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Effective use of iron-aluminum rich laterite based soil mixture for treatment of landfill leachate

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ABSTRACT

Landfill leachate poses environmental threats worldwide and causes severe issues on adjacent water bodies and soil by direct discharge. The primary objective of this study is to analyze the efficient use of compost and laterite mixtures (0, 10, 20, 30 and 40 wt% compost/laterite) on leachate treatment and to investigate the associated removal efficiencies under different sorption processes. Therefore, in the experimental design, laterite is used for providing adsorption characteristics, and compost for activating biological properties of the filter. The filtering process is continued until major physical changes occur in the filter at approximately 100 days. The raw leachate used for the experiment shows higher average values for many analyzed parameters. Parameters for the experiment are selected based on their availability in raw leachate in the Sri Lanka. During filtering, removal efficiencies of BOD (>90%), COD (>85%), phosphate (>90%) and nitrate (75–95%) show higher values for all filters. These removals are mainly associated with biodegradation, which is activated by the added compost. Perhaps the removal of nitrate steadily increases with time, which indicates in denitrification by the added excess carbon from the leachate. The removal of total suspended solids (TSS) is moderate to high, but conversely, the electric conductivity (EC) is unsteady, indicating an association between iron exchange and carbonate degradation. A very high removal efficiency is reported in Fe (90–100%), and wide ranges of efficiencies in Mn (30–90%), Cu (45–85%), Ni (30–93%), Cd (37–98%), Zn (15–98%), and Pb (35–98%) involve heterogeneous sorption processes. Furthermore, the normalization of raw leachate by the liquid filtrate has apparent improvements. The differences ($p > .05$) in removal efficiencies between the filters are significant. It can be concluded that the filter with laterite mixed with 20% of compost has the optimum conditions. Further, the Fourier-transform infrared (FT-IR) models for filter media conclude multiple sorptions and reveal evidence on vacant sites. X-ray diffraction (XRD) analyses indicate secondary minerals gibbsite, hematite, goethite and kaolinite as the major minerals that involved on the sorption process.

1. Introduction

Municipal solid waste (MSW) is a major controversial issue worldwide (Karak et al., 2012; Pellera et al., 2016). New trends in living standards, population growth and economic developments are the major causes of rapid generation of MSW (Renou et al., 2008; Karak et al., 2012; Pellera et al., 2016). The solid waste landfill is known as more economical disposal method than incineration and composting (Renou et al., 2008; Pellera et al., 2016). Most developed countries use sanitary landfills. However, non-engineered disposal methods are common throughout the world (Trankler et al., 2005; Wijesekara et al., 2014).

Leachate is generated in landfills by their internal chemical and biological processes, rain water percolating through the waste and higher moisture level, as well as and liquid release by the reactions (Rivas et al., 2004; Renou et al., 2008). The heterogeneous compositions in leachates depend on the nature of the landfill (Lema et al., 1988; Rivas et al., 2004), age of waste (Chian and DeWalle, 1976; Kulikowska and Klimiuk, 2008; Abbas et al., 2009), climate (Chen, 1996), degree of compaction (Lema et al., 1988; Abbas et al., 2009), waste type and particle size (Lema et al., 1988; Renou et al., 2008). In addition, subsurface lithology and landfill technology have severe impacts on the composition and mobility of leachate (Christensen et al., 2001; Renou et al., 2008).

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Open landfilling is a popular method for disposing of MSW in developing countries, such as Sri Lanka. These sites are not properly managed, due to technological barriers and over-dumping (Basnayake et al., 2008; Hettiaratchi et al., 2010; Sewwandi et al., 2013; Wijesekara et al., 2014). Untreated leachate poses severe threats, especially in open landfills located in sensitive areas, such as forest margins, roadsides, mangroves, and river catchments (Slack et al., 2005; Hettiaratchi et al., 2010). This leads to several acute and chronic health problems. Eutrophication is also a common phenomenon in surrounding waters (Bandara and Hettiaratchi, 2010; Wijesekara et al., 2014). Apparently, a proper leachate treatment system is a primary need for landfills, particularly in developing countries. Natural clay layers in the weathering profile around landfill sites act as a barrier for leachate mobility (Regadío et al., 2015), which give clues for the use of clay on leachate treatments. Many countries have different treatment systems that are found to be unrealistic, due to the high costs involved (Abbas et al., 2009). Thus, a cost-effective technique has a higher demand.

Filtering of leachate is considered one of the most popular methods (Madhukar et al., 2012). Cost- and time-effective sorption techniques are used for leachate filtering (Chen et al., 2007b). However, complex constitutes in leachates have comprehensive chemical and physical properties (Kulikowska and Klimiuk, 2008). Therefore, a single sorption material does not provide optimum conditions. Hence, it is necessary to use a few sorption materials together that have different properties (Svensson et al., 2011: Harlina et al., 2016). For instance, clay minerals adsorb cations to the surface; however, some univalent cations can only absorb in a few types of clay. Conversely, biodegradation should be activated by adding compost to control the redox condition and pH, as well as for the sorption of some anions.

