RICE HUSK AND SCRAP TIRES CO-PROCESSING AND REVERSE LOGISTICS IN CEMENT MANUFACTURING

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Introduction

Technological and market advances have led to certain types of products being discarded before the end of their life-cycle (GUARNIERI *et al.*, 2006). This significantly increases the already high amount of solid waste the public authorities have to deal with (BERTHIER, 2003). The fashion and technology industries are examples of this: materials in good condition are discarded because they have become obsolete before their life-cycle is over. This is because technology quickly becomes outdated or there is a loss in market value. Another factor which increases the amount of waste generated is the high cost of repairing technological and consumer goods, which is almost as high as the cost of purchasing new goods, favoring the replacement of a broken item for a new one and discouraging repairs (BRITO e DEKKER, 2002; LAU and WANG, 2009).

Industrial production also generates solid waste. If waste is used as a raw material for other industries, costs can be significantly reduced, both for those who receive these materials and for those who discard them (GONÇALVES-DIAS, 2006). Furthermore, stricter legislation and greater consumer awareness have led companies to become more responsible in relation to the environmental consequences of their operations (GONZÁLEZ-TORRE *et al.*, 2004). This includes the environmental impact aggravated by waste generated both during the production process and after consumption (CHAVES e BATALHA, 2006).

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A large proportion of industrial waste is disposed of in landfill or industrial sites. Even when landfills are made impermeable and protected to prevent liquids and gases resulting from the decomposition process from contaminating the environment, they are not a sustainable solution, because large amounts of waste do not decompose, that is, they are not absorbed by nature. An alternative which is less damaging to the environment is the co-processing of industrial waste in cement kilns (INSTITUTO VOTORANTIM, 2012). Co-processing in cement factories is highly efficient and allows for the total recovery of calorific power: one kcal of waste substitutes one kcal of fossil fuel (HENDRIKS *et al.*, 1998).

Cement production is responsible for approximately 2% of global energy consumption and 5% of the global energy used by industries. This is because the chemical reaction, $CaCO_3$ ’! $CaO + CO_2$, which takes place during the process of making the main raw material, clinker, is highly endothermic (MASTORAKOS *et al.*, 1999). Due to the intensive use of fossil fuels, the cement industry is responsible for approximately 5% of global CO_2 emissions (HENDRIKS et al., 1998). A tonne of clinker generates around a tonne of CO_2 (HENDRIKS et al., 1998). The speed of the chemical reaction is restricted by the amount of heat the internal wall of the kiln can support (SPANG, 1972). One of the ways of dealing with this problem is using a mix of fuels, generally of lower calorific power. This costs less and is less harmful to the environment (MASTORAKOS et al., 1999). In view of this situation, the industry has striven hard to substitute fossil fuels for alternative fuels (ZABANIOTOU and THEOFILOU, 2008). Out of forty-seven Brazilian factories, thirty-six are licensed to co-process waste, representing over 80% of national clinker production, the main raw material in cement making (ABCP, 2012).

Waste burning in cement kilns is widely practiced in the United States and Europe. In Norway, co-processing of waste is the official means of disposing of hazardous waste and occurs due to the high temperatures and the long period of time gases remain within the clinker kiln. It is often necessary to mix different sources of waste in order to homogenize the mass that is to be co-processed so as to obtain a better performance and improve the quality of the product, leading to financial gains. Co-processing totally destroys waste through controlled atmospheric emissions, providing savings in relation to non-renewable natural resources (CETRIC, 2012).

In short, reusing materials in waste co-processing has had a significant role, both in preserving the environment, through discarding less, and in economic terms, since part of the value of the product is rescued and reused (HEESE *et al.*, 2005; DOWLATSHAHI, 2000).

Co-processing operations depend on reverse logistics practices. Reverse Logistics studies reverse flow operations which re-integrate used products and waste within the production cycle (GONÇALVES-DIAS, 2006), not necessarily within the same industry. Souza e Fonseca (2009) provide an example of reverse logistics in the steel industry which uses scrap metal from other industries as a raw material. Reverse logistics has become more important in the business strategy of many companies, not only because of the financial return, but also to meet the requirements of environmental preservation (DOWLATSHAHI, 2000).

The main focus of this article is to describe co-processing practices in cement production based on reverse logistics operations. The main research question is thus: How reverse logistics operations should be organized to support co-processing practices in cement production? Our research method was a case study. Specific objectives: (i) Describe the factory in which co-processing took place (ii) describe implemented reverse operations and (iii) discuss results of case study.

There are similar studies in the Brazilian literature. A selection of these studies were consulted in order to provide researchers with an initial idea of the status quo in terms of knowledge relating to industrial co-processing and reverse logistics in Brazil (SANTI, 2002; SIQUEIRA, 2005; CAMPOS, 2006; CHAVES e BATALHA, 2006, GONÇALVES-DIAS, 2006; GONÇALVES e MARINS, 2006; GUARNIERI *et al.*, 2006; GONÇALVES-DIAS e TEODÓSIO, 2006; SELLITTO e ADLMAIER, 2007; FREITAS e COSTA, 2009; LAGARINHOS e TENÓRIO, 2009; NÓBREGA, 2010; FIGUEIRÓ, 2010; GARDIN *et al.*, 2010; ROCHA *et al.*, 2011; SANTOS NETO e BARROS, 2011).

