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Review

Generation, characterization and reuse of solid wastes from a biodiesel production plant

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ABSTRACT

The aim of this study was to identify and characterize industrial solid wastes generated by a biodiesel production plant in Brazil, as well as to present strategies for the management of these materials. This plant produces every year around 100,000 tons of biodiesel from vegetable oils and animal fats. The methodology of the study included technical visits, interviews with the operational and environmental management staff as well as analysis of documents, reports and computerized data systems. An approach to reduce the generation of hazardous waste was investigated. It was take into account the amount of raw material that was processed, reduction of landfill disposal, and the maximization of the their recycling and reuse. The study also identified the sources of waste generation and accordingly prepared an evaluation matrix to determine the types of waste with the higher potential for minimization. The most important residue of the process was the filter material impregnated with oil and biodiesel, requiring, therefore, measures for its minimization. The use of these residues in the production of ceramic artefacts (light bricks) was considered to be very promising, since no significant effect on the physico-chemical and mechanical properties of the artefacts produced was observed. Phytotoxicity test using seeds of *Lactuva sativa* (lettuce), *Brassica juncea* (mustard), *Abelmoschus esculentus* (okra), *Chrysanthemum leucanthemum* (daisy), *Dendranthema grandiflorum* (chrysanthemum) and *Allium porrum* (leek) were carried out. The results clearly show incorporation of the waste material into bricks did not influence relative germination and relative root elongation in comparison to control tests.

1. Introduction

Nowadays, environmental concern has reached different sectors of society and, notably the industry. By fostering identification of competitive advantages, profitable opportunities along with positive evaluation of stakeholders, many industries adapt their activities to the sustainability concept (Sheldon and Yoxon, 2006). Thus, an adequate system for natural resources, solid wastes, effluents and atmospheric emissions management is a prerequisite to remaining competitive in short- and long-term (Restall and Conrad, 2015; Carter and White, 2012; Theodore and Theodore, 2009). Besides, an effective system allows the planning of activities aiming to eliminate or minimize environmental adverse impacts through preventative actions, mitigation measures or remediation (Glasson et al., 2013).

Both municipal and industrial solid wastes are usually related to environmental contamination since they may contain toxic components, harmful to human health and environment (Santos et al., 2015; Maciel and Jucá, 2011; Giusti, 2009; Mbuligwe and Kaseva, 2006). Thus, in an effective environmental management plan takes into account the amount and types of wastes generated, as well as strategies for their minimization, especially when the main goal is the manufacturing of environmentally-friendly end products (Marchettini et al., 2007). Freeman and Lounsbury (1990) defined waste minimization as the adoption of techniques to reduce or eliminate the volume of waste and its negative impact on environment. In many cases, due to the costs associated with the reduction in the volume and toxicity of wastes (Leemann, 1988), coupled to the concept of sustainable business, development of strategies for effective waste management is required, particularly for new industrial processes, such as the large-scale production of biodiesel (Felizardo et al., 2006). This research aimed to identify and characterize the industrial solid wastes generated

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by a biodiesel production plant in Brazil and to present strategies for the management of these residues.

2. Methodology

This research was based on two approaches; at first, an exploratory study was carried out aiming to identify obstacles and possible solutions related to the application of proper waste management practices. Interviews were carried out *in loco* with both operational and management staffs, also documents, reports and environmental balances at the industrial plant were evaluated. Method employing case studies requires an in-depth analysis of one or more situations and analysis of the behavior of the factors associated with each of the phenomena (Campomar, 1991). Finally, experimental assays were carried out with the objective of classifying, characterizing, and ranking solid wastes for their minimization and potential reuse in the production of ceramic artefacts.

2.1. Case study

2.1.1. Study location

The industrial plant has a built area of 5 ha and a total area of 77 ha. Currently, it processes approximately 285 tons of vegetable oil and animal fats per day for the production of biodiesel.

Process facilities (PFs) and service facilities (SFs) are required in order to make it possible the industrial process. The PFs include the pre-treatment units and the catalytic reactors. In the former, the vegetable oils and animal fats are filtered before being sent to the reactors, providing suitable and controlled conditions for the alkaline transesterification reaction. The SFs include unities for the production of ultrapure water for vapor generation, units for the treatment of atmospheric emissions and effluents from the industrial processes and the offices. Each biodiesel production plant is unique due to the variety of equipment available, the number of PFs and SFs unities and their configuration and, also the efficiency of each installation. However, regardless the geography location and other specific factors, vegetable oils and animal fats are used as raw materials with the aim to obtain products with higher added value, predominantly biodiesel. Thus, information about the effectiveness and applicability of waste management practices from one specific industrial plant can be useful to other biodiesel producers.

