The Quality in the Separation of Rigid Packaging of High-density Polyethylene – Application to a Real Case in Portugal

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Abstract
In recent years, companies producing high-density polyethylene have been affected by huge reductions in sales volumes as well as the value of these same sales.
The PFAU-PMP collects and treats different types of plastics that, due to their physic-chemical characteristics, can be recycled, valued, and subsequently reintegrated into the value chain (for example, high and low density polyethylene, polypropylene and polycarbonate). PFAU's Portuguese office had the necessity to improve the quality of 4000 tons of high-density polyethylene, currently packaged in bales. To do it the company felt the need to proceed with a correct sorting solution, taking into account that the Portuguese recycler involved in this project (for reasons of confidentiality will be called Company ABC) has some legal obligations with product treatment, and also that some value must be added to the final product. The objectives of this research are to study how to proceed to the correct separation of the packages, through product quality criteria, and to define which of the processes, mechanical or chemical, is the most correct for the treatment of 4000 tons of polyethylene. Based on this study, it is concluded that it is possible to improve the quality of the final product by introducing a pre-automatic manual sorting carpet, allowing correct color separation, removal of contaminants and identification of the polyethylene. Finally, it is also concluded, that the process of mechanical recycling is more appropriate than chemical recycling, since the chemical processes are extremely expensive and technically complex.

Keywords: High-Density Polyethylene, Recycling, Sorting, Quality, Improvement.

Introduction

With the decline of the construction market that we have seen in recent years in Portugal and Spain, companies producing high-density polyethylene were affected by huge reductions in sales volume as well as in the value of sales. This phenomenon has been observed not only in the market of new products (granulated products to be used for the first time in the production of plastic parts from the petrochemical industries), but also in the market of recycled products (although these products are also granulated, they have origin in packaging already treated by the recycling industries).

From the analysis by Nakatani and Hirao (2011), applications for recycled products may be roughly the same as those for new products, depending on the fulfillment of some quality parameters required by the demand, that is, they end up competing in the same markets, for the same customers, and using the same logistic channel. According to Johnson, Scholes and Whittington (2009), and Soares and Mendes (2018), logistics as a primary value chain activity may include the reception, storage and distribution of inputs for the product or service, material handling, stock controls, transportation, storage of outputs or product distribution.

It was in this aggressive, and extremely competitive context, that the company PFAU-PMP contacted with the national recycler "Company ABC" to find solutions that would allow PFAU-PMP to maintain its sales and operational levels. PFAU-PMP is the "Iberian arm" of Hong Kong-based Asia Fukutomi, which operates in the recycling and trading of all types of plastics in the Asian continent.

The analysis by Plasticindustry (2011) shows that the Asian and European markets (natural markets of PFAU-PMP and Company ABC) are fundamental to the polyethylene market, as shown in Figure 1.

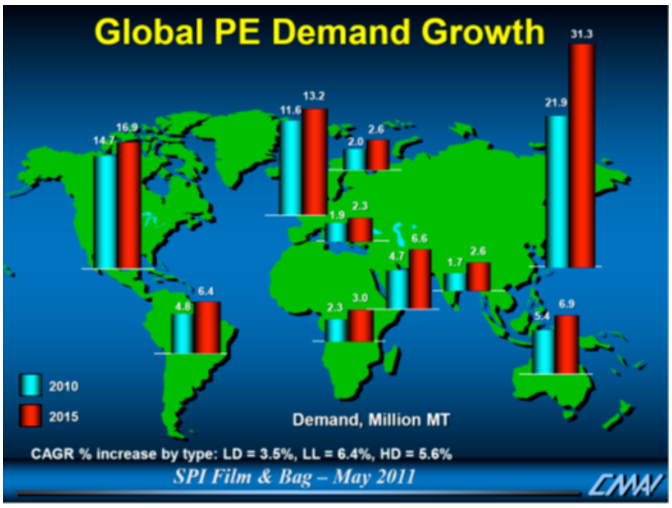

Figure 1 – Global PE Demand Growth
Source: Plasticindustry, 2011.

PFAU-PMP Chemicals Industries y Merchandising Espanola SL, is a company founded in 2002, with headquartered in Cabanillas del Campo in Guadalajara, Madrid, Spain, and it manages all types of plastics, such as polyethylene of high and low density, terephthalate polyethylene, polypropylene, acrylic, polycarbonate, ABS, polystyrene, expanded polystyrene (commonly styrofoam), among many others.

