycling of wastes differs in developed countries from that in the countries under development. In the latter, it is the informal recovery process that recycles part of the waste, as it was during the Second World War.

3.3. Principles of recycling

Recycling makes it possible to avoid the waste of natural resources and energy, to secure the industry's supply of raw materials, and to reduce its environmental impacts. The incorporation of recycled materials allows to: (a) reduce the use of energy and the water consumption, and (b) reduce the CO_2 emissions. Since the 2000s, recycling has been the key enabler to:

- Increase the industrial production as a result of waste management policies: recycling targets, development of extended producer responsibility (EPR) sectors,
- Grow the demand for material,
- Meet the environmental and economic constraints.

This evolution has led to the industrialization of recycling as we know it today in a dynamic driven by the circular economy.

3.4. Actors in the waste recycling industry

At the present time there are three main families of recycling techniques: chemical, mechanical and organic.

- **Chemical** recycling uses a chemical reaction to treat waste. Examples include separating certain components using chemical reaction,
- **Mechanical** recycling is the transformation of waste using a machine. Examples include grinding of waste or components separation using eddy current,
- So-called "**organic**" recycling involves, after composting or fermentation, producing fertilizers or fuel.

3.5. Recycling of plastic bottles

Nowadays, plastic is everywhere and people throw it in the nature almost every day. This plastic is often not biodegradable and breaks down into toxic elements that can seep into the ground and mix with the groundwater, Since plastic as a material is very difficult to recycle, there are only 4 main families of recyclable plastic, namely PP (polypropylene), PET (polyethylene terephthalate), HDPE (high-density polyethylene) and LDPE (low-density polyethylene). Recyclable plastic is identified by a triangular symbol where the plastics industry has created a system based on 7 key principles, numbered 1 to 7, corresponding to plastics with different characteristics and properties, Table. 1.

Table 2. Existing Codes for Recycled Plastic Identification

Code	Plastic type	Utilization
1 PETE	Polyethylene Terephthalate (PET)	fizzy drink bottles, cooking oil bottles
2 HDPE	High Density Polyethylene (HDPE)	detergent bottles, fruit juice bottles, milk bottles, etc.
3 V	Polyvinyl Chloride (PVC)	water bottles, shampoo bottles, plastic film, etc.
4 LDPE	Low Density Polyethylene (LDPE)	plastic bags and packaging, bin bags, etc.
5 PP	Polypropylene (PP)	yoghurt pots, margarine tubs, children's cups, flasks, etc.
6 PS	Polystyene (PS)	plastic cups, yoghurt pots, hamburger boxes, etc
7 Other	Any other type of plastic	

The recycling of plastic bottles and flasks takes place in three stages (Fig. 3):

- Bottles and flasks in plastic are sorted in sorting centers, automatically or manually.
- Each plastic bottle or flask is washed, then crushed into petals or grains.
- The petals or grains are melted and processed by different techniques to give new products.

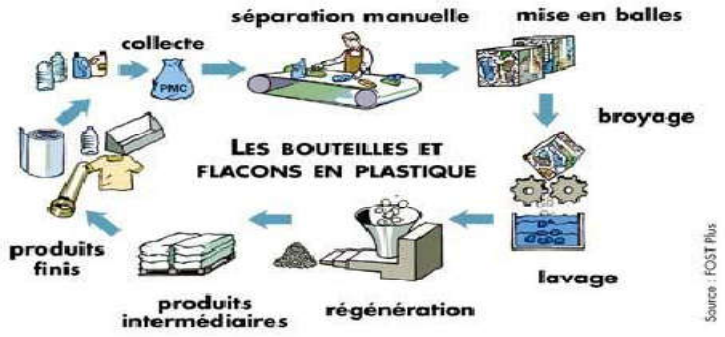

Fig.2. Recycling Cycle of Plastic Bottles or Flakes

3.6. Environment and economical impacts

Overall, plastic represents 11% of the waste. For the UN, recycling plastic is a crucial issue and raises many concerns. Plastic present in the fauna and flora requires between 100 and 1000 years degrading. Recycling of plastic will help:

- Save fuel: 1 kg of plastic film = 0.8 kg of crude oil earned,
- 1 plastic bad: powers a 60 Watt bulb for 10 minutes,
- Reduce the energy borrowing of professionals: 22 million tons of plastics per year,
- Produce energy: 50% of recycled plastic production = 5 million kilowatt hours of energy,
- Create new products: 1 bottle = 7 smart cards,
- Create new jobs: 120 researchers + 6 plastic processing units.

