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EVALUACIÓN AMBIENTAL DE LA PRODUCCIÓN DE BLOQUES DE CERÁMICA CON ADICIÓN DE LODO DE LA FOSFATACIÓN: ANÁLISIS DE CICLO DE VIDA

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ENVIRONMENTAL EVALUATION OF THE PRODUCTION OF CERAMIC BRICKS WITH ADDITION OF PHOSPHATE SLUDGE: LIFE CYCLE ANALYSIS

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Abstract

The value of phosphatization sludge (PS), a solid waste generated from the phosphatization process of automotive parts, as a product and raw material for manufacturing ceramic hollow bricks demands an environmental analysis of the product. The methodology developed on bench scale consisted on the waste chemical and mineralogical characterization followed by preliminary tests where the specimens were molded with the addition of 0%, 2.5%, 5.0% and 7.5% (by weight of PS) to the clay and these were sintered at 850, 900 and 950°C. Then, physical, mechanical and environmental characterization tests were conducted. The industrial scale test was performed with 2.5% PS addition. The production process was monitored during approximately 5 years with a periodic sampling (each 6 months) and samples had been physically, mechanically and environmentally characterized. Tests developed showed that PS can be used as raw-material in the ceramic hollow brick production process without compromising the final product properties. Besides, the use of the environmental tool "Life Cycle Analysis" allowed a comparative evaluation of the environmental impacts linked to the extraction, transport and production phases of generating conventional bricks and bricks with a 2.5 wt% addition of waste to the mass. The results showed that the consumption of clay, diesel oil and atmospheric pollutants were the most significant detected impacts. The production of containing PS bricks, in consuming less clay, ensures the clay pit a longer useful life, thereby; contributing to the conservation of a non-renewable natural resource and also conserving the local ecosystem. It also avoids the disposal of this solid waste in an industrial landfill.

Key Words: phosphatization sludge, co-product, recycling, ceramic hollow brick, life cycle analysis.

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Resumo
El valor del lodo de fosfatación (PS), un residuo sólido generado por el proceso de fosfatación de partes de automoción, como producto y materia prima para la fabricación de ladrillos huecos de cerámica, exige un análisis ambiental del producto. La metodología desarrollada a escala de banco consistió en la caracterización química y mineralógica de los desechos, seguida de pruebas preliminares donde los especímenes fueron moldeados con la adición de arcilla al 0%, 2.5%, 5.0% y 7.5% (en peso de PS) Sinterizado a 850, 900 y 950 ° C. Luego, se realizaron pruebas de caracterización física, mecánica y ambiental. La prueba a escala industrial se realizó con 2.5% de adición de PS. El proceso de producción fue monitoreado durante aproximadamente 5 años con un muestreo periódico (cada 6 meses) y las muestras habían sido físicamente, mecánicamente y ambientalmente caracterizadas. Además, el uso de la herramienta del medio ambiente "Análisis del Ciclo de Vida" permitió una evaluación comparativa de los impactos ambientales relacionados con la extracción, transporte y producción fases de la generación de bloques y bloques convencionales con una adición de 2.5% en peso de los residuos a la masa. Los resultados mostraron que el consumo de arcilla, aceite diesel y contaminantes atmosféricos fueron los impactos más significativos detectados. La producción de bloques que contiene PS, un consumo menor de arcilla, asegura la mina de arcilla una vida útil más larga, de ese modo; contribuyendo a la conservación de un recurso natural no renovable y la conservación del ecosistema local. También evita la eliminación de estos residuos sólidos en un vertedero industrial.

Palavras-clave: fosfatación de lodos, co-producto, reciclaje, ladrillo cerámico hueco, análisis del ciclo de vida.

1. Introduction

The waste management is becoming a priority and the construction sector has becoming one of the most useful sectors for diverse application solutions in order to close with value the certain products life cycle (Modolo *et al.,* 2010). This sector is one of the less sustainable activities on the planet: with a consumption of 40% of the materials entering the global economy and the generation of 40–50% of the global output of greenhouse gases (Rivela *et al.,* 2013). A large number of studies related with the use of wastes in the construction sector have been developed stimulated by a growing concern on production and use of materials, as well as the great challenge of saving natural resources (Modolo *et al.,* 2010; Demir *et al.,* 2005; Schiessler *et al.,* 2007; Akbulut and Gürer, 2007; Saltan and Findik, 2008; Schnitzer, 2009; Rajamma *et al.,* 2012). This area accounts for a significant share of environmental impact due to a high consumption of non-renewable natural resources and energy. One way of minimizing such impacts could be the incorporation of industrial waste in constructive products.

Environmentally, the use of recycled materials is preferred, since the environmental impacts associated to the process of recycling materials are lesser than those associated to the extraction and process of virgin raw materials (Moraes *et al.,* 2010). The wastes valorization can avoid their disposal in landfills and also could allow non-renewable resources to be sparingly used (Chen *et al.,* 2010). Either by reducing costs or diminishing the impact caused by the Construction Industry, waste recycling could be seen as a crucial practice for sustainability. Following this context, this work proposes an evaluation of the use of phosphatization sludge (PS) in ceramic six-hole hollow bricks.

