Reverse Logistics Applied to the Sustainable Management of Post-Consumer Cement Packaging

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***Abstract* — *One of the main global challenges is developing methods for the sustainable destination of non-recycling wastes. In this study, a sustainable treatment and destination for post-consumer cement packaging through analyses of its potential as an alternative fuel in cement production and the evaluation of the use of reverse logistics as a tool for the management of this waste were carried out. A methodology was adopted through bibliographic research, laboratorial evaluation of cement bags and case study of reverse logistics in a large Brazilian cement company that uses co-processing. The results proved, through laboratory analyses, the suitability of the post-consumer cement packages for use as alternative fuel in clinker kilns. The viability was proven through the use of the reverse logistics tool as a management model, using facilitating levers such as return freight and collected packing volumes. The results of these experiments can provide a basis for cement companies, especially in South America, to use similar methods to ensure the final reverse logistics of their waste.*

Keywords* — Cement industry; Reverse logistic; Waste management.

I. INTRODUCTION

It can be said that in the absence of alternatives and new technologies aimed at reducing the life cycle of products, consequently, there is a significant increase of the discard. In this scenario, some companies have sought to focus their sustainability strategies on the impacts generated in after-sales and post-consumption activities. In Brazil, after the adoption of more restrictive legislation regarding the final disposal of products at the end of their useful life, some companies have adopted the return of their products from final consumers, aiming at a possible reuse, recycling in their production cycle or in others cycles, or even to the final disposal [1-4].

In Brazil, the National Solid Waste Policy (NSWP) defined the mandatory waste that must undergo a process of structuring and implementing a reverse logistics system: I-agrochemicals, waste and packaging; II-batteries and accumulators; III-tires; IV-lubricating oils, their residues and packaging; V-fluorescent, sodium and mercury vapour lamps and mixed lamps; VI-electrical and electronic products and their components.

The NSWP defines reverse logistics as an instrument of economic and social development characterised by a set of actions, procedures and means to enable the collection and restitution of solid waste to the business sector, for reuse, in its cycle, other productive cycles or another environmentally appropriate final destination [5-6].

Rogers and Tibben-Lembke [7] define reverse logistics as the process of planning, implementing and controlling the flow of raw materials, in-process and finished products and information, from the final consumer to the supplier, in order to recover value or make an appropriate environmental disposition.

In Brazil, cement packaging does not fall under the list of wastes with the obligation to be treated by the reverse logistics process [5]; however, the responsibility for the life cycle of the products is established in the National Solid Waste Policy, and there must be a commitment on the part of the government, companies and society on the final disposal of waste.

In the specific case of cement, after its use in the works in general, the cement packages torn and/or impregnated of the cement itself are not collected by the collectors (social organisations of urban waste collection) and end, directly or indirectly, in the final disposal of public waste.

Cement is characterised as the base and main component of concrete, which is the most consumed product in the world. Brazil is among the 10 largest cement producing countries in the world, with its internal cement production exceeding 70 million tons, being

https://dx.doi.org/10.22161/ijaers.6.6.41 ISSN: 2349-6495(P) | 2456-1908(O)

consumed practically in all residential, commercial or major infrastructure works.

Correct cement storage is essential to prevent losses and changes in product characteristics. Multi-sheet kraft paper bags are used as the packaging suitable for transport and for quick application. The paper bags meet the requirements of the production flow of the bagging machines, which is the only one that allows filling with the still very heated material coming from the production process.

The practice of reverse logistics in order to recycle or reuse the post-consumer packages may present some bottlenecks due to the presence of cement or even other contaminants in these packages, making it unfeasible for reuse in the manufacture paper and cardboard due to the high removal costs of contaminants and industrial processing.

In its production process, the cement industry has an inherent need for fuel with high heat of combustion. Thus, the sector is positioned with an alternative to the disposal of solid waste with high calorific value, as they are desirable as fuel for thermal processes in the cement industry [8]. Thus, it becomes an activity of interest, both for society to ensure an environmentally correct destination and for the cement industry for its economic gains. However, environmental viability must be evaluated objectively, systematically and holistically.

