CASE STUDY OF THE COMPARATIVE LIFE CYCLE ANALYSIS (LCA) OF GLAZED PORCELAIN TILE (BIa) AND RED-BODY STONEWARE TILE (BIIa) PRODUCTION

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1. INTRODUCTION

Ceramic tile manufacture is a capital-intensive sector, set in the area of non-metal materials, which fabricates products such as earthenware tiles, stoneware tile and porcelain tile for use in civil construction. Porcelain tile stands out among these products owing to current decorative and architectural trends. On the other hand the ceramic tile industry in general and the porcelain and red-body stoneware tile industry, in particular, need to address certain issues in their environmental performance. The ceramic industry is a great consumer of raw materials, fuel, and electricity. It also contributes to producing solid wastes and liquid and gaseous effluents. There is, therefore, great interest in minimising the environmental impacts of these manufacturing processes. The recycling of solid wastes and water, the treatment of particle emissions, chlorides, and fluorides, and the increased energy efficiency in thermal systems are examples of actions being applied by the ceramic tile sector for economic as well as environmental reasons.

Environmental impacts can be evaluated by life cycle analysis (LCA), which analyses the environmental impacts of a product from the extraction of the natural resources and energy involved in making it, to its disposal after use. Life cycle analysis can also be performed for products in the internal cycle within the factory, which alternative production processes (Pereira, 2004), such as the dry and wet manufacturing routes, to be compared. The environmental performance of different types of products used for the same purpose can further be compared, such as ceramic tiles and natural stones like marble (Nicoletti *et al.*, 2002). LCA is now standard in a group of the ISO 14000 series. ISO 14040 (2006) establishes general principles and ISO 14041 (2006) deals with the definition of goal and scope, and inventory analysis. In addition, ISO 14042 (2006) deals with the assessment of life cycle impact and ISO 14043 (2006) the interpretation of the life cycle.

This study uses the LCA methodology to compare the eco-efficiency indicators of the glazed porcelain tile and red-body stoneware tile manufacturing processes in a company in Brazil.

2. METHODOLOGY

The inventories in the production processes are detailed in this study, from the preparation of the body to the packaging of the product. The adopted functional unit was that of compiling information per square metre (m^2), because this type of ceramic product is marketed in this unit. The limits or bounds of the evaluated systems are tile body preparation and finished product packaging. This frame is applied to two products: glazed porcelain tile, sized 45x45 cm (BIa), and red-body stoneware tile, sized 45x45 cm (BIIa), classified according to ISO 13006 (1998).

The products selected for this study displayed technical and aesthetic similarities and differences. In both cases, engobe, glaze, and screen printing applications were used. In addition, natural gas was used as fuel for the spray dryers, dryers, and kilns. The differences lay in the raw materials and processing conditions used (compaction pressure, spray-dried powder moisture content, maximum firing temperature, etc.). Figure 1 shows the scope of the manufacturing process for both products. In red-body stoneware tile production two layers of screen printing inks were used, while in glazed porcelain tile production only one layer was used.