PS as a solid waste is classified as Non Inert - Class IIA Solid Waste, according to the NBR 10004 Standard (ABNT, 2004). It is generated through the production of automotive parts, from a Brazilian company of the metal mechanic sector, during the phosphate coating process. This consists of immersing the metal parts in several stages (baths) as shown in Figure 1. The process generates an effluent which becomes phosphatization sludge after its treatment. Approximately 12 cubic meters of sludge per month are generated and landfilled. Outstanding, the waste phosphatization sludge main chemical compounds are Al and Fe and elements profusely found in clays typically used in this type of application (Kazmierczak, 2010).

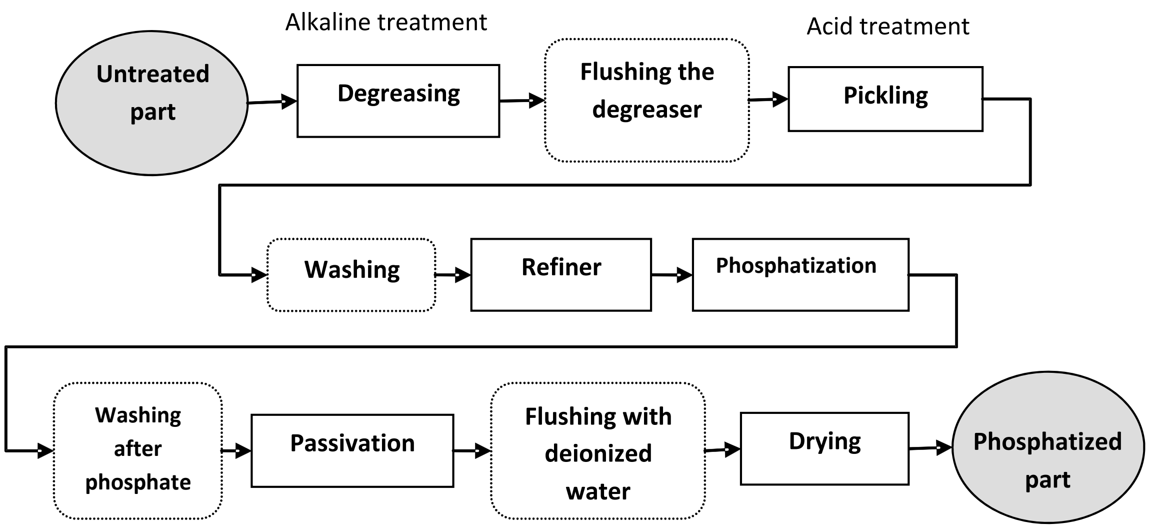

Figure 1. Phosphatization process

In addition, the red color, due to Fe presence and the texture make the PS an interesting material resource alternative saving (**¡Error! No se encuentra el origen de la referencia.**). Hence, the importance of this waste valorization solution had been ensured and justified by the environmental analysis of the product worldwide recognized as an important part of research projects which purposes to convert a waste into a marketable product with constructive results. Nevertheless, the solid waste generating company could have not only an opportunity of reducing the disposal costs, but also develop a product contributing forward to the conservation of non-renewable natural resources (clay) employed by the target company.

Figure 2. Phospahtization sludge (PS) solid waste

1.1. Life Cycle Analysis

Life Cycle Analysis is an environmental tool used to evaluate the potential environmental impact and aspects associated to a product, process or system, through the compilation of an inventory of energy and materials consumption, as well as the environmental emissions during its whole life cycle (Calderón *et al.,* 2010; Frenette *et al.,* 2010) .The tool allows for an environmental comparison among the products which fulfill the same objective (Haes and Heijungs, 2007) In addition, LCA has widespread applicability. In the applications, the influence on the decision-making process highlighted the product and process design, strategy definition, the identification of improvements, the selection of environmental indicators, environmental labeling and the declaration of ecological products, among others (Calderón *et al.,* 2010). The methodology is based on international standards ISO 14040 Standard series (ABNT, 2001). It consists of four phases: objective and scope definition, inventory analysis, environmental impact evaluation and interpretation. The objective's definition phase describes the purpose of LCA, while the scope defines the functional unity, the physical characteristics and the geographical borders of the system which will be under analysis. The inventory analysis records the environmental data related to the variables involved (interpretation phase results), occurring an impact analysis and the data consideration for the decision-making process (Jørgensen *et al.,* 2004).

1.2. Case studies in construction sector

LCA is recognized as an innovative methodology which improves sustainability in the construction industry throughout all stages of the building life cycle (Jørgensen *et al.,* 2004). The tool can be used for environmental diagnosis and prognosis in the different sectors and is more easily applied and used in the production of civil construction materials when applied to construction sector (Carvalho, 2002).

Lee and Park (2005) had been used LCA to quantify recycling environmental credits for the recycling of blast furnace slag. The results yielded higher environmental credits quantity when there is an application of the solid waste as raw material for manufacturing cement.

Librelotto and Jalali (2008) applied the LCA methodology to evaluate the environmental performance of two residential buildings in the town of Cruz Alta – RS – Brazil. The GBTool 2005 software was used for Impact Analysis. The authors state that LCA not only allows adaptation to different evaluation contexts, but also can be easy to use in editing the tool factors default. The study results allowed for modifications to be proposed in places where the buildings could be improved. In addition to that, the research showed that the proposed alterations are feasible in ecological and financial terms (Librelotto and Jalali, 2008).