The company's method is to buy bale-shaped products without any prior treatment, in order to guarantee to its Asian counterpart the delivery of quality products and free from contamination (mixing of various plastics), followed by the process of crushing the different types of plastics, which is done internally.

For a 4,000 tons business, such as the one being studied, the company does not have sufficient treatment capacity and it should be assessed specifically from the remaining activity.

PFAU-PMP collects, treats, and sends different types of plastics that, due to their physicochemical characteristics, can be recycled and reclaimed and subsequently reintegrated into the value chain.

The main plastics the company works with are now presented (Figure 2), using information from the British Plastics Federation (2012).

1 PETE	PET	*polyethylene terephthalate*	*Water bottles, soft and fizzy drink bottles, pots, tubs, oven ready trays, jam jars*
2 HDPE	HDPE	*high-density polyethylene*	*Chemical drums, jerricans, carboys, toys, picnic ware, household and kitchenware, cable insulation, carrier bags, food wrapping material.*
3 V	PVC	*polyvinyl chloride*	*Window frames, drainage pipe, water service pipe, medical devices, blood storage bags, cable and wire insulation, resilient flooring, roofing membranes, stationary, automotive interiors and seat coverings, fashion and footwear, packaging, cling film, credit cards, synthetic leather and other coated fabrics.*
4 LDPE	LDPE	*low density polyethylene*	*Squeeze bottles, toys, carrier bags, high frequency insulation, chemical tank linings, heavy duty sacks, general packaging, gas and water pipes.*
5 PP	PP	*polypropylene*	*Polypropylene can be processed by virtually all thermoplastic-processing methods. Most typically PP Products are manufactured by: Extrusion Blow Moulding, Injection Moulding, and General Purpose Extrusion. Expanded Polypropylene (EPP) may be moulded in a specialist process.*
6 PS	PS	*polystyrene*	*Toys and novelties, rigid packaging, refrigerator trays and boxes, cosmetic packs and costume jewellery, lighting diffusers, audio cassette and CD cases.*
7 OTHER	Other	*other types of plastics*	

Figure 2 - Typologies and recyclability of plastics
Source: British Plastics Federation, 2012.

The objectives of this paper are as follows:

- Correctly separate the packaging through product quality criteria (color of packaging, process used in the production of packaging, and whether or not polypropylene capsules exist);

- Optimize the quality of the purchased product, giving it the correct processing state (broken, ground or granulated);

- Define which process, mechanical or chemical, is ideal for treating the 4000 tons of polyethylene.

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Literature review and research questions

Santos (2009) states that while the separation of industrial plastic waste is relatively simple due to the degree of cleanliness of this type of waste, the separation of plastic waste from municipal systems is extremely complex due to contamination and mixing of plastics.

In order to understand better the problem of separation and management of plastic waste by municipal systems, an analysis was made of what is going on in Qatar. Qatar is a small country where the problem of country size does not arise, and where too we find that there is a management entity, the Qatar General Cleaning Project, which, similarly to the management companies in Portugal, is concerned with separating recoverable plastics, such as polyethylene, from other waste that is sent to the landfills. Such landfills do not have active and efficient regulation or supervision, according to Al-Maaded, Madi, Kahraman, Hodzic and Ozerkan (2012). In practice, the authors also make their analysis based on Life Cycle Assessment and not on Quality, recognizing, however, the importance of separating valuable plastics from worthless products or waste.

Given the inability to treat the 4,000 tons of high-density polyethylene internally due to equipment and space constraints, a solution must be found to enables PFAU-PMP to receive and send the product to its Asian counterpart, ensuring the required quality levels, minimizing contamination with other plastics, and maximizing profit for the group.

According to Nakatani and Hirao (2011), the quality of the output of the recycling process depends very much on the quality of the input used. In this case, we can say that the quality depends a lot on the bales collected by the Municipal collection system in Portugal and Spain. According to the information provided by the supplier "Empresa ABC", most of the high-density polyethylene bales in stock come from the Municipal Waste Management Company in Spain and from Sociedade Ponto Verde in Portugal.

In an attempt to validate the statements of Nakatani and Hirao (2011) where it is stated that the issue of product quality is approached as a "substitution factor or performance ratio", similar expressions were found in the literature, but always from a perspective not directly related with quality. For example, Lazarevic, Aoustin, Buclet, and Brandt (2010) refer to this issue as "degree of substitution of new product", under which a sensitivity analysis could be made by varying this variable alone or in conjunction with other variables, in a context of Life Cycle Assessment (Figure 3).