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Co-processing

In co-processing, two or more types of waste from different sources are employed together, either in the manufacturing or heat generation process. Waste can substitute raw materials or fuel (CUGINI *et al.*, 1989; LUO and CURTIS, 1996; SU *et al.*, 2009). According to resolution 316/2002 of the Brazilian National Council for the Environment (CONAMA), co-processing of industrial waste means reusing in thermal processes a material or substance deemed as scrap or one which does not have other economic uses resulting from industrial, urban, agricultural, health services or commercial activities. This operation should be carried out at temperatures above 800°C (CONAMA, 2010). In the cement industry, the main clinker kiln fuel is either coal or petroleum coke. Some calorific power can be obtained by the combined processing of fossil fuels and industrial residues such as paint sludge, rice husks, scrap tires and shavings from certain plants (SELLITTO, 2002). Apart from the economic benefits, given the lower cost of waste materials, there are also some environmental benefits, both due to the reduced requirement to extract and process fossil fuels and because a use is found for this waste (SANTI, 2002).

According to the Brazilian Association of Portland Cement (ABCP, 2012), co-processing means the burning of industrial waste and environmentally liable materials in kilns in order to produce Portland clinker. According to ABCP (2010) Brazil produces around 2.7 million tonnes of industrial waste per year, but only co-processes 800,000 tonnes. Instituto Votorantim (2012) states that Votorantim Cimentos installations are reusing more than 200,000 tonnes/year of waste sourced from other industries.

Due to the natural and environmental limitations of fossil fuels, thermal processing industries, such as the cement industry, have encouraged research in order to discover and make use of co-processing alternatives (SIQUEIRA, 2005). Generally the issue is more complex than simply making use of the physicochemical characteristics of waste, because the process involves monitoring resulting emissions (SANTOS NETO e BARROS, 2011) and may necessitate the setting up of a reverse logistics network, without which the process would not be economically viable (SANTI, 2002).

Technical advances and new regulations on the treatment of industrial waste have stimulated an increase in co-processing. Sectors which produce waste with co-processing potential, such as the paint, food, forestry, plastics, and rubber, agro and furniture industries have been sponsoring research to make the use of their waste viable in industries which require large amounts of energy such as the cement industry. Research needs to address two questions: How to use this waste in a way that is environmentally safe and beneficial to the industry that receives it? How to set up a reverse logistics chain so as to ensure economic viability and maintenance of supply?

Currently, the following items are processed in cement factories: vegetable waste, tires, steel and aluminum manufacturing waste, solvents, paint sludge, plastics, contaminated soil, oils and oily substances, catalysts, resins, glues, latex, contaminated EPI and wood, paints, rubbers, STE sludge, paper and refractory materials (CETRIC, 2012; INSTITUTO VOTORANTIM, 2012). The following are not allowed: hospital, radioactive and domestic waste, corrosive materials, pesticides and explosives (CONAMA, 1999; CONSEMA/RS, 2000).

Some of the characteristics of co-processing are prescribed by resolutions (CONAMA, 1999; CONSEMA/RS, 2000): (i) the inferior calorific power (ICP) should be greater than 2700 kcal/kg, equivalent to the burning of rice husks ii) when waste-blending is used, the ICP of each material should be greater than 1700 kcal/kg iii) waste fed into the kiln should preferably be in the hottest part (2000 ºC). However, it must also be possible to feed the kiln in a secondary or pre-heating zone (850 ºC to 1200 °C) iv) the impact of emissions should be at most equal, or similar, to that of incineration v) there must be constant monitoring for specific components which may be found in emissions.

Two examples of co-processing which are both economically and environmentally viable and supported by a reverse logistics chain are rice husk and scrap tires (DELLA *et al.*, 2006; FREITAS e NÓBREGA, 2010; MONTEIRO e MAINIER, 2008). The rice husk ICP is approximately one third of that of petroleum coke (DELLA *et al.*, 2006). Tire ICP is approximately half (RENNÓ, 2007). A clinker kiln with a production capacity of 1000 tonnes/day can consume up to 5,000 tires or 20 tonnes of rice husk (ABCP, 2012). Rice husk is fed into the kiln *in natura*, whilst tires should be burned whole or shredded into 5cm chips (MOTTA, 2008).

In relation to rice husk, the handful of initiatives undertaken focus on the cement industry. In relation to tires, service providers send them for re-treading, to recycling centers or to landfill sites. Trash collectors recover a proportion of the tires. A reverse logistics route collects tires from recycling centers, stores and processes them, and delivers them for co-processing. Around 95% of the material in recycling centers is co-processed in cement factories (MOTTA, 2008). In 2011, over forty-two million tires were co-processed (RECICLANIP, 2012). In Europe, this figure is around one hundred and ten million tires per year and in the United States, around sixty-five million (ABCP, 2012). Figure 1 shows the main reverse routes observed in Brazil (RECICLANIP, 2012).

