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Characteristics of geotextile clogging in MSW landfills co-disposed with MSWI bottom ash

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ABSTRACT

As a main byproduct of municipal solid waste incineration (MSWI), bottom ash (BA) has become a big challenge in operating MSWI plants. The most common method for BA treatment is co-disposal with MSW in landfills, which may cause clogging in the leachate collection system (LCS). This research investigated the characteristics of geotextile clogging in landfills with BA co-disposal. The co-disposal of BA changed the characteristics of leachate, especially increasing the concentration of Ca^{2+}. During the experiment, 0.14 g $CaCO_3$ was precipitated in the MSW geotextile, while it increased to 0.52 g $CaCO_3$ in the BA co-disposed geotextile. Based on mass balance of calcium and thermogravimetric (TG) analysis, the formation of biofilm was the main contributor to the mass increment, accounting for about 82% and 57% mass increment in the MSW and BA co-disposed geotextile, respectively. Moreover, CO_2 in landfill gas played an important role in the clogging process, including $CaCO_3$ precipitation and biofilm formation. The results suggested that the co-disposal of BA with MSW can increase the risk of geotextile clogging in landfills.

1. Introduction

Managing of bottom ash (BA) from municipal solid waste incineration (MSWI) plants has become a big environmental issue in recent years. Over the last decade, more and more MSWI plants have been constructed in China. There were 220 MSWI plants in China with a total treatment capacity of 219,080 $t{\cdot}d^{-1}$ in 2015, and the waste incineration rate increased from less than 3% to 25% during 2003–2015 (National Bureau of Statistics of China, 2016). As a result, a large amount of incineration bottom ash (BA) was produced annually (Su et al., 2013; Xia et al., 2017). Although BA can be reused as a construction material, there is a lack of market demand due to economic reasons. The most common method for BA treatment is co-disposal with MSW in landfills (Lo, 2005; Xia et al., 2015; Yao et al., 2013). A large amount of BA has been used as daily cover materials, and leachate drainage materials in MSW landfills (Lo, 2005).

Research has been conducted to investigate the environmental impact of BA co-disposal in landfills, mainly focused on leaching characteristics of heavy metals, such as Cu and Zn (Boni et al., 2007; Lo, 2005; Su et al., 2013; Yao et al., 2017). However, few studies have addressed the potential clogging problem resulting from co-disposed BA. Clogging of leachate collection system (LCS) is a common phenomenon in landfills (Bazienė et al., 2012; Beaven et al.,2013; Kuscu et al.,2013; Maliva et al., 2000; McIsaac and Rowe, 2008; Rowe and Yu, 2012; Stibinger, 2017). LCS clogging can cause leachate mounding on the landfill liner resulting in increasing leachate seepage from covers and leakage through the bottom liner (Rowe and Yu, 2012). LCS clogging reduces not only the efficiency of landfill gas collection but also shear strength of waste which, in turn, increases the risk of landfill slope failure (Xu et al., 2012; Yu, 2012). Field investigations and characterization of clogging materials showed that the major chemical component of clogging was calcium carbonate ($CaCO_3$) (Bazienė et al., 2012; Cardoso et al., 2008; Fleming et al., 1999; Maliva et al., 2000; Vangulck et al., 2003; VanGulck and Rowe, 2004). As a mineral assemblage, BA contains a considerable amount of calcium (Ca). With the co-disposed BA, more Ca^{2+} can be leached out and thus increase the risk of LCS clogging. Xia et al. (2015) investigated the leaching characteristics of calcium-based compounds and MSWI BA, and concluded that co-disposed BA in MSW landfill increased the clogging risk of LCS (Xia et al., 2015).

Geotextiles have been extensively used as a filter of LCS to minimize the movement of particulates (silts and fine sands) into the drainage system. Research showed that geotextile clogging

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occurred under different conditions (Fleming and Rowe, 2004; Junqueira et al., 2006; McIsaac and Rowe, 2006; Palmeira et al., 2008). McIsaac and Rowe (2006) reported that chemical clogging on a nonwoven geotextile caused a reduction of hydraulic conductivity by about 90% (McIsaac and Rowe, 2006). However, geotextile clogging is a result of various fouling mechanisms, including physical sediment (deposition of suspended solids), chemical precipitate (precipitation of minerals), and biological clogging (growth of biomass) (Paksy.A et al., 1998; VanGulck and Rowe, 2004; Rowe and Yu, 2012; Yu and Rowe, 2012, 2013; Rowe and Yu, 2013a, 2013b, 2013c). Palmeira et al. (2008) observed a significant decrease of geotextile permeability caused by biological clogging (Palmeira et al., 2008). Miszkowska et al. (2017) presented the changes of water permeability characteristics due to clogging and cyclic water flow. Most studies on LCS clogging were conducted under MSW landfill conditions but few studies addressed the potential geotextile clogging caused by co-disposed BA (Xia et al., 2015).