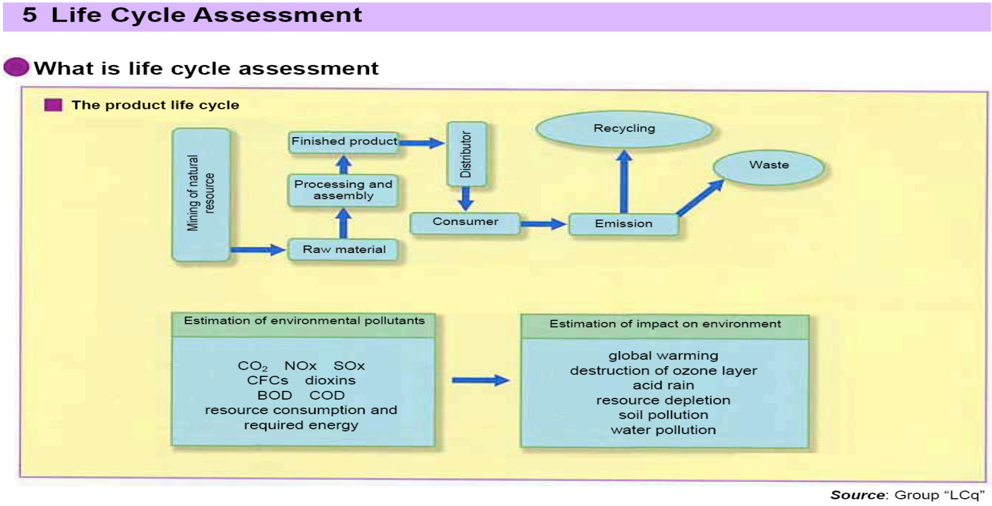

Figure 3 - Life Cycle Assessment
Source: Plastic Waste Management Institute Japan, 2004.

The problem of polypropylene caps placed on packaging, raises yet another quality issue, as it is a known contaminant that deserves special attention from operators, recyclers and academics. Polyethylene and polypropylene appear to be one of the most common mixtures of plastics and therefore it needs a highly optimized screening and selection processes, and to be subject to an efficient quality control as a means of leading to quality certification of products resulting from recycling processes (Serranti, Gargiulo & Bonifazi, 2011).

In order to be able to be efficiently and smoothly reused for the production in which it will be applied, polyethylene must have a quality/separation degree above 97% (Bakker, Rem & Fraunholcz, 2009; Serranti et al., 2011), being the flotation technique the one that guarantees the best quality and efficiency in recovery, according to Bakker et al. (2009). However, this technique is only applied in processes where the material is already in the form of flake, that is, it has already undergone a screening, washing, shredding and grinding process.

Quality is only part of the design of a process of collecting and recycling plastic. Attention is drawn to the fact that this work focuses only on a small part of a very complex problem, and with many interests or factors that condition or complement each other. Figure 4 shows this problem.

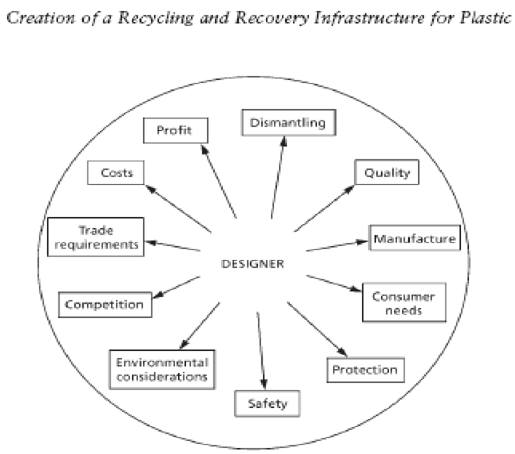

Figure 4 – Creation of a Recycling and Recovery Infrastructure for Plastic
Source: Goodship, 2007.

Plastics are known to occupy large volumes relative to the generality of waste, however this large volume is characterized by low weight, causing problems in transportation. Because of its fundamental importance and perceived cost, transportation has traditionally received a considerable amount of attention from management, with almost all companies, large or small, having transportation managers (Bowersox, Cooper, Closs & Bowersox, 2012; Soares & Mendes, 2017).

In order to avoid high transportation costs and unnecessary space usage, packaging is usually torn apart at the sorting centers, or simply baled, actions also identified in the processing of materials in the recycling units, and where, sometimes, contamination occurs (Kipper, 2005).

Being recognized the importance of input (waste) concerning the quality of output (recycled waste), the role of plastic separation in this process is emphasized. We can say that there are at least two important stages of separation of plastic waste:

- The first occurs at sorting centers, and is the separation of whole or broken packaging;

- The second occurs in the production process of recyclers in the product-shredding phase, and these two points of waste separation are fundamental to product quality (Letras, 2008).