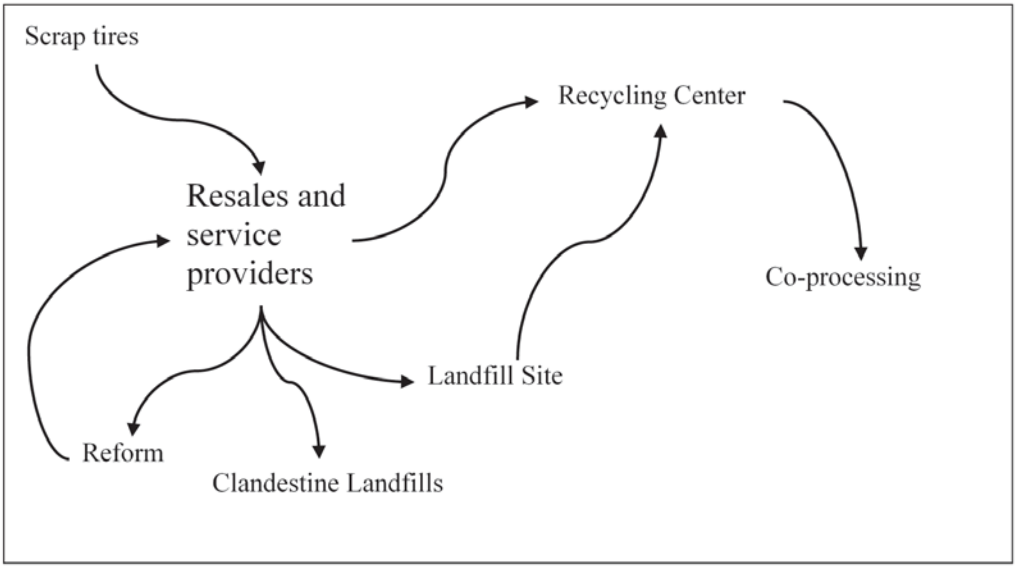

Figure 1: Tire Recycling

Source: adapted from Reciclanip (2012

Reverse Logistics

Despite the fact that it has been the subject of discussion in business and academic circles, there does not appear to be a widely applicable definition for reverse logistics. There is not as yet a unifying and encompassing vision of what this technique means. The reason for not being able to arrive at a definition which satisfies all potentials of the technique may be explained by its complexity and the constant input of new possibilities. In this article we have adhered to the definition provided by the Reverse Logistics Executive Council (RLEC).

According to RLEC (2012), reverse logistics is the process of planning, implementing and controlling the flow of raw materials, in-process inventories, finished goods and related information, from the point of consumption back to the point of origin, for the purpose of re-capturing value from or disposing properly of material goods. For Sheriff *et al.* (2012) reverse logistics management should ensure both the environmental and economic efficiency of the value recovering process. In short, reverse logistics is the process of moving materials which have already been used in order to recover a part of their value or dispose of them in the most appropriate way.

Reverse logistics activities include the remanufacturing or re-composition of goods, or parts of goods, which were broken, quite often before reaching the end consumer, but which can be fixed or reused. It also concerns paying due attention to packaging and conserving energy when transporting and storing goods. Reverse logistics activities can be carried out by the main company or be contracted out to logistics operating companies (GOVINDAN *et al.*, 2012).

The concept of reverse logistics is based on the reverse operation of sourcing, collecting, organizing, storing, transporting and delivering goods. Recovery activities such as recycling, reuse, remanufacturing and re-utilization have been incorporated within industrial supply chains. In particular, companies must establish how to collect and monitor waste, and where and how to re-process it, so as to recover at least part of its existing value. Understanding the trade-offs inherent in decisions relating to network projects is crucial for the development of efficient reverse logistics networks (BARKER and ZABINSKY, 2011).

Terms such as reverse flow and reverse channels are not recent additions to the literature about operations management. These terms have appeared in the literature since the 1970s, but they used to be more associated to urban and industrial cleaning services, and the environmental management of cities and production sites. Pohlen and Farris (1992) introduced the notion of flow direction, that is, operations in which used or scrap materials are collected and reused as a resource for generating value. Subsequently, reverse flows and channels became definitively associated to the notion of recovering economic value (BRITO e DEKKER, 2002). The inclusion of reverse logistics in strategy processes can result in a significant improvement in competitiveness, considerable financial return and the consolidation of corporate image (ROGERS and TIBBEN-LEMBKE, 2001). This raises the profile of reverse logistics network projects for recovering the residual value of industrial waste (BARKER and ZABINSKY, 2011).

According to Adlmaier e Sellitto (2007) reverse logistics shares some objectives with so-called green logistics, given that it takes into account environmental aspects in logistics activities, such as the consumption of natural resources, atmospheric emissions, use of roads, sound pollution and the disposal of hazardous waste. Reducing the need for packaging and increasing transport efficiency are also objectives of green logistics.

A concern of reverse logistics managers is the management of reverse flows and channels integrated to the supply chain (ROGERS and TIBBEN-LEMBKE, 2001). Managing returns is part of the management of the supply chain which involves sourcing, selecting, collecting, organizing freight, return transporting and unloading. It also includes two activities carried out before field operations: analyzing the attractiveness of waste and the viability of the operation (ROGERS *et al.*, 2002). In relation to co-processing, the latter can involve carrying out field tests in order to discover the calorific power of a particular waste type.