Rivela *et al.* (2013) applied the life cycle assessment methodology to quantify the environmental impact of the green roofs materials to analyze its environmental profile. The identification of hot spots of the system permitted an ecodesign strategy that effectively reduces environmental burdens associated with roof construction, optimizing the environmental performance. The results identified the high environmental impact associated to the structure, the important contribution of the felt wick irrigation system and the extruded polystyrene thermal insulation.

Ortiz *et al.* (2010) applied the LCA to an apartment brick to evaluate the environmental impacts during the construction stage. The research revealed that the environmental evaluation management tool allows evaluating how the construction phase contributes to the environmental impact of the activity (Ortiz *et al.,* 2010).

The technical and environmental feasibility of rice husk ash (RHA) incorporating to mortar coating to reduce the natural resources consumption and in the same time improve the cementitious matrix adherence was evaluated through the life cycle analysis tool (LCA) by Moraes *et al.* (2010). The evaluation involved surveying all the processes and impacts associated to the production of mortar coatings, from the extraction of the natural resources to product application. The results revealed a 100% increase in bonding strength for mortars with a 5% content of RHA and also identified a smaller number of significant impacts compared to mortar without additives. Thus, the study showed that mortars with RHA had better technical and environmental performance when compared to the usual type of mortars (Moraes *et al.,* 2010).

2. Methodology

2.1. Phosphatization sludge characterization and preliminary tests

The PS was chemically and mineralogically characterized by Inductively Coupled Plasma/Optical Emission Spectrometry analysis and X-ray diffractometry. The moisture content was determined by mass loss at 525 ± 25 ºC. Preliminary tests were developed on bench scale. The specimens were molded using 0%, 2.5%, 5.0% and 7.5% (by weight of PS) by addition to the clay. The specimens were sintered at 850, 900 and 950°C. Physical, mechanical and environmental characterization tests were carried out. The results showed the technical feasibility of adding up to 5%. The detailed results of the preliminary study have been described in Brehm *et al.* (2008).

2.2. Production in industrial scale and products properties control

The industrial scale test was performed with 2.5% PS addition. This value had been selected to ensure a safety coefficient during the ceramic hollow brick production. The production process was monitored during approximately 5 years with a periodic sampling (each 6 months) and samples had been physically, mechanically and environmentally characterized. Batches were chosen randomly. The specimens' procedures sampling and geometric measurements were carried out as described in official Brazilian standards NBR 15270-1 (ABNT, 2005) and NBR 15270-3 (ABNT, 2005), respectively.

The products mechanical performance was evaluated through compressive strength tests according to NBR 15270-3 (ABNT, 2005). Final products environmental control had been developed by leaching and solubilization assays. They were conducted as specified in NBR 10005 (ABNT, 2004) and NBR 10006 (ABNT, 2005), respectively. The detailed results obtained confirmed the technical and economic of the solid waste recycling industrially feasibility. It can be verified in Brehm *et al.* (2008) and Kulakowski *et al.* (2015). However, apart from positive technical results and aiming to further evaluate the technological results, the study proceeded to consider the environmental parameters required to enable PS recycling. This analysis was established using "Life Cycle Analysis" (LCA), the most frequently used environmental management evaluation tool (Calderón *et al.,* 2010). This tool was applied qualitatively, to compare the productive chain of the bricks with and without the addition of phosphatization sludge (from the raw material extraction process to the production of bricks). Apart from atmospheric emissions, the employed production process on the bricks allowed a quantitative input/output analysis.

2.2.1. Conventional bricks production

Clay extraction occurs through the use of a front loader which loads trucks that transport raw-material to the ceramics plant industry. Figure 3 presents the conventional brick production system. The clay is carried through conveyors to the clod breaker, which reduces the clods in size. After that, it is carried out to the mixer where it is homogenized and receives water in case the mixture is too dry. Following, it goes to the laminator where becomes more homogenized. Later lamination, the clay is conducted to the extruder where it is formed into ceramic hollow bricks. Subsequently shaping, the bricks are naturally dried. The following step consists in firing the bricks in an intermittent wood fired kiln, or kiln. The bricks are fired at an average temperature between 850 to 900ºC and next that removed to cool naturally. Moreover, the bricks go through a selection process where broken, split or over fired bricks are discarded. Finally, the broken pieces are used as floor ballast at the brick factory. After eliminating the inadequate bricks, the products are sent to storage where they remain until they are transported to the consumers. It should be noted that all the lighting and the power feed for equipment and production line are supplied by the power company and the water by the local utility company.

