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Research article

Study of factors involved in the gravimetric separation process to treat soil contaminated by municipal solid waste

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ABSTRACT

The current research investigated the effectiveness of a gravimetric process (shaking table) to treat soil contaminated by municipal solid waste. A detailed characterization of the inorganic pollutants was performed, followed by concentrating the metals within smaller volumes using the shaking table technology. The densimetric examination of the 1–2 mm and 0.250–1 mm fractions of the contaminated soil showed that lead (Pb), copper (Cu), and tin (Sn) were mostly concentrated in the heavy fraction (metal removals > 50%). Scanning electron microscopy coupled with elemental analysis indicated the relevance of using gravimetric processes to treat this soil sample. The influence of shaking table parameters was determined using a Box–Behnken design. The tilt and washing water flow demonstrated significant effects on the motion of the 1–2 mm soil fraction and on the removal of Pb, Cu, and Sn. The results obtained under the optimal settings of the shaking table defined using the Box–Behnken methodology when treating the 1–2 mm fraction were close to those obtained when using dense media separation. The recovered mass of the concentrate was approximately 20.8% ($w.w^{-1}$) of the total mass. The removals of Pb, Cu, and Sn were estimated to be 67.3%, 54.5% and 54.6% respectively. The predicted and experimental mass distributions of the medium (1–2 mm) and fine-sized (0.250–1 mm) particles were compared successively under some selected conditions. The mass distribution of both fractions showed similar tendencies in response to the forces applied by each condition. However, lowering the forces induced by the bumping action and the flowing film was recommended so as to efficiently treat the fine fraction (0.250–1 mm). The recovered mass of the concentrate (10%) was slightly lower than that obtained by dense media separation (13%). However, satisfactory removal yields were obtained for Pb, Cu, and Sn (42.7%, 23.6%, and 35% respectively).

1. Introduction

Industrial expansion and population growth densities led to the establishment of municipal solid waste management strategies (Collett et al., 1998). Waste combustion is commonly used to reduce the total volume of solid waste that should be disposed of by 80–90% (Prasad and Shih, 2016). The first such device was developed in England in 1870. Thereafter, incinerators began to appear in many industrialized countries to treat domestic, commercial, and industrial solid wastes (Chandler et al., 1997). Prior to the Second World War, the absence of serious environmental regulations promoted the discharge of toxic chemicals and ashes into the environment (Santoleri et al., 2000). Therefore, the inadequate management of waste has contributed to the contamination of urban soils (Hutton et al., 1988; Thornton, 2009). The contamination of soil by metals presents a potential risk for the exposed population and fauna (Olawoyin et al., 2012). The management of contaminated sites has become of a major concern in developed countries. Remediation technologies available to treat sites contaminated by inorganic compounds are classified into physical, chemical and biological techniques. Rehabilitation costs involved are usually the major challenge defining the practical application of such remediation technologies (Khalid et al., 2017). Solidification/Stabilization is the most relevant technology and the most commonly used method to manage soil contaminated by inorganic compounds (Iskandar, 2000). It aims to reduce the mobility of the hazardous materials. In a second step, the contaminated soil is