4. Design of the Plastic Waste Collection Unit (REC.ECO.PLAST)

This section provides the description and operating principles of the collection unit and the function of each of it's of the sub-systems [5, 6].

4.1. Description and operating principles of the collection unit

4.2. Components of the collection unit

A table 1 includes the critical specifications of the crusher system. Since the desired final volume of the recycled plastic bottles varies according to the size of the holes of the grid placed at the bottom of the crusher, the distance between two consecutive e blades is 6 mm. The width of the machine being 148 mm, there will be a set of 14 blades installed along the hexagonal shaft, each separated by a 6 mm long ring. The blades and shaft assembly is designed for ease of assembly and disassembly of the blades during any required maintenance. To increase the efficiency of the cutting blades and to cover a larger cutting surface, the blades are placed in a circular arrangement and cover 360° around the shaft with a 20 ° angular offset between any 2 consecutive blades. An electric motor, coupled to the crusher shaft is used to rotate the blades.

Table 2. Crusher System Specifications

Type of Machine	Crusher
Number of rotating shafts	1 shaft with 14 blades
Number of fixed shafts	1 shaft with 27 blades
Rotating shaft speed	70 RPM
Power in KW	±500 W
Cost	≤ 5000 DA
Speed control	Easy
Special requirement	Very robust and waterproof
Operational requirement	Ease of use and adaptability

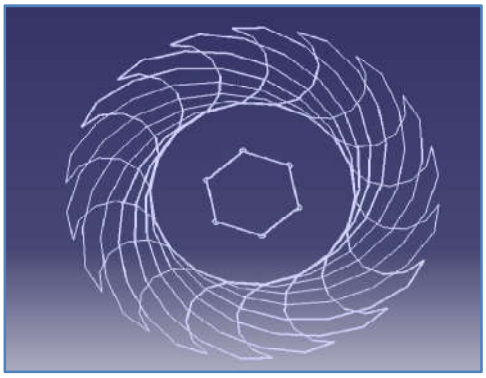

Fig.3. View of the Blades Layout

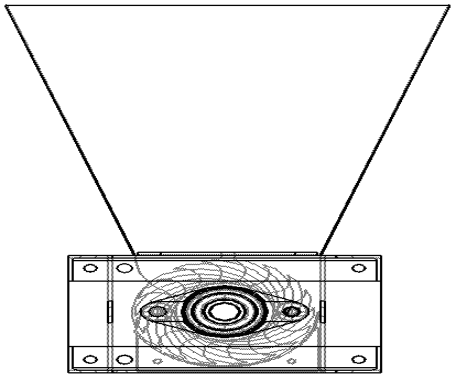

Fig.4. Front View of the Crusher

When a plastic bottle is damped into the crusher, the rotating blades cut the bottle into small pieces. This process continues until the size of the pieces is less than a certain size; the small pieces will then cross the holes of the grid, installed below the cruhser at 3 mm from the periphery of the blades. The diameter of the holes varies according to the desired dimensions of the bottle debris. Between any two consecutive blades, a 6 mm thick metallic piece is fixed to the shaft supporting the blades to ensure that bottles will not escape thru the space between the two consecutive blades without being cut.