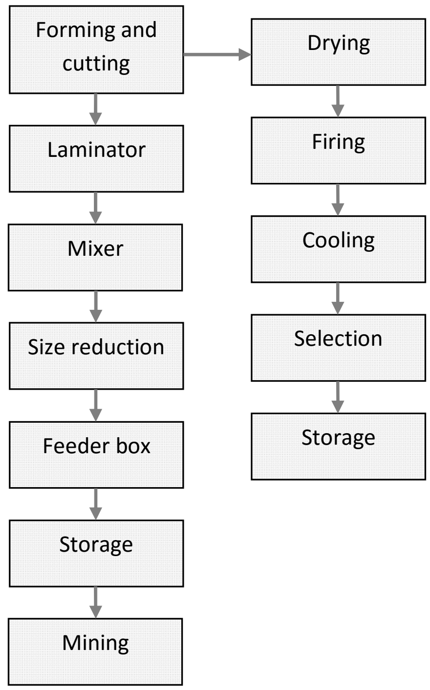

Figure 3. Flow chart of the production process for bricks without PS addition

2.2.2. Industrial waste valorization process

In the production of bricks containing phosphatization sludge, the waste is stored at the generating company's Industrial Waste Landfill, where it is collected by a skip and transported by truck to the brickworks. The Operating License issued by the environmental authority (Municipal Secretary for the Environment) does not permit the brick factory to store this waste at its premises, only the container with the PS in use can stay on the factory. Hence, the waste generating company is responsible for transporting the PS in such a way that no waste is stored at the brick factory.

The container will be unloaded at the brick producing line and the waste will be added to the process at the brick factory. Meanwhile, the clay passes through the conveyor on its way to the mixer equipment. Therefore, the process follows the same as used to produce conventional bricks, as seen in Figure 4 with the addition of 2.5% of PS.

In order to achieve the established objectives, this study was conducted according to the four phases: objective and scope definition, inventory analysis, environmental impact evaluation and interpretation. The stages involved the forms and flow charts elaboration, interviews and photographic records, as well as literature research. Figure 5 presents the adopted methodology stages flow chart. In the following items, it will be presented the analyzed production means and the impact evaluation method used.

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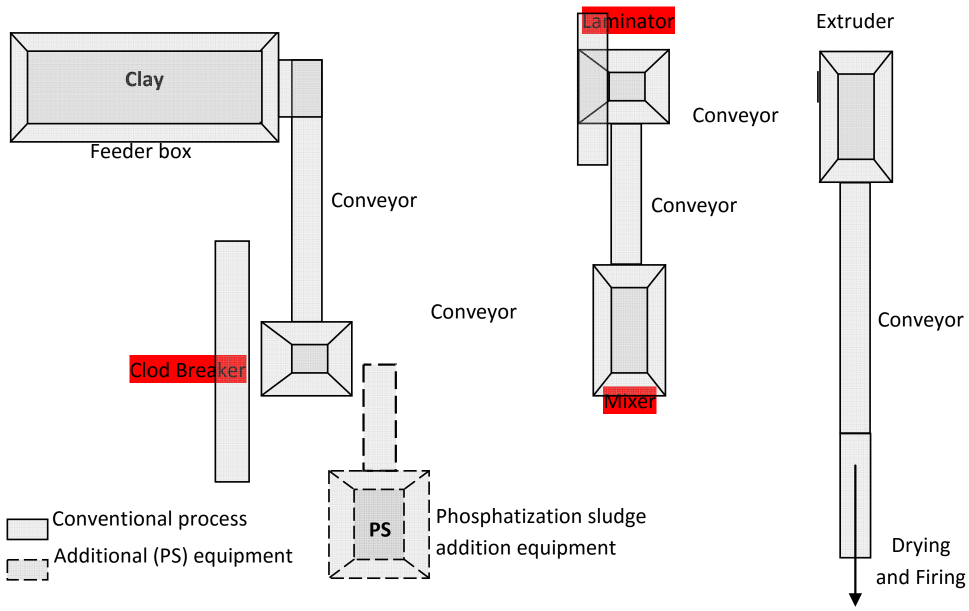

Figure 4. Visualization of the production process of bricks with residue addition