Operations such as urban cleaning services, involving sourcing and collecting waste, stand on their own. However, within the context of achieving an efficient supply chain, reverse flows and channels must be integrated to other operations, utilizing material resources such as vehicles, overflow stations and warehouses (ROGERS *et al.*, 2002). Given the increase in the complexity of the system resulting from integrating operations, it may be necessary to leave aside quantitative methods for optimizing routes, trajectories, freight and storage levels, and other variables (DAUGHERTY *et al.*, 2001; GONÇALVES e MARINS, 2006).

The research

The main focus of this article is to describe co-processing practices in cement production based on reverse logistics operations. Apart from the case study, which constitutes the core of this research, a literature review specifically relating to the industry was conducted, as well as interviews with managers and participant and non-participant observation. The analysis involved two cement production plants, a freight consolidation center and the reverse logistics chain which connects these installations. The plants analyzed belong to a group which operates eight factories in Brazil and has the capacity for producing seven million tonnes of cement per year. They are responsible for 10% of the market share. The plants are 400 km apart. Plant A is a complete cement factory and produces both clinker and cement. Plant B receives clinker from plant A and manufactures cement. Co-processing occurs in plant A.

Data was collected between May and July 2011 and refers to 2010. The research included a literature review, semi-structured interviews and non-participant observation.

Two production supervisors, a logistics coordinator and one of the plant's managers were interviewed. Interviews were recorded with the consent of interviewees and they lasted approximately half an hour.

The first stage of the work involved a literature review in sources specific to the cement industry with a verification of the production process and contextualization of the co-processing procedure. After this stage, interviews were conducted and the history of the co-processing process was put together. The production and co-processing processes were verified through non-participant observation and interviews. Furthermore, reverse logistics networks were located, observed and confirmed. Results were presented, analyzed and described through a process of interviews.

The company requested confidentiality in relation to its economic investment in the reverse logistics supply chain.

The production process

Portland cement is produced by heating a mixture of calcium compounds, based on grinding limestone and other carbonates, to a temperature of 1,450ºC. The heating process generates a nodular intermediary raw material, clinker, which is ground together with gypsum compounds and other carbonates to produce cement (TAYLOR, 2004). The name Portland derives from its color which is similar to stones observed on the island of Portland in England (FARENZENA, 1995). Limestone is the main raw material for the production of cement, made up of calcium carbonate ($CaCO_3$) and a number of impurities such as magnesium, silicon, aluminum and iron. When exposed to a temperature in excess of 800ºC, part of the $CaCO_3$ decomposes into 0.56 CaO parts and 0.44 CO_2 parts. Given that CO_2 escapes, there is a loss of raw material during the manufacturing process, thus requiring the factory to be close to the quarry.

The cement manufacturing process is as follows:

– extraction of limestone from natural quarry, its breaking and crushing;
– process of homogenization in order to reduce the variability of carbonate content;
– grinding the limestone to reduce the size of its granules: the product then becomes known as limestone flour;
– homogenization of the flour as a mixture;
– burning the flour in the kiln: the product then becomes known as clinker;
– open storage of clinker;
– grinding the clinker in a ball mill together with gypsum, various types of low carbonate limestone and possibly inorganic fillers such as coal ash and types of silica; and
– bagging the cement produced in paper bags and loading them in purchaser's vehicle.

This entire process takes place in plant A, whereas in plant B the process starts with the storage of clinker received from plant A.

Cement production process, Figure 2

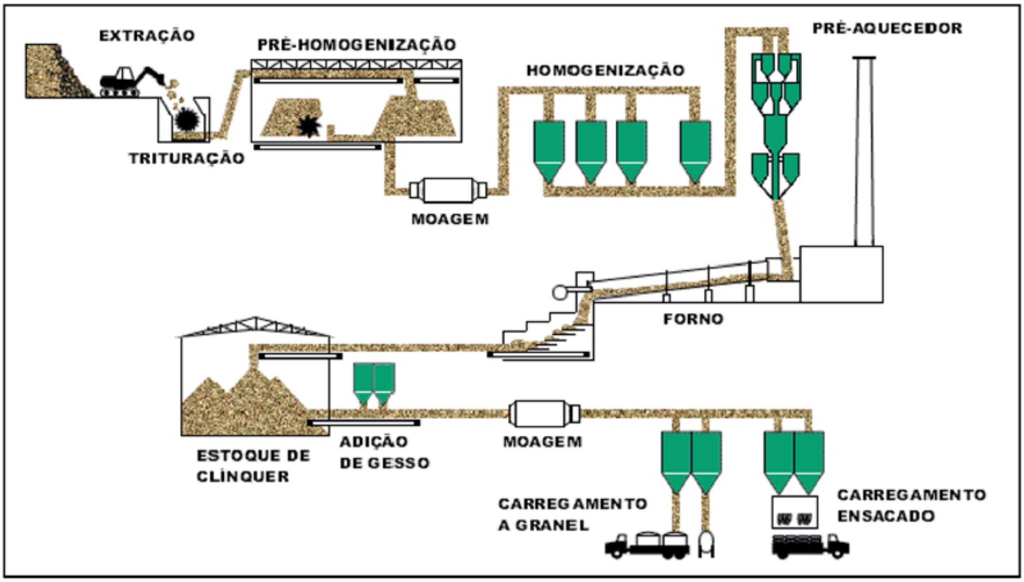

Figure 1: Cement Manufacturing

Source: Renó (2007)

