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Impact of co-landfill proportion of bottom ash and municipal solid waste composition on the leachate characteristics during the acidogenesis phase

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ABSTRACT

Incineration has become an important municipal solid waste (MSW) treatment strategy, and generates a large amount of bottom ash (BA). Although some BA is reused, much BA and pretreatment residues from BA recycling are disposed in landfill. When BA and MSW are co-landfilled together, acid neutralization capacity and alkaline earth metal dissolution of BA, as well as different components of MSW may change environmental conditions within the landfill, so the degradation of organic matter and the physical and chemical properties of leachate would be affected. In this study, the effect of co-landfilled BA and MSW on the leachate characteristics during the hydrolysis and acidogenesis phase was studied using different BA/MSW ratios and MSW compositions. The results showed that the co-landfill system increased leachate pH, electric conductivity and alkalinity. For MSW with a high content of degradable components, the release and degradation of total organic carbon (TOC) and volatile fatty acids (VFA) from MSW were promoted when the BA ratio by wet weight was less than 50%, and the biodegradability of leachate was improved. When the BA ratio exceeded 50%, the degradation of organic matters was inhibited. For MSW with low content of degradable components, when the proportion of BA was less than 20%, the release and degradation of TOC and VFA from MSW were promoted and alkalinity increased. When the BA ratio exceeded 20%, the degradation of organic matters was inhibited. The 50% BA ratio could improve the biotreatability of leachate indicated by the leachate pH and C/N ratio. However, BA inhibited the release of nitrogen (TN and NH_4^+-N) at all BA ratios and MSW compositions. At the same time, the addition of BA increased the risk of leachate collection system clogging due to the dissolution and re-precipitation of alkaline earth metals contained in BA.

1. Introduction

Because of the significant reduction in volume and mass, incineration has become an important municipal solid waste (MSW) treatment strategy. For example, in China, MSW treated by incineration accounted for 32.3% of the amount collected in 2015 (National Bureau of Statistics of China, 2016). Thus, the generation of MSW incineration residues, including bottom ash (BA, 20–25% (Chandler et al., 1997) of incinerated MSW by mass) and fly ash (FA), is a problem to be addressed (Xia et al., 2017). BA is a mixture of slag, stone, glass, metals and ceramic debris (Ilyas et al., 2014). It can be used as aggregate or binder in roads, dams and landfill covers (Ilyas et al., 2014; Travar, 2009). However, landfilling is still the main disposal method for BA due to market fluctuations in building materials, competition from low-cost natural materials, and environmental problems of BA reuse. In addition, even if BA is recycled, there is still need to landfill a certain percentage of treatment residues. Therefore, disposal in landfill sites, including landfill cover is a common way of BA management. For instance, all BA is landfilled in Switzerland, 90% of BA is landfilled in the United States, and the ratio of landfilled BA is 80% in Italy and 48% in Norway (Kahle et al., 2015). In China, there are no national regulations or standards on

Abbreviations: MSW, municipal solid waste; BA, bottom ash; FA, fly ash; LCS, leachate collection system; ANC, acid neutralization capacity; TOC, total organic carbon; VFA, volatile fatty acid; TN, total nitrogen; NH_4^+-N, ammonia nitrogen; EC, electrical conductivity; ALK, alkalinity; TS, total solid; VS, volatile solid.

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the landfill of BA. In general, BA or the leftovers from BA pretreatment and utilization is co-landfilled with MSW.

Compared to raw MSW, BA contains a large amount of alkaline earth metal oxides and has strong acid neutralization capacity (ANC) of approximately 1.2–4.1 meq H^+/g (Chandler et al., 1997; Johnson et al., 1995). Studies have shown that pH and salinity are the main factors that affect the hydrolysis and acidogenesis of organic matter (He et al., 2006; Wang, 2015). Therefore, co-landfilled BA and MSW may influence the degradation behavior of MSW by changing the landfill environmental conditions, such as pH, salt composition and alkalinity. Some studies have shown that co-disposal of BA and MSW can increase leachate alkalinity and pH, reduce leachate total organic carbon (TOC), and increase the gas production (Banks and Lo, 2003; Lo et al., 2012a, 2012b; 2010). The possible mechanisms are discussed as: (1) the high ANC of BA can neutralize the acidic substances produced during MSW hydrolysis and acidogenesis process, so that the pH environment is more conducive to the degradation of organic matter (Banks and Lo, 2003); (2) the release of alkaline metals and anions could increase the electrical conductivity (EC, reflecting the change of salt and total dissolved solids) and salinity in the leachate, thus affecting the degradation behavior of organic matter (Wang, 2015); and (3) the release of Co, Mo and W, etc. could increase the biogas production rate (Lo et al., 2012b). The effect of co-landfill is also related to the mixing ratios of BA and MSW (Li et al., 2014; Lo et al., 2009). When the BA/MSW ratio is low (volume ratio 1:10), it is not possible to provide sufficient ANC for MSW with high organic composition (w/w = 45%), while at a higher proportion of BA (volume ratio 1:5), the concentrations of TOC, volatile fatty acids (VFAs), total nitrogen (TN) and ammonia nitrogen (NH_4^+-N) in leachate decrease. The BA/MSW ratio should be determined according to the composition of the MSW (Li et al., 2014).

