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Research article

Assessment of the use of organic composts derived from municipal solid waste for the adsorption of Pb, Zn and Cd

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ABSTRACT

Waste management is a continuous global need. To minimize problems arising from municipal solid waste (MSW) disposal, composting has emerged as a simple alternative for the organic fraction of the waste. The composting process generates organic composts with a high metal retention capacity for potentially toxic elements (PTE). Thus, our objective was to examine how different composting methods (windrow composting, wire mesh composting bin, and passively aerated static pile composting) affect the final product, and how the characteristics of the generated composts influence their adsorption capacity for the lead (Pb), zinc (Zn) and cadmium (Cd) elements from mining waste. Therefore, the physical and chemical properties of Brazilian composts were investigated, as well as their adsorption capacities, through batch equilibrium tests with Pb, Zn and Cd in single-element solutions. All composts revealed promising adsorption characteristics, including a near-neutral pH (6.4–7.7); a negative ΔpH (−0.4 to −1.0); oxidizing conditions (Eh between +267.67 and + 347.00 mV); a considerable presence of organic matter (193.92–418.70 g kg^{-1}); a substantial (albeit very varied) cation exchange capacity (29.00–75.00 $cmol_c$ kg^{-1}); and significant porosity (pore volume between 0.01113 and 0.05400 cm^3 g^{-1}). These results showed that the composts share similar intrinsic characteristics, indicating that the different composting methods influenced subtly the physical and chemical properties of the final products. Overall, the removal selectivity follows the order Pb > Cd > Zn, with the removal percentage ranging from 94.0 to 99.6% for Pb, 55.4–89.8% for Cd and 22.1–64.0% for Zn. Thus, the joint assessment of the characterization and adsorption results shows evidence that composts, a low-cost organic material produced from waste, may be promising as alternative reactive materials for remediation of soils contaminated by Pb, Zn and Cd.

1. Introduction

Waste, water and energy management are key issues for municipal administrations. In fact, globally, MSW is a growing cause for concern as the human population continues to expand, increasing consumption levels and the subsequent need for waste disposal (Leal Filho et al., 2016). Global MSW generation amounts to almost 1.3 billion tonnes per year, with an expected increase to approximately 2.2 billion tonnes per year by 2025. This represents an increase in the global waste generation rate per capita from 1.20 to 1.42 kg per person per day in the coming years. However, it is important to note that these are global averages and that rates vary considerably depending on the region, country, city, and even within cities (Hoornweg and Bhada-Tata, 2012).

Regarding the composition of MSW, the typology of the wastes and their respective percentages of occurrence are affected by factors such as culture, economic development, climate, and energy sources. At the global level, the organic fraction constitutes the largest portion of solid waste (46%), followed by paper (17%), plastic (10%), glass (5%), metal (4%), and other wastes (18%). Considering the economic factor, the MSW composition in developing countries consists mostly of organic waste, whereas in developed countries, the largest proportion consists of paper, plastic and other inorganic materials.

In Brazil, 51.4% of the originated and collected MSW corresponds to the organic fraction (IPEA, 2012). Considering Brazilian legislation, especially the National Solid Waste Policy (PNRS), established by Law 12,305 on August 2nd, 2010 and regulated by Decree 7404 on December 23, 2010 (Brasil, 2010a; 2010b), it is necessary to promote environmentally friendly solid waste management by municipalities.

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The simplicity and the rapid and easy implementation of composting technologies may provide a highly viable management alternative for the organic fraction of MSW, especially when considering the characteristics and limitations of developing countries such as Brazil. Moreover, considering a life cycle inventory assessment in which waste disposal is a key component, composting can be regarded as a biological treatment requiring less economic resources compared to other options that would demand higher implementation and maintenance costs (Thanh and Matsui, 2012; Jara-Samaniego et al., 2017).

Therefore, what was originally used as a simple, small-scale process through so-called "yard composting" has received renewed interest over the past two decades and is now seen as a way to address present challenges in waste management. In particular, composting can serve as an alternative for decreasing the amount of organic matter sent to landfills, with a subsequent reduction in greenhouse gas emissions (Saveyn and Eder, 2014; Cerda et al., 2017; Jara-Samaniego et al., 2017) and increase in the service life of landfills.

From a systematic perspective, the effectiveness of composting depends on management of many factors, such as temperature, oxygen (aeration), moisture content, pH, the C/N ratio and porosity (FAO, 2003; EPA, 2016; Cerda et al., 2017; Onwosi et al., 2017). To this end, several technologies and composting systems have been deployed (Kumar, 2011; EPA, 2016). This includes traditional methods, such as windrow - the most commonly used aerobic digestion technique for the biodegradable fraction (De Bertoldi et al., 1982; Ishii and Takii, 2003; Vigneswaran et al., 2016; De Silva and Yatawara, 2017) and static piles – with or without passive aeration (Vigneswaran et al., 2016), up to the modern in-vessel composting reactors (Wang et al., 2016; Waqas et al., 2018). To optimize the composting of household organic waste, there should be an assessment of other systems, such as a wire mesh composting bin (Karnchanawong and Suriyanon, 2011; Karnchanawong and Nissaikla, 2014).