Extração = Extraction

Trituração = Crushing

Pre-homogenização = Pre-homogenizing

Moagem = Grinding

Homogenização = Homogenizing

Pre-aquecedor = Preheater

Forno = Kiln

Estoque de Clinquer = Clinker stock

Adição de Gesso = Gypsum Addition

Carregamento a granel = Bulk Loading

Carregamento Ensacado = Bag Loading

In this stage, the controlled heating and thermal treatment of the calcitic type limestone mixture takes place. It must have a magnesium content lower than 4%, mixed with clay rich in silica, aluminum and iron. Gas temperature must reach 1,450 ºC and that of the flame 2,000 ºC. The clinker kiln is a cylindrical tube of around 5 meters in diameter and approximately forty meters in height. The length of the oven depends mainly on how long it takes to heat the raw materials until the clinkerization temperature is attained (MASTORAKOS *et al.*, 1999). In the kiln, the raw material moves in the opposite direction to the gases and is transformed into Portland clinker, a nodular, dark-colored material. Before reaching the kiln, in the preheater tower, all remaining humidity is removed from the raw materials and the process of decarbonization of the limestone begins.

The kiln is divided into five parts: (i) calcination at a temperature between 900 and 1,100 ºC, where the process of decarbonisation of the flour is completed, forming C_2S, and where the process of producing C_3A and $C4_AF$ starts; (ii) transition, from 1,100 to 1,200 ºC, this is where the material agglomerates, forming opaque lumps, and the production of C_3A and $C4_AF$ finishes; (iii) fusion, between 1,200 and 1,350 ºC, this is the liquid stage which fills in the empty spaces in the material and starts the conversion from C_2S to C_3S; (iv) high temperature, between 1,350 and 1,450 ºC, the production of C_3S and clinker is completed; and (v) cooling, from 1,450 to 1,200 ºC, with the reduction in the temperature of the clinker and the solidification stage, with gases from the cooler (FARENZENA, 1995). Gases from the cooler are fed in to pre-heat raw materials before they are sent to the kiln, increasing energy efficiency (SPANG, 1972).

The final stage in the production of clinker is the controlled cooling process in two stages: the first takes place inside the kiln where the temperature falls from 1,450 to 1,200º C. The last stage occurs inside an industrial cooler, where the compound attains its morphologic stability at 80º C (FARENZENA, 1995).

The main source of heat for the clinkerization process is the burner, situated on the inside back wall of the kiln and fed by fossil fuels and co-processed waste. After long periods of inactivity, oil fuel is used to heat the kiln as its high calorific power enables it to quickly reach the initial conditions for operation (FARENZENA, 1995). High temperatures, internal turbulence, negative pressure and the time gases remain inside the clinker kiln means it is an efficient means of destroying waste which is difficult to reuse. This type of waste, when incompletely burned, emits high concentrations of toxic substances such as dioxins and furans (ABCP, 2010; SIQUEIRA, 2005). In 2010, co-processing was encouraged through the National Policy on Solid Waste (PNRS) which regulates the final outcome of solid waste produced by industry (ABCP, 2010).

Co-processing requires monitoring in the chimney of the following: particulate material, SO_x, NO_x, main organic hazardous constituents, HCl/Cl_2, HF, metals, sulphur, fluorine, nitrogen pollutants, chlorine, dioxins and furans; and in the electrostatic precipitator and in the clinker, the presence of metals. The internal pressure and temperature of gases in the kiln and in the electrostatic precipitator also require continuous monitoring. The following are also monitored: the flow rate of waste, particulated material (through the opacimeter), O_2, CO, NO_x and total hydrocarbons (THC) in the precipitator chimney. In this case study, the fossil fuel used in plant A is green petroleum coke, from Petrobras/Repsol's Alberto Pasqualini (REFAP) refinery in Canoas, 440 km from the plant, and also from imported supplies which arrive via the port of Rio Grande. The main reason for importing is to regulate the market. Whenever the internal price increases, the company uses imported supplies so as to avoid an increase in the cost of production.

Co-processing and reverse logistics: rice husk and scrap tires

The first time plant A invested in waste co-processing it used rice husks for burning. This type of waste derives from the rice drying and packaging process and is abundant in the central and southern regions of the Brazilian state of Rio Grande do Sul. It is harvested on farms and processed by the region's agribusinesses. Rice husk has good inferior calorific power (ICP) of around 2700 kcal/kg and high silica content, which makes it highly desirable for co-processing in the clinkerization process on two accounts. Its high ICP contributes directly to the internal temperature of the kiln. Silica ensures that a high level of alkalinity is attained in the kiln, so that petroleum coke with higher percentage levels of sulphur can be used, as in imported products, without significant deterioration in the quality of emissions. Rice husk also helps in the final grinding of cement, because the ashes of the burning process can be incorporated into the clinker and contribute to the long-term resistance of the cement and its derivatives.

