Effect of compost aging on zinc adsorption characteristics

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ARTICLE INFO

ABSTRACT

One approach to improving the performance of biofiltration based treatment systems is to amend filtration media with compost to improve metal sorption. The effect of aging these amended compost particles on zinc sorption is investigated using batch and column tests. Batch tests showed that aged compost had a lower rate of zinc sorption but a similar zinc sorption capacity compared with fresh compost. Pseudo-second-order kinetics was found to best fit the batch experimental data. The intra-particle diffusion plot shows that there are differences due to the effect of aging of compost and that intra-particle diffusion is the dominant rate controlling mechanism. Column studies show that aging the compost decreased the sorption capacity by 22% (from 16 mg g^{-1} to 13 mg g^{-1}). It is evident that aging compost media have an effect on the magnitude and kinetics of zinc adsorption. This was also evidenced in the decreased CEC and peak intensities of relevant spectra in the FTIR of the aged compost.

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Introduction

Water Sensitive Urban Design (WSUD) emphasises a more decentralised approach of stormwater treatment systems and often utilise biofiltration media amended with compost. Sorption of heavy metals by woody biofiltration materials (e.g. compost, mulch) wastewater and stormwater treatment has been reported in the literature [1,2].

Woody materials are naturally rich in organic matter and it is well documented that organic matter in soil plays a key role in heavy metal adsorption [3,4]. Structurally the organic matter contains different organic functional groups including carboxyl, carbonyl, phenyl hydroxyl, amino, imidazole, sulfhydryl, and sulfonic groups. These groups provide a wide range of reactive surfaces that are able to bond with heavy metals.

Aging is a natural process where woody amended materials within an operating biofiltration system is subject to a performance change through time or with use, as a result of the degradation processes of the woody amendments. Biofilters are designed to operate over long time periods using woody materials as an amendment. However these woody materials are dynamic and it is a well-known phenomenon [5–7] that the physicochemical properties of woody materials will change with time under different operational conditions. Aging of woody biofiltration

materials may cause leaching of organic matter and therefore change their physicochemical properties and consequently affect their performance for the removal of heavy metals. The effect of aging these materials on metal sorption is not taken into account in the design of field-based treatment systems and has not been widely studied. Sciban and Klasnja [8] found that leaching organic matter does not impact the adsorption of heavy metal ions by woody adsorbents using batch experiments. Another study under high flow conditions using different sizes of compost media have shown the leaching DOC from columns does not stop the metal sorption [9]. Conversely pesticide sorption was found to be affected by aging [10]. It is clear from these studies that there is a crucial need to understand the effect of the aging process (such as long term organic leaching) of woody biofiltration materials on heavy metal sorption.

The goals of this paper are to determine the impact of accelerated aging of compost on zinc sorption from an aqueous solution using batch and column experiments. Various kinetic models, namely the pseudo-first-order, pseudo-second-order and intra-particle diffusion were used to evaluate the adsorption kinetics. It is expected this study will be useful to other researchers and engineers seeking knowledge about the influence of aging on the treatment performance of compost biofiltration amendments.

Experimental methodology

Materials

The compost (Composted Leaf mulch, Australian Native Landscapes) was compliant with AS4454 and consisted of a screened

composted mulch (nominally 10–35 mm) sourced from garden organics. Garden organics includes putrescible garden organics (grass clippings); non-woody garden organics; woody garden organics; trees and limbs; stumps and root balls. The compost was dried at 45 °C for 48 h and then ground using a hammer mill until the required particle size range was obtained. The particle size of compost is 1.18 mm which passed through a 2.36 mm sieve but was retained over a 1.18 mm mesh sieve.

Aging of the compost

To simulate and accelerate the aging process, the compost samples were leached with Milli-Q water using 24 h sequential batch leaching as described in McLaughlan and Al-Mashaqbeh [11]. This sequential batch leaching procedure was repeated every 24 h for 19 days until the DOC of the leachate water had reached a steady-state of DOC release with concentrations below 20 mg L^{-1}. Sample leaching beyond 19 days was expected to have minimal benefit in terms of reducing the leachable DOC content of the compost. All the leached compost samples were subsequently dried at 45 °C for 48 h prior to use (referred to as aged compost).

Analytical methods

All water samples were measured for electrical conductivity (EC) and pH (TPS WP-81). Samples were filtered with a 0.45 μm cellulose membrane filter and preserved by acidifying to pH < 2 using 1 N HNO$_3$ [12]. The preserved samples were analysed for zinc concentrations using Atomic absorption spectrometry (GBC AAS932, air/acetylene flame). All plastic and glassware in contact with samples were acid washed for 24 h with 0.1 M HNO$_3$ and rinsed with Milli-Q water, unless otherwise noted. Cation Exchange Capacity (CEC) of different adsorbents was measured using saturated ammonium extractants at pH 7 [13]. Compost particle structure characteristics (specific surface areas, pore volume and size) were measured by Particle Analysis Service, CSIRO using BET/N$_2$ (Micromeritics Tristar 3000). Lignin, cellulose, and hemicellulose were determined also in the Wagga Wagga Feed Quality Testing Laboratory (Department of Primary Industries, NSW). Total carbon and nitrogen for all solid materials were determined in duplicate using a TruSpec Carbon Nitrogen Determinator. Ash content was measured using the method for Total Volatile Solids at 550 °C [12].