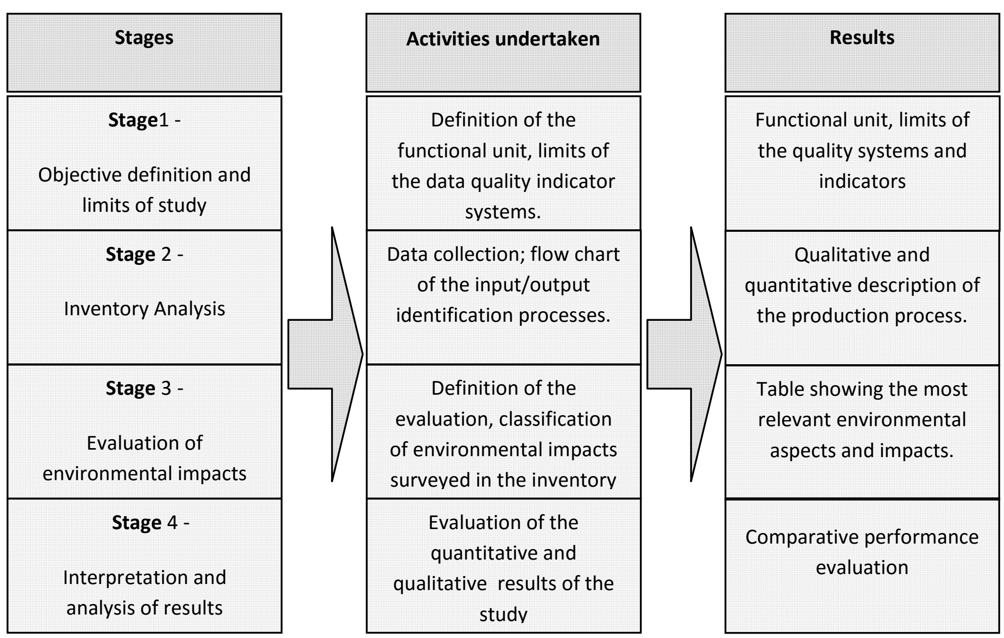

Figure 5. Methodology was used for the study

2.3. Evaluation of the environmental impacts

The study was based on the evaluation of the environmental impacts on the method described by Menezes *et al.* (2006). This method originally based on environmental impact evaluation models found in the literature was improved using field research and interviews with building companies. It is used to identify and evaluate environmental aspects and impacts associated to activities of the urban buildings construction. Although Menezes *et al.* (2006) establishes the significance of an environmental impact due to its relevance, significance filters and the existing control situation, this study only operated with the first criteria due to its scope. As a result, this study considered the stages outlined in Figure 6 to evaluate the environmental impacts.

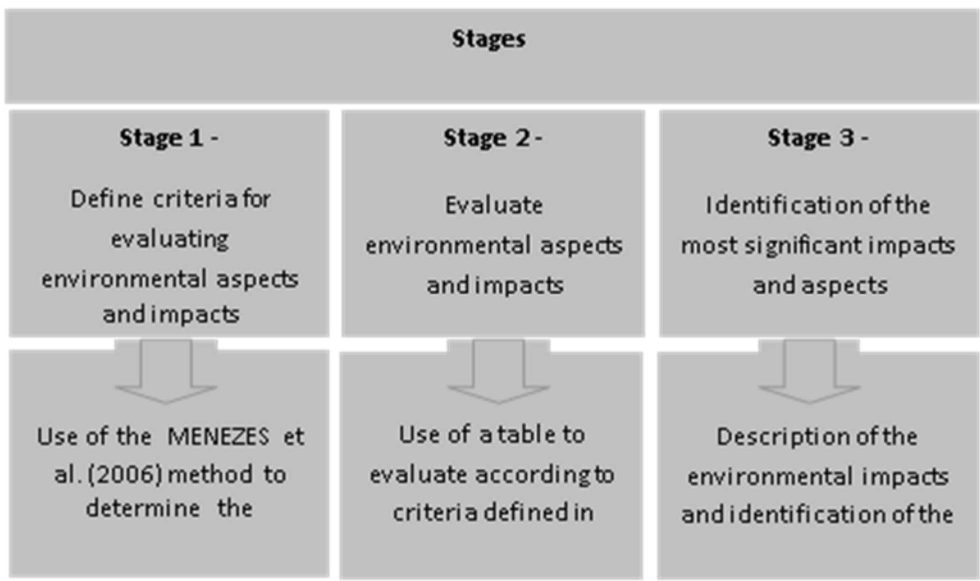

Figure 6. Stages of impact evaluation

2.4. Definition of criteria

The criteria established by Menezes *et al.* (2006) to define the environmental impacts relevance can be verified on Table 1. It can be concluded that the consequence of the impact will depend on its scope and seriousness as well as the relevance (Table 1), which will be obtained from the consequence and its occurring probability. These situations are shown in Table 2 and Table 3.

Table 1. Criteria to define the relevance of the environmental impacts

Criteria		Degrees		
CONSEQUENCE Ratio between Scope X Gravity	ENCOMPASSING Extent of the environmental impact	1	2	3
		AT ONE POINT Restricted to the inside area of the company	LOCAL Encompasses the neighborhood of the company including or not its internal area.	GLOBAL Encompasses the outside area beyond the neighborhood including or not the internal area of the company.
	GRAVITY Intensity of impact	1	3	7
		LOW Low environmental damage, reversed by nature in a short amount of time.	MEDIUM Considerable environmental damage which requires technical resources, time and funding to be reversed.	HIGH Notable environmental damage with an irreversible effect.
RELEVANCE (R) Relationship between Consequence x Probability	PROBABILITY / FREQUENCY Probability that environmental impact or frequency of an associated aspect will occur	2	3	4
		LOW Aspect occurs once during the task and/or impact never took place or will probably not occur	MEDIUM The aspect occurs twice to four times during the task and the impact has already occurred but in a sparse manner.	HIGH The aspect occurs more than four times or continuously and some impact will probably result.

Source: adapted from Menezes et al. (2006)

Table 2. Consequence grading matrix

Consequence (C) = Scope x Seriousness		Scope			Consequence	Classification
		1	2	3	C ≥ 7	Very severe
Seriousness	1	1	2	3	C = 6	Severe
	3	3	6	9	C = 3	Slightly severe
	7	7	14	21	C < 3	Non-severe

Source: adapted from Menezes et al. (2006)

Table 3. Relevance grading matrix

Relevance (R) = Consequence x Probability		Consequence							
		1	2	3	6	7	9	14	21
Probability	2	2	4	6	12	14	18	28	42
	3	3	6	9	18	21	27	42	63
	4	4	8	12	24	28	36	56	84

Source: adapted from Menezes et al. (2006)

2.5 Identification of aspects and impacts

Concerning the processes input/output of aspects and impacts, they were identified based on data collected on inventory analysis, in visits and observations made in the company. Qualitative data was collected about the impacts, considering the environmental aspects in the industry context: raw material, power sources, solid waste and atmospheric emission. The spreadsheet used to list the environmental aspects and impacts enabled to record and calculate their significance according to the defined technical criteria (Table 1) and allowed their subsequent prioritizing. The model used was elaborated based on the one proposed by Menezes *et al.* (2006), and is represented by

Table 5.