Mattos and Peres (2010) also state that it is only possible to have an effective recycling if the quality of the waste is high, or "the best possible" according to their words. Any dirt or contamination may result in the rejection of a complete batch.

These authors also clearly and explicitly refer to the recycling process as starting with packaging, collecting and sorting, then grinding and milling, with the aim of producing granules or flakes that can be incorporated into the production of new products.

We are now in a position to continue research on the quality issue of recyclable (input) and recycled (output) products, bearing in mind that large organizations such as ABC Company have little incentive to invest in quality, because they consider that their size and capacity are considered robust barriers to the entry of new competitors (McIntyre, 2011).

The analysis will take into account the suggestion made by Sun and Zhao (2010), who mention that quality systems based on Total Quality Management also aim to improve product and process quality.

Finally, looking at recycling companies not only as purely productive and industrial units, but also as companies that render services to society, we can say that Soares (1994, 2003) considers that the most relevant trends for the future are the increase of quality in service companies, due to the increasing weight of services in the current economy, and the extension of quality operations to all functions and hierarchical levels of an organization.

Research questions

Therefore, this study aims essentially to answer three research questions:

- How to proceed with the correct separation of the packaging, through product quality criteria?

- How to optimize product quality by giving it the correct processing state (shredded, milled (crushed) or granulated)?

- Is it possible to define which of the processes, mechanical or chemical, is ideal for treating 4000 tons of polyethylene?

Methodology

The study is based on the direct observation at the place where the 4000 thousand tons of polyethylene are stored, and the need to treat them. There is a clear lack of space on the part of PFAU-PMP to receive all quantities.

Several informal interviews were also conducted with the heads of the companies involved in this project, and the flow and production scheme of the ABC Company unit was also observed and recorded.

A comparative analysis of the different waste treatment methods (mechanical and chemical) will be made, and it will be determined which one gives the best quality to the final product.

An analysis will also be carried out on the best processing status to be given to the product (shredded, milled (crushed) or granulated) through interviews with ABC Company, PFAU-PMP, Fukutomi and two consumers of the new and recycled products. Please note that here Fukutomi will also be interviewed as a consumer of polyethylene as it develops both activities.

In the analysis by direct observation in the place where the 4000 tons of polyethylene are stored (ABC's raw material park), it was possible to find and classify 3 types of polyethylene packaging from 2 different sources:

- White, cream and multi colored (blue, green, yellow, pink) packaging;
- Packaging from the detergent industry or the food industry.

It was also observed that at the time of opening the polyethylene bales, other materials were present such as polypropylene and PET, and within the polyethylene, high and low density polyethylene were also identified.

In an interview with ABC's technical manager, it was mentioned that the most efficient and economic method from an industrial point of view was mechanical recycling, which starts with the separation process. Melo (2009) states that this step consists in the separation of contaminants, that is, it consists in removing materials other than those that will be recycled, and this process can be manual or automatic.

According to Spinace and De Paoli (2005) and Schlischting (2003), the product resulting from the recycling process can be reused in traditional injection, extrusion and blowing processes, where it can be mixed with new materials to compensate for the loss of quality observed during reprocessing.

However, those responsible stated that the need to use virgin raw material to address the quality flaws of the recycled product varies depending on the final application, and the characteristics of the recycled product itself.

Letras (2008) analyzes the quality criteria required for recycled polymers, stating that impurity limitations should be below 1% m/m (solute mass per solvent mass).

We present now a diagram of the simplified flow of the production process, to suggest improvements in the product quality (Figure 5):