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mixed with ordinary Portland cement to ensure a subsequent safe landfilling (Ucaroglu and Talinli, 2012). The costs related to the management range from $US190-248 m^{-3} of treated soil (FRTR, 2016). Solidification/stabilization technique requires the maintenance of the secured systems and is deemed to be an unsustainable treatment technology (Guemiza et al., 2017). Hence, alternative and environmentally friendly solutions are necessary to treat soil contaminated by metals. For instance, bioremediation is a simple and economical treatment solution which involves plants, microorganisms and organic amendments to detoxify/remove the inorganic compounds from soils. The effectiveness of the biological techniques depends generally on the bioavailability of metals in the soil and concerns low to moderate polluted mediums (Khalid et al., 2017; Park et al., 2011). In the other hand, soil washing uses physical and chemical approaches to extract effectively metals from soil (Benschoten et al., 1997). Chemical agents such as chelating agents, acids and salt chloride solution are used to transfer the metals from the soils into an aqueous solution (Guo et al., 2016; Yao et al., 2012). Mineral processing technologies, such as gravimetric separation, are frequently implemented to reduce the use of chemicals. Moreover, the volume of soil to be safely managed is considerably reduced, which decreases the operating costs of the decontamination process (ranging from $US70-187 m^{-3} of soil) (Dermont et al., 2008). Gravimetric processes are based on the motion of the soil particles in response to gravity and other forces, such as the resistance to the motion offered by the fluid. Specific gravity, weight, particle size, and shape are the key factors determining the effectiveness of the separation of contaminated particles from uncontaminated soil (Burt, 1999). A significant difference in the density between the soil particles and the particles bearing the inorganic contaminants is necessary to produce a satisfactory decontamination performance (Gosselin et al., 1999). Several works highlighted the suitability of gravimetric processes to efficiently decontaminate soils polluted by incinerator residues (Jobin et al., 2016a; Mercier et al., 2001). These studies reported high levels of Pb and Cu liberation degree according to a pollutant characterization of the municipal solid waste. According to these authors, iron oxides were widely or occasionally involved in the carrying phase of Sn, Cu, and Pb, indicating that gravimetric processes would be a very promising treatment option (Jobin et al., 2016b; Mercier et al., 2001). Unit operations such as soil sizing and attrition scrubbing are usually involved prior to gravimetric treatment. Indeed, the application of a shaking table to treat contaminated soil is restricted to medium and coarse fractions (0.063–2 mm). Finer and coarser particles undergo further treatment such as chemical extraction or other physical treatments (flotation, jig, and magnetic separators, among others) (Dermont et al., 2008). Among the gravimetric processes, the most common equipment available to isolate these contaminated particles from uncontaminated soil are jigs, spirals, heavy-medium techniques, and shaking tables (USEPA, 1995). If used correctly, shaking tables demonstrate high selectivity and satisfactory metal recovery efficiencies, allowing the treatment of contaminated soil and mining ore. Particles introduced to the table are displaced by the forces of the washing water and the longitudinal stroke of the deck. Depending on the density of the particles, the stratification mechanism near the riffles of the deck is also involved in the concentration process. Hence, operational and design variables (characteristics of the deck) affect the treatment performance. Frequent operator attention and adjustment of the shaking table parameters are therefore needed to optimize the separation performance of contaminated particles from the uncontaminated fraction (Falconer, 2003). The principal operational parameters are the throughput of the solid, length and frequency of strokes, tilt of the deck, and water flow (Fitzpatrick et al., 2016). The shaking table has been used to treat a large range of soils, including those polluted by weapon ammunition, mining residues, slags or foundry residues, and municipal solid waste. The chemical and mineralogical heterogeneities of soils induce large variability in the observed performance. For instance, in the case of soils moderately contaminated by mining residues, the removal of Zn, Pb, and Cu ranged from 19% to 26%. The required adjustments to enhance the decontamination of these soils were defined as follows: 20° tilt, feed water flow of 3.5 L min^{-1}, washing water flow of 8 L min^{-1}, and feed pulp composition of 20% total solids (w·w^{-1}) (Veetil et al., 2014). For a soil highly contaminated by Pb, Zn, Cu, and Sb found in military shooting grounds, the removals ranged from 60% to 96% under a feed water flow of 3.5 L min^{-1}, a washing water flow of 8 L min^{-1}, and a pulp comprising 70% total solids (w·w^{-1}) (Laporte-Saumure et al., 2010). The research of Bisone et al. (2013) focused on the treatment of the 0.125–1 mm fraction of a soil contaminated by slags and foundry residues. These samples contained high levels of Cu and Zn. The tilt was adjusted to the maximum level. The principal and secondary water flows were fixed at 6 L min^{-1}, and 3.5 L min^{-1}, successively. The stroke frequency was adjusted to 360 Strokes min^{-1}. The shaking table treatment allowed the removal of 44–68% of Cu. The removal of Zn varied from 30 to 44%. In the case of a soil highly contaminated by municipal solid waste, the removals of Pb, Zn, Cu, Sn, and As ranged from 49% to 80% under an 11° tilt, a stroke frequency of 500 strokes·min^{-1}, a feed water flow of 5 L min^{-1}, a washing water flow of 5 L min^{-1}, and a solid throughput of 100 g min^{-1} (Jobin et al., 2015). Another study, which investigated the decontamination of soil polluted by municipal solid waste, reported that the removal yields of Pb, Zn, Cu, and Sn varied from 0 to 61.2%. The soil was dry fed and the optimal settings comprised a slope ratio ranging from 1:55–1:96, a stroke frequency of 500 strokes·min^{-1}, and a pulp composition of 10% total solids (w·w^{-1}) (Mercier, 2000; Mercier et al., 2001). Consequently, optimal settings vary according to the nature and/or the level of contamination. Modeling the mechanism of the shaking table can help to improve our understanding of the concentration process occurring during the treatment. Previous work investigated the possibility of modeling the performance of the shaking table to recover cassiterite from ore using the Box–Behnken response surface methodology. The statistical design was helpful for finding the optimal parameters of Sn recovery (Youssef et al., 2009).

Hence, a Box–Behnken design was used in the present study to evaluate the influence of operational parameters on the performance of the shaking table, which removed metals from soil contaminated by municipal solid waste. Moreover, the specific characteristics of the contamination and the operational settings involved in the separation process were investigated.

2. Material and methods

2.1. Feedstock treatment

Experiments were carried out with soil samples contaminated by municipal solid waste. More specifically, soil samples were collected from inorganic contaminated land, located in the site of Pointe au Lièvre in Quebec City (Canada). According to the history of the site, the contamination is old and mainly caused by the successive operation of two incinerators from 1939 until 1970. Samples were wet-sieved to produce several fractions, using a vibrating screen (Sweco™) and different sieves. Fractions ranging from 1 to 2 mm and 0.250–1 mm were generated. Then, these soil fractions were put through a scrubbing attrition step performed at 1500 rpm for a duration of 10 min with a solid-liquid ratio fixed at 30% (w·w^{-1}). Attrition disintegrates agglomerates and liberates particles from slim coatings, enhancing the performance of a gravimetric process train (Marino et al., 1997).