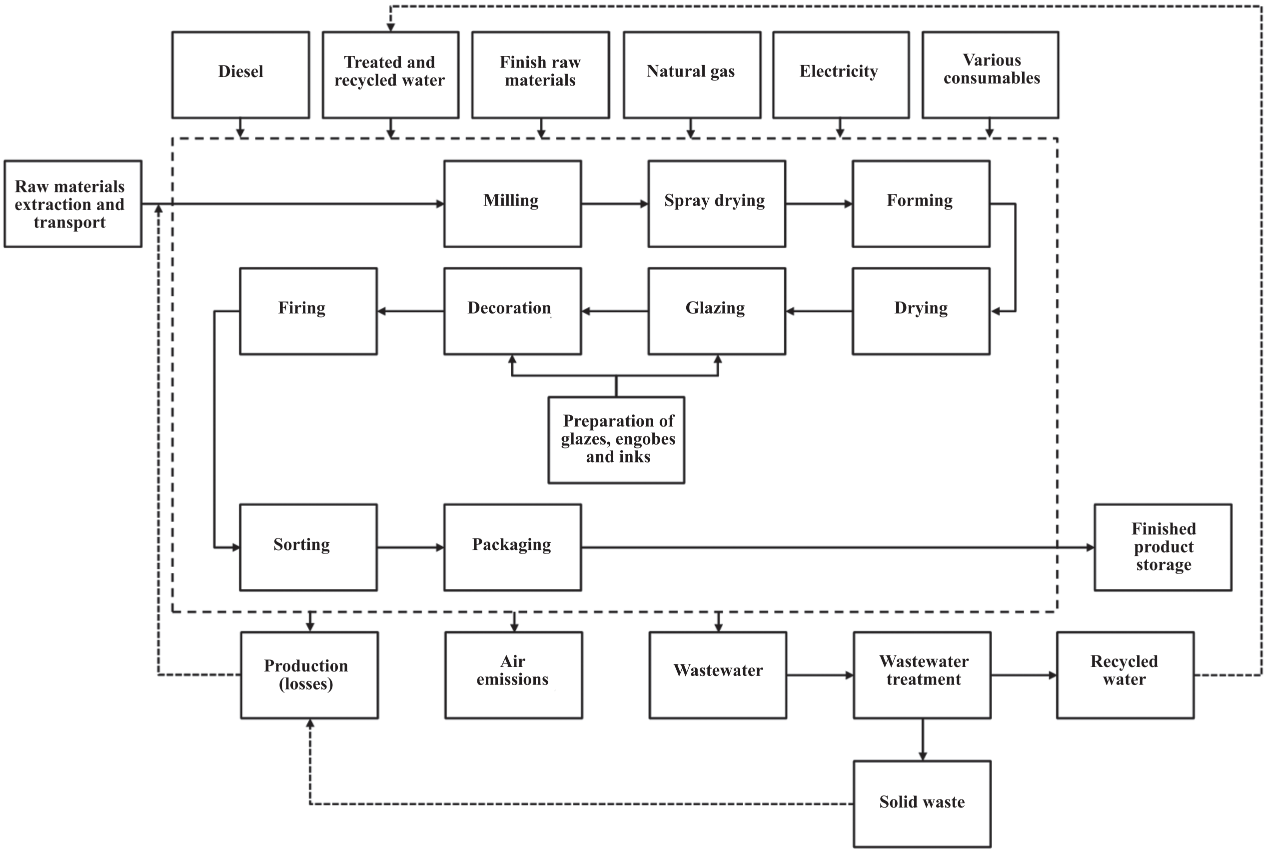

Figure 1 - Flow chart of the ceramic tile production process (study context within the dotted frame).

To carry out a LCA, information is required in order to draw up an inventory, i.e. a mass and energy balance of each step in the production process. For glazed porcelain tile, an average production of 4.000 m^2/day (17,20 kg/m^2), and for red-body stoneware tile an average production of 7.000 m^2/day (16,89 kg/m^2) were considered.

In the body preparation stage, which consists of the grinding and spraying operations, information was obtained on the quantities of each raw material, water, and additives used. In addition, the slurry losses, spray-dried powder loss, slurry water content, powder moisture content, and natural gas and electricity consumption were ascertained.

The information on forming and drying operations was obtained by the same method: powder moisture content in forming, unfired tile mass, dry tile weight, residual moisture content after drying, production losses, natural gas and electricity consumption.

In the glazing and decorating, and glaze, engobe, and ink preparation operations, the relevant information was taken from each product's data sheet, such as the quantity of glaze, engobe, ink, tile back engobe, and process measurements. The data were also considered of the decoration, glaze, engobe, ink and tile back engobe product losses, as well as the energy consumption of the glazing and preparation line. The quantities of each raw material for the preparation of these production consumables were also obtained.

The information on the firing, sorting, and packaging operations were obtained from the product mass, natural gas and electric energy consumption, production losses, packaging and adhesive consumption, and the natural gas consumption of the fork-lift trucks.

The particulate matter in the spray dryer stack, stemming from the raw materials, was measured. In the drying and firing stages their contribution was insignificant, so that they were disregarded. The combustion gases were estimated from the quantity of natural gas consumed in each step (CARVALHO JR and LACAVA, 2003). The methodology was based on studies by Soares and Pereira (2004), Pereira (2004), and Tikul & Srichandr (2010).

The assessments of the eco-indicators and the comparisons of the processes were performed using SimaPro software, with the Eco-indicator 99 method (Goedkoop & Spriensma, 2001). This method was chosen because it is widely used in life cycle analysis in Europe. As the facilities used in the Brazilian industries are very similar to the European facilities, they can be compared.