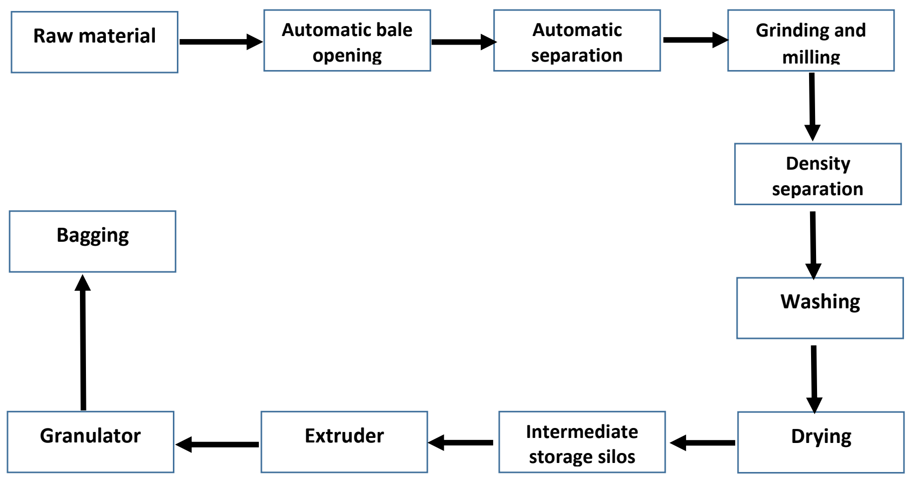

Figure 5 – Simplified flow of the production process
Source: Authors.

As this analysis refers to a company that buys most of its raw materials for recycling in the public auctions of Sociedade Ponto Verde (SPV), it is known the maximum percentage of contamination that the company should eliminate is 12% of the total weight of the material under analysis.

If we are analyzing a 4000 tons batch then a maximum of 480 tons of contaminants will have to be eliminated, which in practice translates into a high risk concerning product quality. Therefore, the concern about identifying the best method of treatment for the 4000 tons, because as mentioned above, the maximum impurities allowed in the recycled end-product should be 1% m / m (solute mass per solvent mass), that is 11% of the total contaminants allowed by the Sociedade Ponto Verde specifications.

Crossing this data with the theoretical conclusions of the different authors, as well as with the results of the interviews with the managers of the companies involved, it is proposed to create an alternative flow, and to make recommendations that aim to fulfill the objectives of the work performed, and to answer the research questions.

Results analysis and discussion

For recycling to happen the product has to be recyclable, and the process economically viable (Mattos & Peres, 2010). But for the (new) product resulting from the recycling process to be increasingly cost effective, improving product quality must be accompanied by a time to market process so that its profitability is high (McNally, Akdeniz & Calantone, 2011).

Due to its size and production capacity and the technical skills of its employees, ABC Company is in a position to shorten its time to market.

Still, the process of quality control of raw materials which is of utmost importance to the quality of the final product (Nakatani & Hirao, 2011) is neglected to the point that no prior separation of materials is made. This is verified by visual inspection of the 4000 tons, according to the photographic record in Figures 6, 7 and 8.

Figure 6 - Photo 1 of 4000 tons of High Density Polyethylene
Source: Authors.

Figure 7 - Photo 2 of 4000 tons of High Density Polyethylene
Source: Authors.

Figure 8 - Photo 3 of 4000 tons of High Density Polyethylene
Source: Authors.

It can be seen that the packaging in the bales are the most diverse, in terms of both geographical origin, color, and the type of product the packaging has packed.

It is understood that a condition of improvement of product quality would be the one mentioned by Nakatani and Hirao (2011) and Grach (2006), that is the input control of raw materials should be manually screened before entering the automatic sorting systems. By doing this, it would be possible to extract some contaminants not identified by the automatic systems, and reduce the color mix of the final product.

It should be noted that in interviews with the heads of Fukutomi and PFAU-PMP, it was mentioned that the final product was more valued the lighter the color, as with light colors it would be possible to place additives to continue producing material in light colors, while dark colors can only produce black materials again.

In terms of presentation of the final product, it was found that ABC Company is able to do any of the following processes, which are to wreck with a 30 to 50 mm sieve, to grind with a 12 mm sieve, or to granulate and extrude.

After some calculations and considering the information provided by the Fukutomi manager, the grinding with a 12mm sieve was considered the most logistically viable option.

Conclusions and recommendations

After the conclusion of this study we can draw some conclusions regarding the objectives initially proposed, and can then say that concerning the first research question, it is possible to improve the quality of the final product by introducing a manual sorting mat prior to the automatic sorting process, allowing correct color separation and removal of contaminants.

Addressing the second research question, it was concluded that the best presentation of the product is milled (crushed) to 12 mm, because it has a lower logistic cost when compared to the shredded to 30-50 mm, and has a lower cost of import in China when compared to the granulated.

Regarding the third research question, it was concluded that the mechanical recycling is more appropriate than chemical recycling, and is thus identified as the ideal method of treating the 4000 tons of high-density polyethylene, since the chemical processes are extremely expensive and of great technical complexity, as mentioned by Pereira (2002).

We can conclude by saying that one of the limitations of this study was the impossibility of immediately implementing the theoretical recommendations presented to the company's managers.

As a final recommendation, it is proposed to the company to gradually introduce the suggested proposals in order to be able to solve the problems of plastic separation.

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