Rice husk is injected into the kiln at two points: through the main burner, near the clinker exit, and in the pre-calcination region, together with the gases which are re-fed from the cooler. Injection via the burner is most common and in some types of kilns this is the only option. Even in kilns which allow for injection at both points, it is more appropriate to inject rice husk via the main burner, since the temperature and residence time are greater (over five seconds at 1,000º C). Subsequently, waste destruction is more efficient. Possible organic contaminants are totally destroyed and metal contaminants are incorporated and fixed within the end product.

The injection of rice husk started in this company and in industry in general at the end of the 1980s and was further developed during the 1990s. On this occasion, stoichiometric tests showed that the addition of rice husk equivalent to up to 30% of the total calorific power did not significantly change the burning process. From 30% upwards, alterations in burning stability are observed and at over 32% burning becomes unstable. The industry started to adopt a target of 30% of calorific power via rice husk or similar type of waste.

Initially, the supply logistics of rice husk was direct: the company contracted vehicles which went to the rice processing companies, loaded the husk and brought it back to the company, where it was weighed as it came in and unloaded. Trucks were weighed again and payment was made according to the difference in weight. Inspection occurred during unloading and any contaminants which could be isolated from the rest of the load were rejected and sent back on the truck. Truckers were paid either according to how much the company could save by substituting fuel or according to the driver's mileage. It was better for both the company and the transporting company if they collected their load from factories nearby. They arrived at a practical rule: up to 90km, transport was always viable; between 90 and 140km, sometimes; over 140km it was hardly ever viable, unless the rice processing plant paid some of the costs in order to get rid of its waste. The negotiation was left with the transporting agency who attempted to obtain payment from both parties. In the 1990s, even when demand was low (around 50 tonnes per day), supply was between 22% and 25%. During the 2000s, it broke the 25% mark but did not reach 30%.

In the factory, the management process of rice husk is as follows: the husk arrives in grain haulers, given they are easy to load and unload; the load is then manually unloaded into a hopper feeder which carries the husk to a depot with capacity to store up to 1,000 tonnes. From this depot the husk is then transported via horizontal and vertical redlers, as well as lifts, to a collection hopper next to the burner which works as a 'lung'. A pneumatic blower moves the husk from the hopper and injects it under pressure into the kiln (as the internal pressure of the kiln is negative, the husk is able to reach the burning area). The injected amount is checked by verifying the cubic capacity of the depot and accounting for the daily entry of the material. The amount of main fuel is also measured, thus the proportion of added husk is calculated and recorded daily.

One of the problems with transporting rice husk is the low density of the product. Trials were conducted with briquette machines to increase the density of the waste, but this did not prove to be cost-efficient.

The other type of material used in co-processing is scrap tires. The company signed a supply agreement with Reciclanip, who manage the supply of tires, coordinating collection from transporting companies and from municipalities which amass tires in landfill sites and collection points. They prepare the material in warehouses and in their recycling centers. The organization pays for the cost of delivery.

Co-processing is so important for the tire industry that up to the middle of the 2000s it paid the cement industry to burn their scrap. More recently, with a rise in the price of imported coal, the cement industry started to receive tires without being remunerated.

Tires are delivered on a daily basis to plant B, where they are shredded into 5cm pieces and stored, before being sent to plant A. The company invested in a scrap tire collection and preparation site, made up of: an industrial depot for unloading and stacking, a conveyor belt which supplies the tire crusher and an industrial crusher. Metal parts are removed by a magnet; there is also a selection sieve with a return facility and container storage in preparation for transport.

Light tires usually produce 25% metal and 67% rubber; whereas freight tires usually produce 30% metal and 70% rubber. In relation to tire chips, there are load issues due to their low density: whilst a vehicle can carry an average of thirty tonnes of compacted material, it can only carry a maximum of eighteen tonnes of tire chips.

In addition to investing in the preparation of tires, at the end of the 2000s the company changed its supply logistics, creating a freight consolidation centre (FCC) halfway between plants A and B. Plant A accesses the FCC via road, whilst the FCC accesses plant B via road and river. The FCC receives, stores and dispatches clinker (from A to B), rice husk (from the region to plant B) and tires (from B to A). Flows are shown in Figure 3.