Fourier transforms infrared analysis (FTIR)

In order to determine which functional groups were responsible for metal sorption, the FTIR spectra of the compost and aged samples were recorded using a KBr disk in conjunction with a Perkin-Elmer infrared spectrophotometer having a resolution of 4 cm^{-1} and range between 4000 and 400 cm^{-1}. Duplicate KBr disks were prepared by mixing 0.003 g of compost and 0.005 g of aged compost dried sample with 0.25 g KBr crystals, the resulting mixture being ground to a fine powder. Finally, the mixture was pressed into a KBr disk and used as such for FTIR studies.

Sequential batch sorption test

The kinetics experiments used a sequential batch extraction methodology [14]. One gram of the specified size of compost was added to 2 L glass bottles filled with a solution of zinc (5 mg L^{-1}). The vessels were shaken on an orbital shaker at 200 rpm for 120 h. Samples (10 mL) were withdrawn at predetermined time intervals and analysed for zinc. The total volume of all withdrawn samples was 60 mL which had minimal effect on the liquid–solid ratio (decreased from 2000:1 to 1940:1). The initial pH for each vessel

was initially set to 5.5 but was not adjusted during the sorption period and was measured immediately prior to each sampling event. Blank experiments with zinc solution without sorbent were carried out to check possible losses of the examined metal. All the sorption experiments were carried out at laboratory temperature 20 ± 1 °C.

All the batch experiments were carried out in duplicate and the results given as an average. Metal sorption at different times was calculated using the mass balance between the solid and the solution as follows:

$$q_t = (C_0 - C_t)\frac{V}{M} \qquad (1)$$

where q_t the amount of metal ion adsorbed at time t (mg g^{-1}), C_t is the liquid phase metal ion concentration at time t (mg L^{-1}), C_0 the initial liquid phase metal ion concentration (mg L^{-1}), V the initial solution volume (L) and M is the mass of sorbent (g). All sorption tests were performed in duplicates and the standard deviation values of duplicate samples were less than 1.

Column specification and sorption/desorption test

The columns were constructed in PVC class 18 with an inner diameter of 5.3 cm and a length of 58 cm, giving a cross-sectional area for filtration of 22 cm^2. Since the ratio of column diameter to median particle diameter is high, the effects of channelling are expected to be negligible [15]. Columns were constructed by sealing a PVC cap at the end of the column using Silastic. A layer of plastic mesh and then a 2–3 cm depth of 3 mm diameter glass beads was placed upon the end cap at the influent end of the column. A plastic mesh was placed over the glass beads to support the filtration media. Both columns had a mix of 68 g of 1.18 mm compost and aged compost with 1663 g of 0.6 mm glass beads (≈20–25%, v/v compost). The mix was wetted and then added in increments using continuous column vibration without any compaction over the filtration media surface [16]. The final depth of filtration media in the columns was approximately 55 cm with a total bulk density of 1.5 g cm^{-3}. The sorption columns were initially saturated with distilled water for 2 h, then zinc solution (∼5 mg L^{-1}) was pumped using peristaltic pump (Masterflex Model 7553-85) from a 45 L PVC container into the column in up flow mode. The average flow rate was approximately ∼12 mL min^{-1}. Influent and effluent samples were taken at different time intervals and analysed for EC and pH. Samples (40 mL) were filtered with a 0.45 μm cellulose membrane filter and preserved by acidifying to pH < 2 using 1 N HNO$_3$ [12]. All glassware in contact with samples was acid washed for 24 h with 0.1 M HNO$_3$ and rinsed with Milli-Q water. Zinc chloride was added to distilled water to form the zinc effluent with pH adjustment using dilute HCl and NaOH solutions. Metal salt and other reagents used were all of analytical grade.

To determine the reversibility of the sorbed metal to clean water during actual operation in the field, once the zinc effluent concentration matched the influent concentration (5 mg L^{-1}), a desorption cycle was started using distilled water (pH of 5.5, EC < 3.5) at a similar flow rate (∼12 mL min^{-1}). The column sorption experiments were continuously carried out for three weeks with an influent (5 mg L^{-1}) of zinc solution with a pH ∼ 5.0 to prevent zinc hydroxide precipitation. The performance of a filtration based treatment system for removing dissolved contaminants is often evaluated through the use of a breakthrough curve. The zinc breakthrough curve for a column is determined by plotting as the ratio of effluent zinc concentration (C) to inlet zinc concentration (C_0) against either elapsed time, effluent volume or pore volume for a given filtration bed height. The maximum sorption capacity of zinc onto compost and aged compost in the