The main focus of this article is to present the reverse logistics applied to post-consumer cement bags recovered in buildings under construction, considering that contaminations of these garages prevent or are not attractive to use as a raw material (pulp) in the manufacture of paper and cardboard.

The company's main activity is the manufacture of four types of cements; it is located near the raw materials (limestone and silica) and is at a distance of about 200 km from the sale of cement bags and 150 km of recycling companies that supply fuels from industrial waste.

II. CEMENTS INDUSTRIES

The cement industries are considered specific when it comes to the need for thermal energy, since the process needs to reach high temperatures. Usually, fossil fuels such as coal, fuel oil and petroleum coke are used and generate large amounts of carbon dioxide (CO_2) into the environment. Considering that the raw material is limestone ($CaCO_3$) and the sources of energy are fossil fuels it is almost impossible to change this matrix. Co-processing in the cement industry is a thermal waste destruction technique in which the thermal energy generated by the combustion of these materials is used in the clinker manufacturing process, maintaining the quality of production in accordance with the standards and without altering the quality of the cement produced. The use of organic wastes from agriculture (sugar cane bagasse, rice straw) and petroleum/petrochemical industry waste, papers, plastics, paints and tires is common. In this process, the wastes are initially pre-processed and transformed into a mix of alternative fuels, in order to be injected into the production process in high-temperature areas, partially replacing traditional fuels. However, the cement industry must always be aware of the origin of the waste and guarantee the final quality of the alternative fuel mix, in order to avoid any changes to the environment and the quality of the cement produced [9].

The waste is injected in the rotary kiln at temperatures of 1200 °C and 2000 °C. The high temperatures associated with the residence time of approximately 30 minutes for solid materials and 3 seconds for gases, suitable oxygenation conditions, high turbulence, alkaline environment, exchange of heat between the flue gases and the raw material can guarantee the destruction of practically all organic compounds, neutralisation and adsorption of some contaminants and the incorporation of the ashes of the inorganic compounds into the clinker, without impairing the quality of the fabricated cement [10-12]. Before such waste is placed in clinker kilns (the main raw material for cement), there are pre-treatments to ensure that the characteristics of the waste remain constant and do not cause adverse effects to the cement produced or to the environment [13].

According to Galvez-Martos and Schoenberger [14], the United States achieves an average of 11% thermal replacement of fuel by cement production, while Europe achieves an average of 28% replacement. Among the member states of the European Union, however, replacement rates are very different, ranging from less than 5% to more than 80%. For example, in Austria the current replacement rate is 46%, 61% in Germany and 83% in the Netherlands. In these countries waste co-processing is well implemented and, therefore, the manufacture of clinker can play an important role in national and international waste policies.

In Brazil, the first practice began in the 1990s, having been nationally regulated in 1999 by CONAMA Resolution 264[15]. The Brazilian cement park consists of 102 units, 60 of which are integrated with rotary kilns, predominantly in the Southeast and Northeast, where 37 of these units are licensed for co-processing. The processed waste represented the elimination of an environmental liability of 1.12 million tons. Of this amount, 20% of the waste was used as substitutes for the raw materials and the remaining 80% as alternative fuels. The rate of thermal replacement in that year due to the use of alternative fuels reached 8.1% [16,17].

III. PROPOSED REVERSE LOGISTICS APPLIED TO THE CIMENTAL INDUSTRY

The concept and execution of reverse logistics have existed in companies since the beginning of capitalism but have been restricted to two forms: either through products that have suffered some kind of process error, return damage without being consumed or have reached market obsolescence, known as aftermarket reverse logistics or those post-consumer, which have fulfilled their useful life but remain as usable waste. In this last form, there are two types of products: those residues that have important added value and, therefore, are returned by the market without much difficulty, such as metals, engine parts and medical equipment and those that do not return, since their waste products do not have sufficient added value and do not yet require development to make return logistics attractive. This is the typical case of plastics, Tetra Pak packaging and debris [18].

According to Govindan et al.[19], reverse logistics starts with end users (first customers), where used products are collected from customers (return products), and attempts to manage end-of-life products through different process including recycling (to have more raw materials or raw parts) remanufacturing (to have them sold to the second markets or, if possible, to the first customers), repair (to sell in the second markets through repairs), and finally, disposal of some used parts.