3. RESULTS AND DISCUSSION

The results of all measurements made, in accordance with the established functional unit (1 m^2), were combined for each product and production stage, as set out in Tables 1, 2, 3, 4, and 5.

The solid waste resulting from the production losses in each step of the process was recycled as raw materials, as were the wastes from the effluent treatment process. It was observed that 2,41 kg/m^2 waste was generated in the glazed porcelain tile production process and 1,42 kg/m^2 in that of red-body stoneware tile, highlighting the need to recycle these wastes. The liquid effluents of both processes were used in cleaning and in body preparation after appropriate treatment. The estimated electricity consumption for porcelain tile production was 3,58 kWh/m^2 and that for red-body stoneware tile was 1,87 kWh/m^2, again displaying an opportunity for upgrading the glazed porcelain tile process. The total natural gas consumption was 2,36 kg/m^2 for glazed porcelain tile and 2,34 kg/m^2 for the red-body stoneware tile. This difference was due to the higher firing temperature of glazed porcelain tile, which was 1205°C, compared to 1165°C for the red-body stoneware tile. The quantity of CO_2 released by the ceramic tile production process was significant (4,94 kg/m^2 for glazed porcelain tile and 5,04 kg/m^2 for red-body stoneware tile). That gas contributes to global warming, as described Tikul and Srichandr (2010).

Input				Output			
Consumable	Unit	Glazed porcelain tile 45x45 cm^2	Red-body stoneware tile 45x45 cm^2	Item	Unit	Glazed porcelain tile 45x45 cm^2	Red-body stoneware tile 45x45 cm^2
	(x/m^2)	Quantity			(x/m^2)	Quantity	
Clays	kg	18,74	16,75	Spray-dried powder	kg	19,04	17,82
Water (recovered)	kg	11,00	9,42	Evaporated water	kg	9,55	7,98
Deflocculant	kg	0,21	0,21	Slurry (loss)	kg	0,43	0,44
Diesel	kg	$1{,}18.10^{-3}$	$2{,}62.10^{-3}$	Spray-dried powder (loss)	kg	0,22114	$7{,}47.10^{-2}$
Natural gas	kg	1,21	1,14	Retained particles (bag filter)	kg	0,71	$5{,}82.10^{-2}$
Electricity	kWh	1,63	0,27	Particles (stack bag filter])	kg	$1{,}65.10^{-3}$	$1{,}54.10^{-3}$
				CO*	g	0,33	0,33
				HCl*	g	$6{,}20.10^{-3}$	$1{,}38.10^{-2}$
				NO_x*	g	0,35	0,33
				SO_x*	g	$1{,}93.10^{-2}$	$2{,}23.10^{-2}$
				CO_2*	kg	2,20	2,20
				Particles (fuel) *	g	0,36	0,35

* Source: Carvalho Jr and Lacava (2003) and Pereira (2004).

Table 1 - Body preparation (milling and spray drying) inventory.

Input				Output			
Consumable	Unit	Glazed porce-lain tile 45x45 cm^2	Red-body stoneware tile 45x45 cm^2	Item	Unit	Glazed porce-lain tile 45x45 cm^2	Red-body stoneware tile 45x45 cm^2
	(x/m^2)	Quantity			(x/m^2)	Quantity	
Spray-dried powder	kg	18,90	17,71	Dry tiles	kg	17,62	16,64
Natural gas	kg	0,21	0,24	Evaporated water	kg	1,17	0,98
Electricity	kWh	1,18	0,64	Tiles (losses)	kg	0,12	$8{,}46.10^{-2}$
				CO*	g	$2{,}06.10^{-3}$	$2{,}35.10^{-3}$
				NO_x*	g	$5{,}96.10^{-2}$	$6{,}80.10^{-2}$
				SO_x*	g	$2{,}77.10^{-3}$	$3{,}16.10^{-3}$
				CO_2*	kg	0,50	0,57
				Particles (fuel)*	g	$6{,}17.10^{-2}$	$7{,}04.10^{-2}$

* Source: Carvalho Jr and Lacava (2003) and Pereira (2004).

Table 2 – Forming and drying inventory.