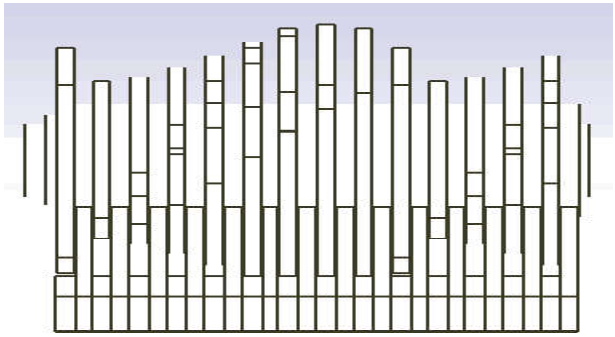

Fig.5. Bottom View of the Crusher Shaft and Blades

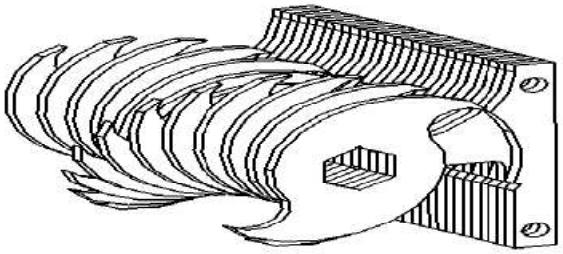

Fig.6. Iso View of the Crusher Shaft and Blades

The shape of the blades and their layout, on the rotating and fixed shafts, are selected to maximize the crusher performance; this requirement is achieved by minimizing the angle of rotation required for a new contact between the blade and the damped bottle. The curvature of the blade helps to better dissipate the contact forces, it minimizes the instantaneous cutting surface and consequently makes cutting easier.

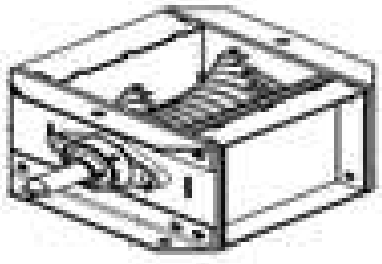

Fig.7. Technical Drawing of the Crusher

Fig.8. Product of the Crushing Operation

4.3. Solar system of the collection unit

To ensure that the collection unit is eco-friendly, the system is equipped with a solar system to charge the batteries powering the electric motor of the crushing unit. This system includes a solar panel connected to a 12 volts solar controller; the controller activates the system whenever the charge of the batteries reaches half capacity. This solar system is also equipped with an inverter and a starter pin to ensure that the loss of current is at minimum during the start of the engine. Finally, the collection unit is equipped with a 12 Volts switch that connects the electric motor to the electric network and to the batteries powered by the solar system. This hybrid power supply will reduce the operational cost and at the same time will ensure continuous operation during dark or cloudy days.

4.4. Sorting system of the collection unit

To ensure that only selected types of plastics (PET, HDPE, LDPE. and PP) get into the crusher system, an optical system is used to sort the objects that are dropped in the collector of the unit. A conveyor system is used to re-route the bad objects to a dumpster attached to the unit, while the recyclable object are routed to the crusher. The optical system includes a high speed camera which detects colors and geometric shapes and compares them to shapes and colors stored in its database using an ultra-fast microcontroller. It also includes a metal detector to prevent metallic objects getting into the crushing unit and damaging the blades. In addition, a force sensor is also incorporated in the system to eliminate any object that may causes an overload in the system. With this sorting system in place, the collection unit can operate efficiently and safely.

5. Conclusion

This project offers an engineering solution to the problem of plastic waste that is crippling a world going thru a midst of economic upheaval and facing significant environmental challenges. In the particular case of Algeria, this project is critical to support the economic development of the country, which relies on small and medium-sized enterprises, and to alleviate the significant issue related to the plastic waste present in the nature.

There is a significant business opportunity in Algeria due to the increase in plastic made products, the increase in plastic waste damped in the nature and to the limited recycling capabilities. Plastic waste are damped in the nature mainly because of the lack of community engagement in the recycling process. This behavior has a terrible impact on the environment, since it takes between 100 and 1000 years for the plastic to degrade in the nature. It also degrades people's health and reduces the non-renewable natural resources.

The objective of this project is the design of a mobile plastic waste collection unit that can be located within the different communities. The vision of this projects is to get the community members engaged in the recycling process by offering a unit that is accessible, efficient and easy to use. This effort will result in cleaner environment and improved life condition; it will also create new jobs and new raw materials and reduce the reliance on natural resources.

This report includes the engineering study performed to identify the key components of the collection unit critical to any recycling cycle.

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