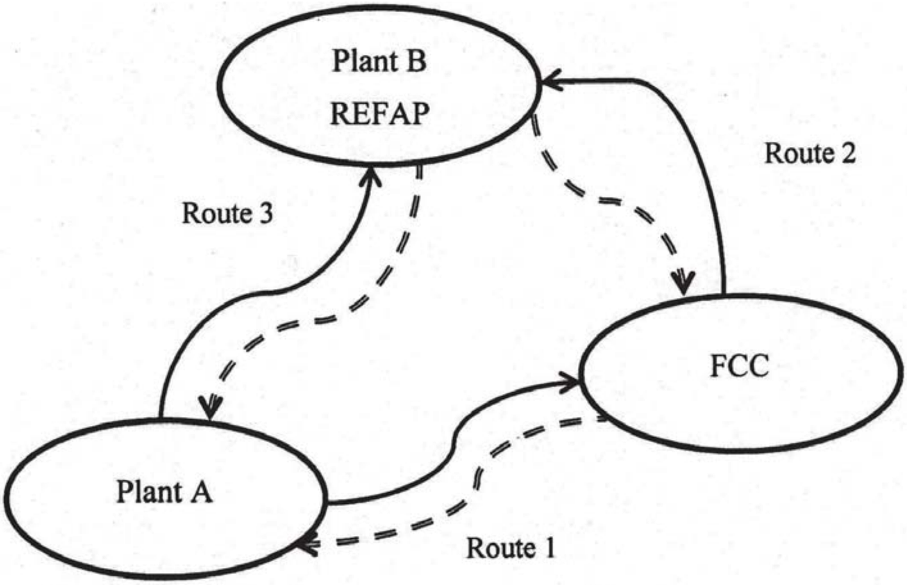

Figure 1: Logistics Flow with Implementation of FCC

Previous to the logistics reorganization, clinker was moved from A to B via road. Sometimes there was a lack of return load, often due to loads not being synchronized. It was more expensive to leave trucks idle than wait for a possible return load. Since the reorganization, clinker goes from A to FCC, where it is stored. When trucks are available, clinker is taken to B via road; otherwise, it travels to B via river. Previously, petroleum coke went from the refinery (REFAP), near B, to A without a guarantee of return. Now, if there is no return from A, the vehicle goes to the FCC, where there is always a load, significantly reducing idle capacity. The supply of rice husk used to occur as described, directly from producers to A. Now it goes to the FCC, where it is stored, and then to A, and the vehicle returns full to the FCC. Vehicles which used to be 50% full of husk are now almost 100% full. The flow of scrap tires also became viable. Tire co-processing would not be viable without concentration, given its low volume and the collection distances. In short, in Figure 3, routes one and two are usually used to maximum capacity, whilst in route 3 there is a high guarantee of return. A logistics operator was contracted to manage the transport, storage and management operations. The fleet is used in other activities, further increasing the time vehicles are in use, reducing co-processing costs.

There has also been a change in the supply of rice husk. The FCC is situated in a region with a large number of rice processing businesses. Therefore, the supply of husk has significantly increased, this means that the company reduced freight and restricted the use of rice processing firms to those up to 50km from the FCC, subsequently reducing the problem of low density, so that the addition of husk is rarely below 30%. The service is provided by two small transporting companies who collect from various points, freight and unload at the FCC.

Table 1 shows some of the savings resulting from the company's logistics reorganization. These are average values observed in 2010 which relate to the transport described above. The reduction in costs deriving from the substitution of fuel was not taken into account because this income is costed independently from the reverse logistics operation. Figures in Brazilian *reais* were not provided by the company. However, we worked with estimates, and with data concerning the percentage cost reductions achieved through the changes. Absolute reduction was significant and fully justified the investment.

Table 1: Chart comparing transport costs.

Route	Cost of Transport	
	before	after
01	1,000	641
02	466	330
03	383	291
total	1,850	1,262

Source: Researched company

The average logistics cost reduction was 31.7%. This is a significant amount and fully justified the investment, allowing the company to systematize the use of scrap tires and definitively increase the use of rice husk to reach the desirable technical limit. Other lesser but similarly desirable benefits were observed. The company no longer makes isolated freight contracts, increasing fleet use and significantly reducing waiting time at the REFAP, since vehicles and drivers have been registered beforehand, so there is no need to carry out security training before each load.

Finally through load concentration, it was possible to standardize transport operations, rationalizing the use of vehicles and the transport schedule. Due to this rationalization, there was a significant reduction in both the number of accidents en route and in the overtime paid to drivers and load and unload operators.

In relation to environmental results, co-processing consolidation based on reverse logistics flow reduced the use of fossil fuels by approximately 10,000 tonnes per year. Given that each tonne of petroleum coke burned produces 3.4 tonnes of CO_2 (CETESB[7], 2009), there is an estimated reduction of over 30,000 tonnes of CO_2 per year. Furthermore, deposits are less exploited, emissions of CO_2 are lower and a significant amount of waste is totally destroyed, their ashes being incorporated in the end product.

Moreover, the case of tires has helped reduce a serious public health problem: the proliferation of the dengue mosquito. Given that co-processing activities started a number of years ago, the amount of natural resources saved for future generations has been significant up to this point.

In relation to the maintenance of the operation, it seems unlikely that there will be a lack of rice husk in the region. It is also unlikely that there will be a lack of scrap tires, given the restricted amount of this waste that co-processing manages to absorb. New modes of transport, such as river transport, may change current operations. In this case, extra infrastructure may be necessary in order to maintain the efficiency of the operation.

Conclusions

The main focus of this article was to describe co-processing practices in cement production based on reverse logistics operations, using a case study as our research methodology. The study encompassed, by means of a qualitative field research, the co-processing of solid waste in clinker kilns supported by reverse logistics integrated to direct transport flow. Limitations of the research are inherent to the methodology of taking a single case, which restricts its generalization.