In recent years, research has been conducted and new technologies have been developed to obtain highly pure composts (Saveyn and Eder, 2014) with guaranteed maturity (Li et al., 2015), higher nutrient and lower PTE contents (Saha et al., 2010; Huerta-Pujol et al., 2011; Hoornweg and Bhada-Tata, 2012; Sharifi and Renella, 2015). Studies have shown the possibility of optimizing of composting using biochar (Vandecasteele et al., 2016; Waqas et al., 2018), microbial inoculation (Karnchanawong and Nissaikla, 2014; Onwosi et al., 2017) and that earthworm activity can effectively destroy bacterial pathogens in vermicomposting (Soobhany, 2018).

The main use of compost is as an organic fertilizer, favouring the growth and development of plants; this is a way of adding value to this material and can also be regarded as an environmentally friendly solution by minimizing the need for chemical applications (Lelis and Pereira Neto, 1999; Kiehl, 2004; Mehta et al., 2014). Data from the Brazilian Association of Fertilizer Diffusion (ANDA) shows that Brazil – a worldwide agribusiness power – imported over 70% of the fertilizers sold nationally in 2016. Hence, although using organic fertilizers does not quench the demand for mineral fertilizers in a conventional agriculture context, composting may be an option for reduction and diversification. Indirectly, the increase in the amounts of compost added to the soil possibly increased its pH, which can be agriculturally interesting because acidic soils are predominant in most of Brazil (Jordão et al., 2006).

Nonetheless, beyond the classic agricultural use, organic composts may also be regarded as reactive materials with a high PTE adsorption potential, stemming from the large presence of humic substances (Farrell et al., 2010; Zhou et al., 2017), favouring its use in the treatment of industrial wastewater (Kocasoy and Güvener, 2009) and in the remediation of metal-contaminated soils (Farrell et al., 2010; Farrell and Jones, 2010a; Paradelo and Barral, 2012; Venegas et al., 2015; Simantiraki and Gidarakos, 2015; Zhou et al., 2017). Abad-Valle et al. (2017) indicated that the compost derived from MSW was the most efficient remediator of polluted mine soil (containing high concentrations of Zn and Cd). This amendment decreased mobile PTE contents, with the restoration of soil chemistry and microbiota. This possibility represents the combined management of two different types of solid waste: organic municipal solid waste, used as the input for compost generation, and mining waste, containing considerable concentrations of metals that should be immobilized by organic composts. This combined management has not been widely studied, justifying the present research.

Therefore, the objectives of this study are (1) to characterize Brazilian organic composts originating from different composting methods (physical, chemical, physicochemical, morphological and elemental experimental analysis), as the standards regulating the characterization of composts are usually limited to agricultural activity, making it sometimes necessary to adjust existing regulations for soils and peats (organic materials); (2) to evaluate the potential of using these composts as low-cost reactive materials in metal cation immobilization, through batch equilibrium tests (with Pb, Zn and Cd); and (3) to jointly assess the characterization and adsorption results to support decision-making when evaluating the potential applicability of said composts for the remediation of PTE-contaminated regions (in this case, Pb, Zn and Cd), aimed at stability and equilibrium in the short- and long-term.

2. Materials and methods

2.1. Sample preparation

The organic composts used herein were synthesized at mid-scale and under environmental conditions from the organic fraction of the solid waste from the campus restaurant of the São Carlos School of Engineering, University of São Paulo (Brazil), via different composting methods: windrow composting, wire mesh composting bin, and passively aerated static pile composting. These methods were adapted to the study scale.

Windrow composting is a procedure based on overlaying organic fraction layers in a quadrangular format over branches, leaves, sawdust, or even matured compost, placed at the base of the compost pile. The organic residues are deposited in the centre, and dry matter is placed on the lateral and upper surfaces.

Wire mesh composting bin involves filling a vertical cylindrical wire mesh structure using, once again, twigs (in this case, pineapple crowns) as the base to avoid direct contact with the soil. In this pile, the organic residue must be deposited on the inside of the wire mesh structure, and the inner side must be covered with straw, preventing the contact of waste with the exterior. The vertical setup allows for better aeration, as air circulates with greater ease through the compost mass.

Passively aerated static pile composting is based on an overlay system, with the organic residue being placed at the base, directly over the soil. Each layer of residue must be covered with dry matter, and a new waste mass is added on top of the previous layer of straw and must be covered with a new straw layer.

The composting process occurred between the last week of March and the second week of June 2016. The effect of the composting system on the final product was assessed via three heaps – one per composting method – containing pre-preparation organic waste from the campus restaurant (peels, stalks and raw vegetables). The resulting composts were referred to as the windrow compost (WC), wire mesh compost (MC), and static compost (SC).

In addition to these three composts, a fourth pile consisting of pre-preparation and leftover cooked food organic waste (e.g., rice, beans and, rarely, meats) was also managed. This compost also followed the windrow method and was termed the total compost (TC). It was used to comparatively evaluate the effect of input materials on the final composts. Storino et al. (2016) state that for effective management of organic waste via domestic composting, it is essential that more types of waste be processed, including those of animal origin. Thus, composting,