Table 4. Environmental Impact Classification

Relevance	Classification	Description	Classification
R ≥ 14	Very relevant	Severe or very severe consequence with medium and high probability of occurring	Significant (S)
14 > R ≥ 9	Relevant	Severe consequence with low probability of occurring, or slightly severe with medium to high probability of occurring	
R < 9	Irrelevant	Further situations	Non-significant (NS)

Source: adapted from Menezes et al. (2006)

Table 5. Environmental Evaluation Spreadsheet

Identification			Significance					
What aspect?	At what stage does it take place?	And what is its impact?	Consequence			Probability /Frequency	Result	Significance
			Scope	Seriousness	Scope x Seriousness			

Source: adapted from Menezes et al. (2006))

3. Results and discussion

3.1 Phosphatization sludge characterization

The moisture content of the phosphatization sludge is approximately 64% (total weight). Its chemical composition is shown on Table 6. The waste is majoritly composed by Fe followed by S, Zn and Al.

Table 6. Chemical composition of phosphatization sludge (mg/l)

Fe	S	Zn	Al	P	Mn	Ni	Cr	Na	K	Cu	Sr	Mo
245	23	6.2	4.9	4.9	1.35	0.66	0.53	0.52	0.16	0.12	0.12	<0.012

3.2 Ceramic hollow bricks characterization

The geometric parameters indicate the quality and the regularity of production in a brickyard. As can be seen on

Table 7 every measurement results were within the limits established in the standard. Mean resistance along the 5-year period PS specimens evaluated was 3.2 MPa. It means that the average of mechanical strength was also not affected been the value above the low limit established by Brazilian standard (ABNT, 2005). According to Kulakowski *et al.* (2015), since the process used, it is identical to that used to produce conventional bricks with no PS, it may be hypothesized that the waste does not interfere in the parameters assessed. The detailed results of leaching and solubilization can also be verified in Kulakowski *et al.* (2015).

Table 7. Average of 10 sampling (13 specimens each sampling) during 5 years of industrial production

Specimens	Dimencions (mm)[a]			Compressive Strength
	Lenght	Width	Height	(MPa)
SP[b]	187.5	89.6	140.1	3.2
ST[c]	190	90	140	1.5

"a": Tolerance of ± 3 mm variation when related with average of samples; "b" hosphatization sludge specimens; "c": Standards specimens. Source: Kulakowski et al. (2015)

3.3 Scope

One thousand bricks were adopted as the functional unit due to this is the quantity which is the commercial unit usually used by NBR 15270-1 Standard (ABNT, 2005). The limits of the life cycle study defined for producing a thousand conventional bricks include the stages of clay extraction, transport to the brick factory, and every production stage up to warehousing and storing prior selling. In the production of a thousand with 2.5% of PS, the sludge storage, its removal and transportation to the brick factory were considered. The study analyzed the inputs and outputs: the diesel consumption, the electrical power, clay, PS, water, sawdust, firewood, solid waste discard, atmospheric emissions and ashes. The limits of the system, as defined for the study are outlined on Figure 7.

3.3.1 Data collection

Data collection for the variables quantification which are related to the product life cycle involved visits and interviews to the company. It also involved the bricks production and the industry which

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generates the phosphatizing sludge. Hence, the information linked to the processes is thoroughly related to the quality of data received from the interviewees. A simple rule of three was used to obtain the data referring to the functional unit (consumption or generation) for information that was not directly related to the production of a thousand bricks. This method was used to determine the quantities of clay, phosphatized sludge, water and diesel consumed.

