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Review

Applications of life cycle assessment and cost analysis in health care waste management

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A B S T R A C T

The establishment of rules to manage Health Care Waste (HCW) is a challenge for the public sector. Regulatory agencies must ensure the safety of waste management alternatives for two very different profiles of generators: (1) hospitals, which concentrate the production of HCW and (2) small establishments, such as clinics, pharmacies and other sources, that generate dispersed quantities of HCW and are scattered throughout the city. To assist in developing sector regulations for the small generators, we evaluated three management scenarios using decision-making tools. They consisted of a disinfection technique (microwave, autoclave and lime) followed by landfilling, where transportation was also included. The microwave, autoclave and lime techniques were tested at the laboratory to establish the operating parameters to ensure their efficiency in disinfection. Using a life cycle assessment (LCA) and cost analysis, the decision-making tools aimed to determine the technique with the best environmental performance. This consisted of evaluating the eco-efficiency of each scenario. Based on the life cycle assessment, microwaving had the lowest environmental impact (12.64 Pt) followed by autoclaving (48.46 Pt). The cost analyses indicated values of US\$ 0.12 kg^{-1} for the waste treated with microwaves, US\$ 1.10 kg^{-1} for the waste treated by the autoclave and US\$ 1.53 kg^{-1} for the waste treated with lime. The microwave disinfection presented the best eco-efficiency performance among those studied and provided a feasible alternative to subsidize the formulation of the policy for small generators of HCW.

1. Introduction

Health Care Waste (HCW) refers to waste generated from human and animal care centers, such as hospitals, clinics, and nursing clinics, among others.

The management of HCW is a major challenge, particularly in most health care facilities of the developing world. Poor practices and inappropriate disposal methods exercised during the handling and disposal of these wastes are creating significant health hazards and environmental pollution due to the infectious nature of the waste (Hossain et al., 2011). According to Bendjoudi et al. (2009), the mass fraction of HCW considered hazardous is 10–25%, representing a potential threat to health care workers, patients, the environment, and even the general population, if not treated and/or disposed of appropriately; 75–90% by mass of HCW is classified as household waste that pose no additional risk to health or the environment.

There are large hospitals that generate waste in a concentrated manner and small ones spread throughout the city generating small amounts daily. For example, in the state of Pernambuco (northeast Brazil), taking all generators into account, 6% of the hospitals generate 80% of the total HCW. The other 20% is generated by 4230 small establishments (Feeburg Junior, 2007). Silva and Hoppe (2005) analyzed the HCW production in Rio Grande do Sul (south of Brazil), and they found a similar trend, with only 2.4% of the generators producing approximately 84% of the total amount of waste. However, we emphasize that the proper treatment of HCW from the small generators is quite important because the appropriate solution involves a combination of available infrastructure and treatment techniques, which may be different from those adopted by the large generators. The small hospitals contribute a lot in terms of health care facilities, but if they use poor waste management practices, they can pose a serious threat in the form of biomedical waste pollution (Pant, 2011). Blenkharn (2006) draws attention to the fact that in developing countries, there is difficulty

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in safely managing this type of waste, and the challenge to the world community to implement practical improvements in this area is often neglected.

To manage HCW, the small generators usually require alternative techniques because of the current technique issues, including the costs of treatment and final disposal, the inconsistent daily volume generated and the low availability of waste storage areas.

According to National HCW Regulating Agency (ANVISA, 2006), alternatives techniques must be evaluated because most of the HCW has no proper destination. In the majority of Brazilian municipalities, HCW are burned in the open air (20% by mass) or incinerators (11% by mass). Other effective techniques of inactivation, such as autoclaves and microwaves, represent only 0.8% of fraction mass of HCW treatment.

Autoclaving and microwave sterilization are HCW management alternatives used in several countries around the world (Prüss et al., 1999; Lee et al., 2004; Diaz et al., 2005; Tonuci et al., 2008; Yang et al., 2009). Tudor et al. (2009) describe these techniques as alternative treatments to incineration used in the United Kingdom. Lee et al. (2004) consider autoclaving the second-most used technique after incineration for the HCW, reaching between 20% and 37% of the total HCW generated in the world. Chemical sterilization with lime is also presented as an alternative technique (Avery et al., 2009), especially in developing countries (Diaz et al., 2005). Due to the risk of air pollution, several countries ceased the use of hospital waste incinerators (e.g., Canada, the United States, and Greece), generating an increase in the use of other disinfection techniques (Karagiannidis et al., 2010), such as those analyzed here.