Reverse logistics can be defined as the part of logistics that aims to relate topics such as: reduction; conservation of the source; recycling; replacement; and disposal of traditional logistics activities, such as supplies, traffic, transportation, storage.

In Brazil, among the National Solid Waste Policy determine the importance of shared responsibility for the product life cycle and reverse logistics [5].

Considering the assumptions presented previously, the reverse logistics applied to the evaluated cement plant is centred on the following points (Figure 1):

- Laboratory analysis of cement packaging;
- Development, compaction and assembly of packing bales;
- Quantification of cement production;
- Logistic feasibility of transportation of cement trucks and bales.

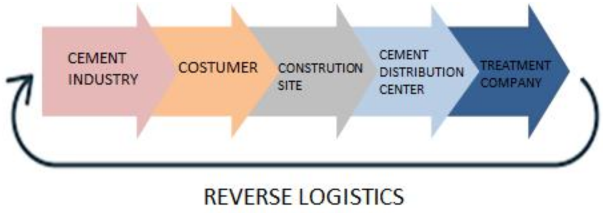

Fig. 1 - Reverse logistics flow for cement packaging

IV. MATERIALS AND METHODS

In order to represent the cement packages, 50 samples of the cement bags were collected in two random constructions and in the industrial unit (samples of cement bags before filling and consumption, called clean packs), respecting the four types of cement produced in the company. At the time of collection, priority was given to the intact packaging, those with only one opening (tear) for consumption, thus avoiding possible divergences in the evaluations. Thus, 5 samples of each type were selected for weighing the samples as shown in Figure 2.

Fig. 2 - A, B and C samples of post-consumer packaging and D unused packaging

For the physico-chemical analysis, the samples of each group were cut in sizes 5 cm x 5 cm and placed separately in the knife mill. The residues from this operation are collected in plastic bags for homogenisation and a reduced sample as shown in figure 3.

Fig. 3 - Knife mill and samples after grinding and a reduced sample.

4.1—Laboratory analysis of cement packaging

https://dx.doi.org/10.22161/ijaers.6.6.41 ISSN: 2349-6495(P) | 2456-1908(O)

Laboratory analyses are important and should be performed to assess the suitability of these wastes for the co-processing phase in such a way that they do not impair the residue as an energy source and do not cause damage to the final quality of the cement.

4.1.1 Determination of the weight increase of post-consumer cement packaging

At this stage, the selected packages were weighed in a calibrated electronic balance and with reference to unused (clean) packages weight.

4.1.2 Determination of ash and higher calorific value (kcal/kg)

The calorific value and the ashes of the packages were determined by placing 1g of the crushed sample of the package in a pre-weighed nickel crucible. Thereafter, said crucible was placed in a calorimetric pump to be burned with pure oxygen. The ash inside the crucible was calculated by the mass difference. The calorific value, that is, the potential capacity of a material to release a given amount of heat, was determined in the calorimeter based on ASTM D240-17 [20] and the results are presented as kcal/kg.

4.1.3 Determination of chloride content in post-consumer cement packaging

The determination of the soluble chloride in the packages was carried out with titration of silver nitrate ($AgNO_3$).

4.2 Development, compaction and assembly of bales

Considering the heterogeneous conformation of the packages after the use and the economic feasibility for the reverse logistics, a bundle of compressed packages was developed for the transportation by trucks as shown in Figure 4. In this bundle, enveloped with cardboard and with mooring strips of carbon steel, with dimensions of 1.1 m x 0.50 m x 0.80 m, 1,113 packages with a total weight of 182.45 kg were used.

Fig. 4 - Loading of pressed packages for trucking

V. RESULTS AND DISCUSSION

The annual production of the industrial unit under study is 720 thousand tons of cement. The expedition of the cement in a radius of 200 km is realized of two forms: cement in bulk using bulk cement trucks and in sacks of cement of 50 kg. 308 thousand tons are transported in bulk and 420 thousand tons representing 840 thousand sacks of cement of 50 kg. In bulk they are arranged in cement storage silos, and the bags with cement go directly to a distribution centre or directly to civil works.