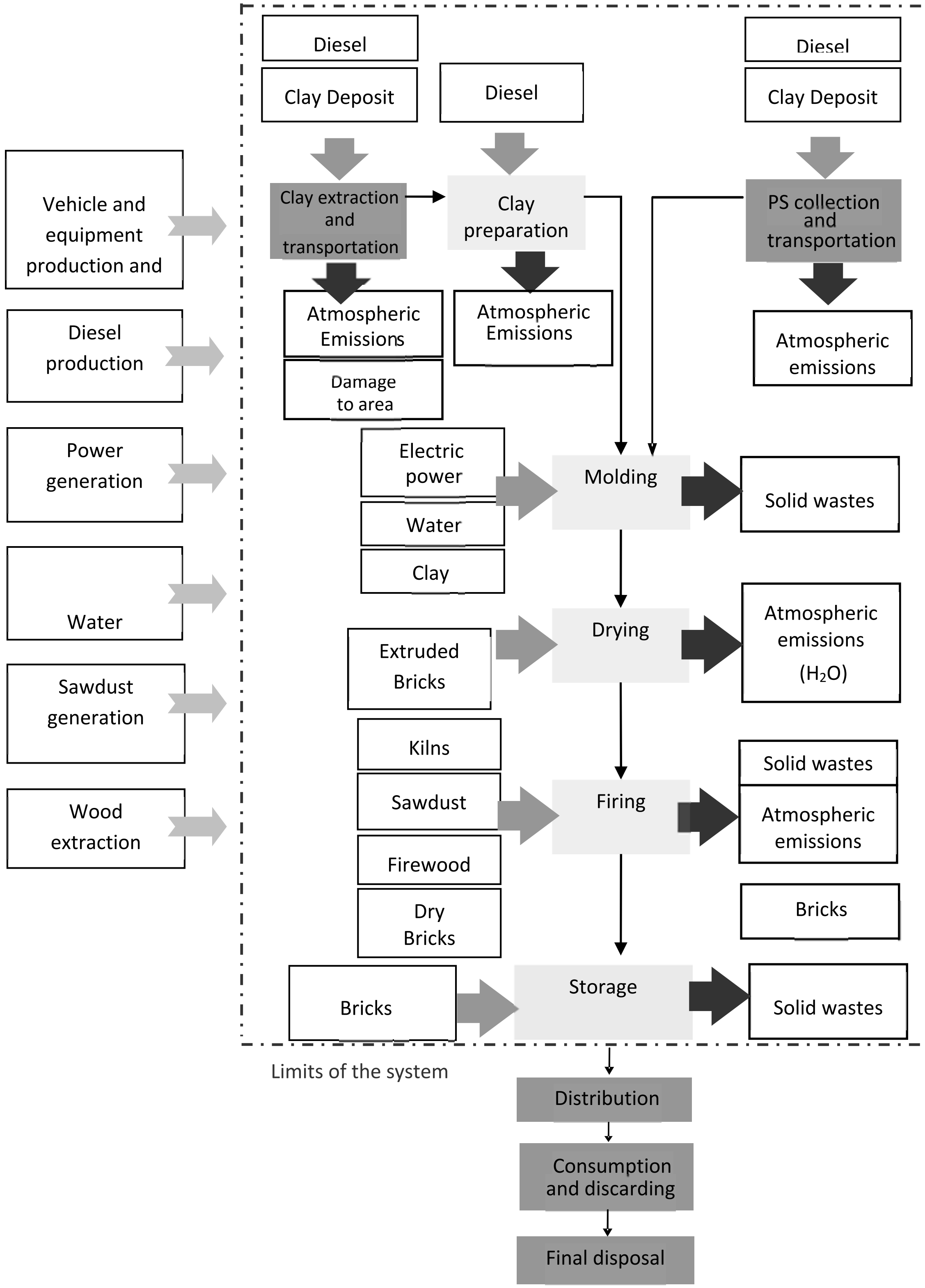

Figure 7. Outlining the limits of the brick production system

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3.3.2 Results analysis and Interpretation

The inputs and outputs of Table 8 were obtained from the information collected during the analysis of the inventory. Analysis and the proposed method of impact evaluation were based on the inventory. Table 9 was formulated in order to identify and determine the most significant aspects and environmental impacts related to the stages of the processes. As it can be seen in Table 9, the impacts are closely linked to the use of raw-material, power sources and the release of pollutants into the atmosphere. Despite these fact that clay mining is considered an activity with medium polluting it potential by the environmental authority (FEPAM, 2011) and that the brick factory being licensed for the activity, contributes to area degradation. The authors state that extraction involves damage to the soil and the local biodiversity, besides altering the scenery (Grigoletti and Sattler, 2003).

Table 8. Inputs e Outputs of the productive processes

Inputs			Outputs		
Items	Bricks without PS	Bricks with PS	Items	Bricks without PS	Bricks with PS
Diesel	1.16 liters	1.48 liters	Bricks	1000	1000
			Rejects	1% =10 Bricks =27 kg clay	1% =10 Bricks =27 kg clay
Power	99.38 kWh	99.87kWh	Atmospheric emissions	H_2O, CO, CO_2, NO_x, HC, SO_2 e SO_3, Particulate material	H_2O, CO, CO_2, NO_x, HC, SO_2 e SO_3, Particulate material and others
Clay	2.700 kg	2.632.5 kg			
PS	-	67.5kg			
Water	60 liters	60 liters			
Sawdust	3 m³	3 m³			
Firewood	2 m³	2 m³	Ashes	1.5 kg	1.5 kg

Removing the land cover has a strong negative impact on the microbiota of the soil, reducing the number of bacteria, fungi and soil microbial activity (Schiavo, 2005). Furthermore, as clay is a non-renewable resource, its exhaustion must be considered due to large scale consumption, which leads to open new clay pits, continuing the further impact on the ecosystems. Thus, the lower the consumption of this raw material, the higher the life cycle for the clay pits and the lesser damage to the ecosystems.

Based on this aspect, the use of phosphatizing sludge is shown to be positive, since it lowers the impact related to clay extraction. For instance, in a thousand bricks there is an economy of 67 kg of raw material. In the course of one month 16.750 kg would be saved. Therefore, solid waste incorporation is a strategy for the impacts reduction from the clay extraction and consumption and production costs (FEPAM, 2011). In fact, this by-product uses to manufacture bricks means that the generating company does not need to allocate space for landfill, which reduces disposal costs and, especially PS contributes as raw material in a new process.