On the other hand, the release rate of alkaline metals and anions from BA is much higher than that from fresh MSW in landfill. Alkaline metal salts are the main compounds that result in the clogging of a landfill leachate collection system (LCS) (Fleming et al., 1991). Studies have shown that the substances responsible for clogging mainly consist of calcium carbonate, together with a small amount of magnesium carbonate and calcium sulfate (Xia et al., 2013). The formation of the clogging materials in the landfill is mainly a biochemical process, in which calcium, magnesium, and iron are the main substances involved (Van Gulck et al., 2003). Xia et al. confirmed that the release of large amounts of calcium-containing compounds in BA and FA was an important factor for the risk of LCS clogging during landfill operation, according to the results of experiments and model simulations (Xia et al., 2015).

As mentioned above, when BA and MSW are co-landfilled, the environmental conditions of the landfill are changed, which consequently influence the amount and composition of dissolved matters from BA and biodegradable derivatives from MSW. Thus the environmental characteristics of the landfill and the operating stability of LCS was affected. However, existing studies mainly focused on the impact of BA on methanogenic process when BA was co-disposed as landfill cover, thus a low proportion of BA (less than 30%) was filled in layers among MSW, and anaerobic sludge was usually used as inoculant. Furthermore, the influence of waste degradability on the co-landfill leachate characteristics has not been investigated before. In this study, the evolutions of the amount and composition of biodegradable derivatives from MSW and dissolved matters from BA in leachate during the hydrolysis and acidogenesis phase (when the release of biodegradable derivatives from MSW and dissolved matters from BA are concentrated) were investigated using different ratios of BA and MSW and different compositions of MSW. The co-disposal ratios of MSW to BA ranged from 0:1 to 1:0, which could simulate MSW mono-fill, co-landfill, as well as BA mono-fill scenarios.

2. Materials and methods

2.1. The waste and bottom ash samples

The waste degradation and the impact of BA co-landfill on waste degradation were influenced by the waste composition, therefore two waste compositions (Qu et al., 2008; Vigneron et al., 2007) were adopted. Table 1 shows the physical, approximate and ultimate compositions of the two wastes. Synthetic waste A (Qu et al., 2008) contained a higher proportion of degradable components that consisted of 61.5% food waste, 7.1% paper, 4.7% fabric, 2.1% bamboo leaves and 24.6% ceramsite (wet weight basis). The total solids content (TS) and volatile solids content (VS) were 44.1% and 18.6% (wet weight basis), respectively. Synthetic waste B (Vigneron et al., 2007) contained a lower proportion of degradable components that consisted of 28.8% food waste, 29.8% paper, 2.6% fabric, 3.2% bamboo leaves and 35.6% ceramsite (wet weight basis), for which TS and VS were 71.8% and 34.5% (wet weight basis), respectively. The synthetic wastes were manually shredded by scissors into particle sizes of less than 10 mm before use.

The BA sample was collected from a MSW incineration plant in Shanghai equipped with grate furnaces treating 800 metric tons of MSW per day. The waste composition was shown in the Table S1 in the Supplementary material. Approximately 200–300 kg of the water-quenched BA was collected from different piles in the ash pit and well mixed, from which 50 kg was retrieved and sent to the laboratory. The BA was air dried and ground into particles smaller than 5 mm before use by a manganese steel jaw crusher (BB 50, Retsch, Germany). The initial pH of the BA (determined on an extract produced by leaching BA with deionized water at a liquid-to-solid ratio of 10 L/kg) was 12.24, and its ANC was 1.2 meq-H^+/g.

The contents of metals in MSW were relatively low (data not shown): Ca content, 8.7–19.6 mg/g; Mg, 0–1.4 mg/g; Fe, 1.9–4.3 mg/g; and Al, 1.3–3.7 mg/g. In contrast, the contents of metals in BA were much higher, as shown in Table 2.

2.2. Experimental setup

The synthetic wastes (A and B) and BA samples were mixed together with ratios (wet weight basis) of 1:0 (A1 and B1), 4:1 (A4:1 and B4:1), 1:1 (A1:1 and B1:1), 1:4 (A1:4 and B1:4), and 0:1 (BA1). Samples A1 and B1 were used as MSW mono-fill controls, and BA1 was used as the BA mono-fill control. The weights of BA and MSW in waste A groups were 0 and 2 kg (A1), 0.5 and 2 kg (A4:1), 1.5 and 1.5 kg (A1:1), 2.8 and 0.7 kg (A1:4) respectively. The weights of BA and MSW in waste B groups were 0 and 2 kg (B1), 0.375 and 1.5 kg (B4:1), 1 and 1 kg (B1:1), 2 and 0.5 kg (B1:4) respectively. The weight of BA in group BA1 was 4.2 kg.

Column experiments were adopted to simulate landfill conditions (He et al., 2006; Spalvins et al., 2008; Zhang et al., 2014). The mixtures of the waste were respectively filled into nine columns, 150 mm in diameter and 400 mm in length, with an outlet at the bottom and an inlet at the top. There was also a vent hole on the top for collecting gas released from the blended waste. A porous disk was placed on top of the waste to assure an even distribution of leachate over the surface during recirculation.

Tap water was added into the columns to reach water-holding capacity of the filled waste. Then, leachate recirculation using a peristaltic pump was carried out for half an hour per day to improve contact of leachate with heterogeneous waste, homogenize the leachate in the columns and accelerate the degradation process. A volume of leachate (15 mL) was removed at regular

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