Main research results related to the economy and the environment. In relation to economic results, the integration of direct and reverse logistics flow, by means of a freight centralizing centre and the integrated management of flows, reduced by over 30% the average monthly cost of transport. Despite the company not revealing actual figures, its managers claimed that this reduction is significant and represents a competitive gain to the operation. In relation to environmental gains, there was a significant and absolute reduction, in tonnes, of fossil fuels required in the operation. Therefore, the rate of the exploitation of deposits was reduced. Natural resources were preserved for future generations and there was a reduction in greenhouse gas emissions. In addition to the co-processing operation, the company implemented constant and periodic monitoring of emissions to ensure that there is no other environmental damage relating to the practice. Case analysis points to the fact that co-processing may be a sustainable energy solution in the manufacturing of cement, since it contributes to a reduction in the use of fossil fuels in industrial activities.

With the establishment of a freight consolidation centre, the possibility of a shortage in supply was eliminated. Previously, if there was an excess of supply, it could not be stored and when there was a shortage, the flow was interrupted. This was the most significant negative factor in supply, that is, it could have been considered as a bottleneck in the flow of waste provision. Indeed, it was the principal cause for the plant not attaining its maximum co-processing capacity. Once this factor was eliminated and given the increase in the supply of rice husk, due to the location of the consolidation centre in the region with greatest production density, the new bottleneck in production is the schiometric capacity of the clinkerization process to receive more waste. If it was possible to substitute more than 30% of calorific power, there would be enough supply of waste and the logistic capacity to meet this demand. In order for the operation to increase the amount of waste it uses, and given the current process technology, it would be necessary to increase clinker production.

As a continuation of this study, we suggest expanding the research to other co-processing possibilities within the Brazilian cement industry, including the identification of supply bottlenecks. This research was restricted to the case study in question and not to other possibilities. We also suggest that studies analyze other instances of environmental impact reduction which co-processing and reverse logistics can provide. For example, in the food, paper and cellulose, leather-shoemaking, clothes or electronics industries. The role of waste in these industries is significant and it seems it has not yet been adequately explored.

Notes

[6] CNPq [Brazilian National Council for Scientific and Technicological Development]
[7] CETESB - São Paulo State Environ

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RICE HUSK AND SCRAP TIRES CO-PROCESSING AND REVERSE LOGISTICS IN CEMENT MANUFACTURING

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Resumo: O objetivo deste artigo é descrever o caso de um fabricante de cimento que implantou e consolidou o coprocessamento de casca de arroz e de pneus inservíveis em fornos de clínquer, apoiado em práticas de logística reversa, através de estudo de caso como método de pesquisa. A empresa estudada já usava casca de arroz como combustível alternativo e recebeu oferta da indústria de pneumáticos para queima de pneus que não seriam mais aproveitados em fornos de clínquer. Para aproveitar os resíduos, a empresa integrou fluxos diretos e reversos de matéria-prima, combustíveis e resíduos industriais, reduzindo em mais de 30% os custos de transporte. O coprocessamento conjunto substituiu parcialmente combustíveis fósseis originados na indústria petrolífera. O ganho ambiental mais importante foi a redução na queima de cerca de 10 mil toneladas de combustível fóssil, o que acarretava a geração de cerca de 30 mil toneladas de CO_2 por ano.

Palavras-chave*:* Coprocessamento, Logística reversa, Indústria cimenteira, Emissões atmosféricas.

Abstract: The purpose of this article is to describe the case of a cement manufacturer that implemented and consolidated the co-processing of rice husk and scrap tires in clinker kilns, supported by reverse logistics practices. The research method was a case study. The company being studied already used rice husk as an alternative fuel and received an offer from the tire industry for burning scrap tires in clinker kilns. To take advantage of this waste, the company integrated direct and reverse flows of raw materials, fuels and industrial waste, reducing transportation costs by more than 30%. Combined co-processing partially replaced fossil fuels sourced from the oil industry. The most significant environmental gain was a reduction in the burning of about 10,000 tonnes of fossil fuel which previously generated approximately 30,000 tonnes of CO_2 per year.

Keywords*:* co-processing, reverse logistics, cement industry, atmospheric emissions.

Resumen: El propósito de este artículo es describir el caso de un fabricante de cemento que ha desplegado y consolidado el coprocesamiento de neumáticos inútiles y cascarilla de arroz en hornos de clínker, apoyados en prácticas de logística inversa. El método de investigación fue el estudio de caso. La empresa estudiada ya usaba cascarilla de arroz como combustible alternativo y recibió una oferta de la industria neumática para quema de chatarra de neumáticos en hornos de clínker. Para tomar ventaja de los residuos, la compañía ha integrado los flujos directo e inverso de materias primas, combustibles y residuos industriales, reduciendo los costos de transporte más de 30%. El coprocesamiento reemplazó parcialmente combustibles fósiles obtenidos en la industria petrolera. La ganancia ambiental más importante fue la reducción en la quema de unas 10.000 toneladas de combustibles fósiles, que implica la generación de cerca de 30.000 toneladas de CO_2 al año.

Palabras-clave*:* Coprocesamiento, Logística Inversa, Industria Cementera, Emisiones Atmosféricas.