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Table 9. Significance of the impacts

Identification			Significance					
			Consequence					
What is the aspect?	At what stage does it occur?	What is the impact?	Scope	Seriousness	Scope x Seriousness	Probability/ Frequency	Result	Significance
Clay consumption	Extraction	Removal of vegetable covering	1	3	3	3	9	S
	Extraction	Damage to flora and fauna	2	7	14	4	56	S
	Extraction	Alteration of soil quality	2	7	14	4	56	S
	Extraction	Alteration of scenery	2	3	6	4	24	S
	Extraction and process	Use of non-renewable natural resources	1	7	7	4	28	S
	Extraction	Area remediation	2	3	6	4	24	S
Diesel consumption	Extraction, transport and preparation (front loader)	Use of non-renewable natural resources or exhausting fossil fuel reserves	3	7	21	4	84	S
Phosphatization sludge consumption	Collection and production process	Reuse of solid waste from another industrial process	2	1	2	4	8	NS
Power consumption	Collection of PS, clay preparation and conformation	Use of non-renewable natural resources	2	3	6	4	24	S
Water consumption	Clay mixing process (preparation)	Use of non-renewable natural resources	2	3	6	3	18	S
Firewood consumption	Thermal treatment	Use of renewable natural resources	2	3	6	4	24	S
Sawdust consumption	Thermal treatment	Reuse of residues from another industrial process	2	1	2	4	8	NS
Atmospheric emissions	Transportation and Thermal treatment	Greenhouse effect	3	3	9	4	36	S
		Damage to the ecosystem	2	3	6	4	36	S
Solid waste generation	From burning	Scenery alteration	1	1	1	3	3	NS
		Use of the soil	1	1	1	3	3	NS

Firewood, in spite of being a renewable resource causes indirect environmental impacts such as the loss of biodiversity through monoculture, for instance, eucalyptus growing and the loss of native vegetation dependent fauna. At the same time, the sawdust use as energy input in the tunnel oven could be considered an alternative for solid waste generated by sawmills companies,

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avoiding the use of additional firewood in its original form. Another negative impact due both firewood and sawdust usage is the emission caused by the combustion.

When burning wood, not only the water has been eliminated but also carbon monoxide (CO), carbon dioxide (CO_2), soot (or particulate matter), nitrogen oxide (NO_x) and ashes (Pereira, 2004). Among the gases, CO_2 is the one which is considered the main greenhouse effect intensifier, i.e., one of the main problems affecting the ecosphere. The emission of this gas along with other greenhouse gases increases the energy retained amount in the atmosphere due to the heat absorption reflected or distributed by the earth surface. Therefore, it increases temperature and may lead to an increase in the ocean levels and affect all the life forms on the planet (Braga *et al.*, 2005). Besides, producing sulphur oxides (SO_2 e SO_3) e hydrocarbides (HC), diesel combustion also contributes with to the gases emission of the mentioned above. Gases such as sulphur dioxide (SO_2) are also responsible for acid rain. It has been formed when gases, including sulphur dioxide, nitrogen oxides and hydrogen chloride react with water vapor in the atmosphere producing nitric and sulphuric acid. This phenomenon can damage buildings, plantations and forests, besides causing soil and water acidification, killing of fish and other organisms. The use of diesel also involves consuming oil reserves those have taken millions of years to be formed. In addition, all of these gases affect human health in some degree, specially the respiratory system.

There is no large water consumption in the process except in the mixing stage, the only phase in which it is consumed. The electricity to run the equipment and illumination is supplied by the public utility company and generated by hydroelectric power plants.

The solid waste generated during the raw material preparation, molding and drying is reintroduced to the process. The ashes from wood and sawdust burning and rejects of the finished product are disposed in an industrial landfill. The ceramic hollow bricks with sludge addition, having the same environmental classification of the conventional, Solid Residue Class IIA – Non Inert (Brehm *et al.,* 2007) indicated that no dangerous compounds will leachate into the ground or water resources. However, the behavior of these bricks over time can only be determined through future studies.

4. Conclusions

The environmental evaluation, an important stage in research projects aimed at solid waste recycling, through the Life Cycle Analysis methodology, permitted the comparative analysis of the environmental impacts involving the extraction phases, transport and production of ceramic hollow brick with the addition of phosphatization sludge as well as conventional ceramic hollow brick.

The most critic points identified in the life cycle of the processes under study among the identified impacts were the clay and diesel consumption and the atmospheric pollutants emission.

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Conventional ceramic hollow bricks showed diesel oil lower consumption and electric power compared to bricks with sludge due to the distance from the industrial landfill and the addition of one more piece of equipment to the process.

Nevertheless, ceramic hollow bricks with phosphatization sludge consumed fewer clay, therefore, extending the life span of the clay pit, conserving the resource and the local ecosystem. Thus, it allows the environmental impacts reduction associated with clay extraction.

Accordingly, within the limitations of this study, from the environmental point of view, ceramic hollow bricks containing phosphatization sludge can be shown to be a positive solution to reduce the environmental impact of solid wastes generated in industrial processes.

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