Input				Output			
Consumable	Unit	Glazed porcelain tile 45x45 cm²	Red-body stoneware tile 45x45 cm²	Item	Unit	Glazed porcelain tile 45x45 cm²	Red-body stoneware tile 45x45 cm²
	(x/m²)	Quantity			(x/m²)	Quantity	
Dry tiles	kg	17,62	16,64	Glazed and decorated tiles	kg	17,86	17,31
Water (treated)	kg	0,17	0,24	Glazed and decorated tiles (loss)	kg	0,36	0,22
Raw materials	kg	0,70	1,01	Glazes, engobes, and inks (loss)	kg	$9{,}10.10^{-2}$	$9{,}21.10^{-2}$
Sodium tripolyphosphate	kg	$2{,}55.10^{-3}$	$3{,}65.10^{-3}$				
Carboxymethyl-cellulose	kg	$1{,}37.10^{-3}$	$1{,}81.10^{-3}$				
Preservative	kg	$5{,}40.10^{-4}$	$7{,}70.10^{-4}$				
Electricity	kWh	0,26	0,28				

* Source: Carvalho Jr and Lacava (2003) and Pereira (2004).

Table 3 - Inventory of glazing and decorating, and glaze and ink preparation steps.

Input				Output			
Consumable	Unit	Glazed porcelain tile 45x45 cm²	Red-body stoneware tile 45x45 cm²	Item	Unit	Glazed porcelain tile 45x45 cm²	Red-body stoneware tile 45x45 cm²
	(x/m²)	Quantity			(x/m²)	Quantity	
Glazed and decorated tiles	kg	17,86	17,31	Fired tiles	kg	17,20	16,89
Natural gas	kg	0,90	0,95	Loss on ignition	kg	0,51	0,21
Electricity	kWh	0,47	0,65	Evaporated water	kg	0,15	0,22
				SO_x*	g	$1{,}19.10^{-2}$	$1{,}26.10^{-2}$
				CO_2*	kg	2,14	2,27
				NO_x*	g	0,25	0,27
				CO*	g	0,50	0,33
				Particles (fuel)*	g	0,26	0,28
				Fluorides*	g	1,98	1,98
				Chlorides*	g	3,42	2,30

* Source: Carvalho Jr and Lacava (2003) and Pereira (2004).

Table 4 - Firing stage inventory.

Input				Output			
Consumable	Unit	Glazed porcelain tile 45x45 cm²	Red-body stoneware tile 45x45 cm²	Item	Unit	Glazed porcelain tile 45x45 cm²	Red-body stoneware tile 45x45 cm²
	(x/m²)	Quantity			(x/m²)	Quantity	
Fired tiles	kg	17,20	16,89	Finished product (packaged)	kg	16,73	16,44
Cardboard box	kg	0,09	0,13	Tiles (losses)	kg	0,48	0,44
Glue	kg	$1{,}64.10^{-3}$	$1{,}41.10^{-3}$	SO_x*	g	$5{,}70.10^{-4}$	$5{,}00.10^{-5}$
Natural gas	kg	$4{,}34.10^{-2}$	$3{,}49.10^{-3}$	NO_x*	g	$1{,}23.10^{-2}$	$9{,}90.10^{-4}$
Electricity	kWh	$5{,}10.10^{-2}$	$3{,}58.10^{-2}$	Particles (fuel)*	g	$1{,}28.10^{-2}$	$1{,}03.10^{-3}$
				CO_2*	kg	0,10	0,01

* Source: Carvalho Jr and Lacava (2003) and Pereira (2004).

Table 5 – Inventory of the sorting and packaging steps.

4. CONCLUSIONS

The inventory has enabled a preliminary assessment of the environmental impacts of selected products to be performed. In some parts of the glazed porcelain tile production process there is a greater consumption of resources compared to that of the red-body stoneware, diminishing its environmental performance. Another important aspect to be analysed is the combustion gases, because they depend on the type of fuel and raw materials, as well as the formation of harmful gases for the ozone layer. Acid formation, such as HCl, from the chlorides (as well as from the fluorides) contained in the raw materials, must be controlled. The other stages of the life cycle of these products, such as the extraction of the basic raw materials and their transport, and the transport of the raw materials used for the finishes in glaze, engobe, and ink preparation must also be considered in obtaining and assessing the eco-indicators.

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