Environmental impacts and energy savings in waste systems, and in particular in the HCW system, are often quantified by a life cycle assessment (LCA) (Liamsanguan and Gheewala, 2008; Wittmaier et al., 2009; De Feo and Malvano, 2009; Zhao et al., 2011). Apart from environmental results, the life cycle cost (LCC), which can be defined as a process to determine the sum of all the costs associated with a product (Luo et al., 2009), may be used to quantify the total costs of a waste management system throughout its full life cycle, which includes purchase, operation, maintenance, and disposal (Hong et al., 2009; Kim et al., 2011; Massarutto et al., 2011).

The objective of this study is to evaluate the performance of different HCW management scenarios for small generators – involving microwaving, autoclave, and lime disinfection, using LCA and LCC and expressing the environmental and economic impacts thus determined, as a single quantitative index of each management system.

2. Materials and methods

In this study, the HCW management scenarios involving small generators were evaluated based on the disinfection techniques that allow for their disposal in municipal solid waste landfills (MSWLs). The spatial and temporal boundaries of the evaluation are defined in 2.2 and 2.3. The techniques selected were microwaving, autoclaving, and lime disinfection. First, the efficiency of disinfection was evaluated in the laboratory, and then the management scenarios were evaluated using decision-making tools (Fig. 1).

The purpose of the first criterion was to ensure that the disinfection (inactivation) technique proposed in the management scenarios was effective (see Section 2.1). After that, the environmental impacts and the cost analysis of each scenario were evaluated through LCA (see Section 2.2) and LCC (see Section 2.3), respectively. The purpose of the LCC was to ensure the economical sustainability of the scenarios proposed and the feasibility of their application by the generators. The combination of these last two criteria could be used to make decisions based on eco-efficiency. The principle of eco-efficiency analysis, a concept derived from the life cycle approach, is to create economic value while decreasing environmental burdens (Zhao et al., 2011).

2.1. Evaluation of disinfection efficiency

Disinfection (inactivation) efficiency was evaluated for a standard waste (described by Silva (2000)) inoculated under control with *Escherichia coli*, *Pseudomonas aeruginosa* and *Staphylococcus aureus* bacteria, which are representative of the microorganisms found in HCW (Fujikawa et al., 1992; Silva et al., 1997; Tonuci et al., 2008). After inoculation, the disinfection using microwaving, autoclaving, and liming was tested based on the difference between the counts before and after the exposure to the disinfection technique. We varied the mass of waste for all techniques tested and also varied the power and exposure time for microwaving, the exposure time and temperature for autoclaving, and the mass and contact time of liming.

For each technique, we chose the best conditions to ensure 100% disinfection (inactivation) efficiency. In this way, for this first stage of the work, we tried to create a basis for comparison because when all of the techniques resulted in 100% disinfection, then they are comparable (environmentally and economically) to each other.

The characteristics of the equipment and materials used in this work are presented in Table 1.

2.2. Life cycle assessment (LCA)

The LCA was performed according to the International Organization for Standardization (ISO) numbers 14040 and 14044 (ISO, 2006a, 2006b). The functional unit was established considering that the equipment is used only to disinfect wastes. Each day, 1.0 kg of the HCW is treated for 320 days year^{-1} for 10 years, which is the lifetime of the autoclave and microwave service (Masanet et al., 2005; Northwestern University, 2012); this results in a total of 3200 kg of waste during their service life. The first step in the process is the entrance of the waste in the system. The generation of the waste was not considered because it is the same for all of the scenarios; however, the equipment or lime production and other input materials have been assumed because they differ in each scenario. For the use phase, which is the disinfection itself, we included the containers that are used to store the waste in the microwave and autoclave in the analysis. It is important to mention that an extra transportation was needed only for the lime scenario because the acquisition of lime was necessary for the operation phase, while the microwave and the autoclave were already located health care center.

At the end-of-life (EOL) phase, we considered the disposal (without recycling) of the equipment used in the disinfection. The treatments using the autoclave and microwave were performed at the source of generation, while the lime disinfection process was performed at the landfill facilities. All of the alternatives used the same type of sanitary landfill after disinfection. After the disinfection by microwaving or autoclaving, the HCW was considered to be common waste that would be collected and sent to an urban solid waste landfill. For the 30-km route between the HCW generator and the landfill, specific vehicles transported the lime-treated waste. The lime was transported from the lime factory, considered to be located in Botuverá, to the landfill, located in the city of Biguaçu, where the lime disinfection took place. The distance between these two places is approximately 100 km (maps.google.com). Because the landfilling of waste is common to all of the alternatives, it was also disregarded in the study given the comparative objectives of this LCA. In the case of lime treatment, the excess mass from the addition of limestone to be landfilled was considered.