Iron- and aluminum-rich laterite is a common soil type, which is mainly available in tropical countries under wet climate (Oliveira et al., 1992; Thorne et al., 2012). Laterite is considered to have better sorption characteristics of contaminants (Madhukar et al., 2012). Hence, laterite has been used as an effective filter media for contaminated water (Kadam et al., 2009), but it has limited applications in landfill leachate treatments (Syafalni et al., 2012; Harlina et al., 2016). This is mainly because the sorption nature of laterite is inappropriate to filter the complex constituents. To improve the biological properties in laterite, biofiltering should be activated; thus, compost can be used as an enrichment media (Gibert et al., 2003; Rose et al., 2012). The added compost can stimulate microbial activities, thereby improving the filter performance (Jurado et al., 2015). The low-density compost helps to increase the retention time of leachate in the filter media by becoming spongy in nature (Rose et al., 2012). Additionally, the mixed filter materials provide steady conditions for filtering, rather than layer-driven filters, by mitigating the handling and operational efforts (Svensson et al., 2011). Therefore, the scope of this study is to develop laterite and compost mixed materials as a filter medium to remove different constituents produced by landfill leachate. The main objectives are to explore an effective leachate filtering system and to investigate the affiliated sorption processes, biodegradation and removal efficiencies.

2. Materials and method

2.1. Material collection

2.1.1. Laterite and compost sample collection

Laterite soils available in the wet zone of Sri Lanka are extensively developed by in situ weathering of metamorphic rocks (Dahanayake, 1982). Laterite contains large amounts of aluminum, iron, and manganese, with the depletion of free silica and very little or no alkaline. In this experiment, hard laterites acted as the major filter media. Composite laterite samples were collected by auger drilling to homogenize the material. The required compost for the enrichment material was gathered from a standard compost production plant (Tyrrel et al., 2008). Samples were stored in 4 °C cooling boxes, and physicochemical parameters were immediately analyzed (Jayawardana et al., 2012).

2.1.2. Collection of leachate sample

Leachates were gathered from an open active dumping site in Karadiyana, Colombo, Sri Lanka. The total area of the site is approximately 25 acres. Approximately 575 tons of MSW were received daily from 7 local authorities. The samples were collected into 2 L polypropylene bottles on a weekly basis and stored in 4 °C cooling boxes. The basic physicochemical parameters of leachate were immediately tested (Sewwandi et al., 2013).

2.2. Physico-chemical analyses of laterite and compost

The pH of the soil suspension solutions (1: 2.5 = soil: water) and compost were taken using WTW ProfiLine pH 3110 pH/mV meter with ±0.005 variance. The oxidation redox potentials (ORP) of the soil and compost samples were also measured, with SenTix® ORP electrode with ±0.3 mV variance. The ORP and pH values were measured by means of wet sediment analyses method. In the analyses, suspension samples were used to maintain the soil and compost slurry in homogeneity. The conductivity of soil samples was measured using WTW ProfiLine cond3210 conductivity meter with ±0.5% variance of measured value. Moisture content of laterite and compost were measured by direct percentage weight difference method (1):

$$\text{Moisture content} = \frac{W_{wet} - W_{dry}}{W_{wet}} \times 100 \qquad (1)$$

where W_{wet} is initial weight of sample and W_{dry} is the dried sample at 105 °C until the samples reached constant weights.

A loss on ignition (LOI) test helped to estimate the organic matter and inorganic carbon contents in laterite (Wang et al., 2011). A split of the sample was ignited at 450 °C for 24 h to determine the organic matter content, and it was further ignited to 1050 °C for 2 h to estimate the carbonate content. The Walkley-Black wet oxidation technique helped to determine the total organic carbon of laterite and compost (Walkley and Black, 1934).

The laterite and compost samples were analyzed for available major and trace elements by X-ray fluorescence spectrometry, using the Rigaku NEX CG EDXRF analyzer. Splits of each sample were oven-dried for 48 h at 160 °C. Powdered samples (<63 μm) were compressed into briquettes under a force of 200 kN for 60 s. The briquettes were then analyzed for selected major oxides and trace elements. The average error for these elements is less than ±10% relative. The available phosphorus of soil was determined by a spectrophotometer (CECIL CE 1021 series) using sulfomolybdic acid reagents. The total nitrogen content of the compost sample was measured by the Kjeldahl method.

2.3. Filter material preparation and experimental design

The flowchart on the experimental design is presented in Fig. 1. Laterite and compost were air dried for 24 h to remove the moisture and crushed using an agate mortar and pestle. The ground materials were sieved using 0.5 mm and 0.2 mm US standard sieves for compost and laterite, respectively (Kettler et al., 2001; Chen and Wang, 1997). Laterite was uniformly mixed with compost using a mechanical shaker to properly blend the materials while maintaining the compost to laterite weight ratio of 10:90