In the analysed samples of packages (Figure 2), a 17.46% increase in weight was observed in relation to the clean packages, which corresponded to cement and moisture residues. Table 1 below shows the average of the results of the packages referring to calorific value, ash content, humidity and chloride content.

Table 1 - Results of packages analysis

Types of packages	Calorific value kcal/kg	Chloride %	Ashes %	Moisture %
Clean	3614.3	0.10	4.94	3.39
Type I	3516.8	0.09	8.96	6.39
Type II	3638.5	0.07	5.33	10.23
Type III	3622.6	0.04	5.54	5.88
Mixtures	3625.8	0.09	11.67	8.71

All the samples analysed showed calorific values in the order of 3600 kcal/kg and were included in the results of several studies carried out with industrial waste in cement plants where the calorific value ranged from 2800 kcal/kg to 4500 kcal/kg [21-23].

In the analyses, much lower chlorine (chloride) levels were observed when compared to the maximum allowable reference of the unit under study, that is, greater than 0.4%. Some cement plants that burn waste from various sources where the chlorine content is higher than the values of the packages [24].

Unlike the process of transportation and storage of pre-consumer packages, when all care is taken to avoid contact with wet surfaces, the situations found at the sampling points in the post-consumer packages were not as careful. Therefore, post-consumer cement packages are more subject to moisture retention. In the analysis performed, it was possible to observe an increase of 3% to 7% in moisture when compared to the pre- and post-consumption packages.

The amount of ash in the samples is closely linked to the amount of cement removal adhered to the sampled particles, since the cement is the major component. The ashes of the packaging represented 4.94%, and after consumption, there was an increase from 0.4% to 7.5% in the ash content. The low ash content also indicates the ease of burning most post-consumer packages, thus enhancing their ability to generate thermal energy.

The transport of cement bags from the cement plant to the storage and distribution centre is carried out on trucks with a maximum capacity of 36 tons. After delivery in the units, the trucks return to their origin, completely empty. In this scenario, the opportunity of using the return freight was observed between the recycling centres and the cement factory transporting the bales of the pressed packages (Figure 4). The truck has two trailers where it is possible to transport 90 bales with a total weight of 16.4 tons as shown in Figure 5.

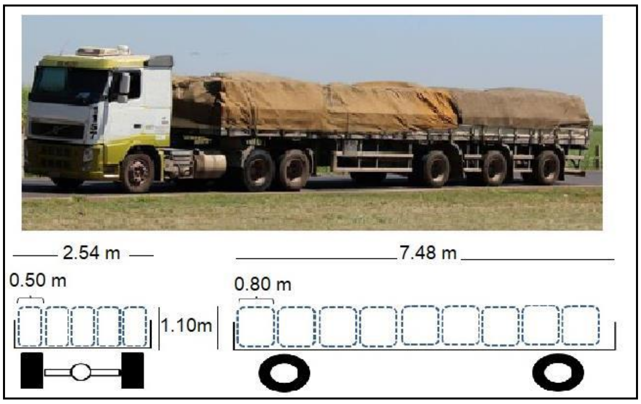

Fig. 5 - Truck with two trailers for loading cement bags or packing bales

VI. CONCLUSIONS

Based on the study carried out with post-consumer cement containers from a cement factory located about 200 km from the distribution and consumption zone, it is concluded that:

- Laboratory tests have shown that the packages have a calorific value of 3600 kcal/kg and ash content acceptable to be used as an alternative fuel for co-processing in a cement plant.
- The test bundle assembly proved feasible in order to ensure the compacting of a larger volume of the waste to be transported by the trucks using the return freight - that is, when the trucks return empty to the factory.
- Sustainable management of post-consumer cement packaging can be made via two sustainable destinations: recycling and coprocessing.
- It is possible to meet the reverse logistics of the National Policy on Solid Waste in Brazil when it accepts some of the requirements, such as an instrument of economic and social development characterised by a set of actions, procedures and means to enable the collection and restitution of solid waste to the business sector, for reuse in its manufacturing cycle, called co-processing.

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