2.1.2. Generation, quantification and classification of solid wastes

The data regarding the amount of waste were obtained based on available reports of the plant. Additionally, analyses were performed to characterize and to classify solid wastes according to the Brazilian Standard 10004 (2004). In order to classify a residue as hazardous or non-hazardous, the Brazilian Norm considers aspects such as inflammability, corrosiveness and reactivity. In addition, the concentrations of several substances and chemical elements transferred to a solution after static and dynamic contact with the residues are taken into account. These tests are named, solubilization and leaching (Toxicity Characteristics Leaching Procedure – TCLP), respectively and are similar to those described in Title 40 of the Code of Federal Regulations of United States and in USEPA (2007). It should be noted that, in Brazil, solid residues encompass liquid or semi-solids whose particular characteristics make them unsuitable for discharge into sewage streams or water bodies, requiring technical and economic solutions that can be unviable, when considering the conventional effluent treatment operations available.

In this study, wastes generated in both PFs and SFs were investigated.

2.1.3. Ranking of solid wastes for their minimization

After an assessment of the types of wastes generated at the plant, an evaluation matrix was prepared in order to select among all the wastes generated at the plant, those with higher potential of minimizations. In the evaluation matrix, values of 1, 2 or 3 were attributed to the following factors: (a) generated amounts, (b) difficulties to find suitable environmental destination, and (c) problems of minimization. General criteria used to assign value to each of the three listed factors (i.e., a–c) obeyed the following rules: a value of 3 was ever attributed to cases where the greatest difficulty or quantity was observed; a value of 1 was attributed to the opposite scenario and, a value of 2 to intermediate cases. In the specific case of ‘problems of minimization’, a value of 3 was adopted when the need for changes in the technologies involved in the industrial process was identified. A value of 2 was used when the objective could be reached with the implementation of good management practices or training and 1 was used for other cases which were not considered. In the case of ‘generated amounts’, as a function of generated solid waste, we have created three subsets with intervals to allow better data assembly, avoiding subsets with counts/frequency equal to zero. A value of 1 was adopted for the generation of up to 12 tons per year, 2 for 12–48 tons per year and, 3 for over 48 tons per year. For ‘difficulties to find suitable environmental destination’ a value of 1 was adopted in cases where the routes of recycling, recovery or reuse are available, 2 relates to other treatment options which are not included in the criteria associated with category 1, and 3 was adopted when there are restrictions regarding the suitable environmental destination or final disposal to landfill. The sum of the values attributed to the different factors related to the wastes was the base for identifying those of greater impact; require additional measures to improve their management.

2.2. Reuse of solid waste

2.2.1. Preparation of ceramic artefacts

In the industrial process studied, both load of crude oils (prior to the chemical reaction) and the produced biodiesel are filtered. In both cases, the filter medium is diatomaceous earth. Diatomaceous earth, also called diatomite, is a non-metal raw material composed of residues of marine algae.

The amount of spent filter material (diatomite) and its chemical composition (high content of silicates and carbonates), as well as the high calorific value (due to the high content of biodiesel, oils and fats) motivated tests to evaluate the reusability of this solid residue as a replacement raw material for the production of bricks (Park and Martin, 2007).

Ceramic artefacts (six holes light bricks) were prepared on industrial scale by mixture of clay soil and 6.25% (m/m) of spent diatomite because bricks previously prepared incorporating greater amount of spent filter medium (8%, 9%, and 12%) yielded samples presenting cracking and wrinkles defects or black marks.

The bricks production process studied was carried out in five stages: (1) preparation of the mixture (clay soil, water and spent diatomaceous earth (6.25% m/m)); (2) molding; (3) drying; (4) firing of the ceramic blocks; and (5) their storage.

The mixing process was carried out in two stages: in the first vehicles equipped with loading shovels, placing on stockpiles were used and, in the second a primary crusher, followed by a pan mill and a roller mill kneaded the mass. The extruder shaped the ceramic paste column, which was then cut to obtain the wet bricks (also called green bricks). The wet bricks were loaded in cars to the drying stage by ventilation at 90 °C and then placed in a tunnel kiln (900 °C per 1 h). Bricks composed of only clay soil were also prepared in order to study the effects of the supplementation with residues on the properties of the product.

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