With the increased prevalence of waste incineration and co-disposed BA in landfills, it is critical to understand the characteristics of geotextile clogging for the design of effective LCS. The objective of this research was to investigate the effects of co-disposed BA on clogging of nonwoven geotextile. Laboratory experiments were conducted to examine the characteristics of geotextile clogging under simulated landfill conditions. The results provide insight into the characteristics of geotextile clogging, which might be used by engineers to design a more efficient LCS in MSW landfills with BA co-disposal.

2. Materials and methods

2.1. Bottom ash and leachate

Bottom ash used in the experiment was collected from an MSWI plant in Shenzhen, Guangdong Province, China. The plant, with an average MSW treatment capacity of 800 t·d^{-1}, consists of two furnaces together with one set of 12,000 kW power generation steam turbines. BA was sampled after water quenching and magnetic separation process. Crystal structures of the BA sample were characterized using X-ray diffraction (XRD) analysis. XRD result is presented in the Supplementary Materials (Fig. S1). Major oxides found in BA included CaO, SiO_2, Al_2O_3 and Fe_2O_3. Table 1 shows the elemental characteristics of the BA sample analyzed using the energy dispersive X-ray spectroscopy (EDX) (EDX-LE, Shimadzu, Japan). Calcium was dominant among the elements excluding oxygen, accounting for 55.4% by weight.

MSW leachate was collected from a lab-scale simulated MSW landfill column operated at 35 °C. The column was constructed using a 15-cm-diameter polyacrylic plastic pipe with a total height of 40 cm. In the simulated MSW landfill, a total of 1.125 kg synthetic waste was compacted, consisting of 65% food waste, 10% paper, 10% plastic, 10% sand and 5% other materials (metals and glasses). The MSW landfill column has been operated for 80 days and methane concentration in the outlet gas was 25.16%, when leachate was collected for the clogging experiment. To simulate leachate percolation through a thick BA layer, the collected MSW leachate was continuously recirculated 5 times through a small BA column which contained 125 g BA with a depth of 20 cm. Table 2 shows the characteristics of the MSW and BA co-disposed leachate.

Table 1
Elemental characteristics of bottom ash samples analyzed by EDX-LE.

Element	Percentage (%)
Ca	55.4
Si	9.1
Mg	5.6
S	3.7
Na	1.4
Mn	0.3
Fe	9.5
Zn	7.4
Al	4.3
K	2.2
Cu	0.8
Pb	0.3
Total	100.0

2.2. Experiment setup

As illustrated in Fig. 1, glass serum bottles with 310 mL volume were used as reactors to simulate conditions that geotextile contacted with leachate. Each reactor contained 40 mL leachate collected directly from the simulated MSW landfill or leachate contacted with BA. Before being added into the reactors, leachate was filtered through a 30-μm filter paper (Jiaojie, China) to remove suspended solids. A piece of nonwoven geotextile (5 cm diameter, mass per unit area of 200 g m^{-2}, Xiangtan, China) was immersed in the leachate in each reactor. In addition, deionized (DI) water (40 mL) was used in the control reactor. The reactors were flushed with synthetic landfill gas (50% CO_2 and 50% CH_4, v/v) for 2 min and then quickly sealed with a butyl rubber stopper and an aluminum crimp cap to ensure anaerobic conditions. Each reactor was then connected to a 200-mL gas bag filled with the synthetic landfill gas. All reactors were placed into an incubator operated at 35 °C.

2.3. Sampling and analysis

The experiment was conducted for 20 days to evaluate the change of geotextile characteristics. On days 10, 15, and 20, the geotextile was taken out for analysis, including mass measurement, permeability testing, scanning electron microscope (SEM) (Supra®55, Zeiss, Germany) and thermogravimetric (TG) analyses (TGA-50, Shimadzu, Japan). Geotextile samples were dried at 105 °C and measured by an analytical balance (AUW120D, Shimadzu, Japan). A permeability test was conducted using a ceramic Buchner funnel with a diameter of 50 mm. The geotextile was placed at the bottom of the Buchner funnel and was subjected to water flow with a constant head of 85 mm. The permeability of the geotextile was calculated as following:

$$P = \frac{V}{t \cdot A} \quad (1)$$

where P is the permeability of geotextile, m s^{-1}; V is the volume of water in a given time, m^3; A is the area of the geotextile, m^2. The quantity of water was recorded versus time and the permeability was determined using the average value of three measurements. TG analysis was conducted by heating the geotextile from room temperature to 1000 °C with a heating rate of 10 °C min^{-1} and an

Table 2
Comparison of leachate properties.

Properties	MSW leachate	BA co-disposed leachate
pH	6.09	8.56
COD (mg/L)	89,764	57,681
BOD_5/COD	0.63	0.51
Conductivity (ms/cm)	20.17	29.82
Ca^{2+} (mg/L)	5231	14,400
Mg^{2+} (mg/L)	98	102
SO_4^{2-} (mg/L)	1065	1346
Cl^- (mg/L)	543	733
TDS (mg/L)	10.09	14.91