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Impact of intermittent aerations on leachate quality and greenhouse gas reduction in the aerobic–anaerobic landfill method

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ABSTRACT

The aerobic–anaerobic landfill method (AALM) is a novel approach in solid waste management that could shorten the landfill post-closure period and minimize the environmental loads. In this study, the aerobic–anaerobic landfill method was evaluated by using intermittent aeration. In addition, the nitrification–denitrification process was assessed as a means of reducing the emission of greenhouse gases (GHGs) and improving the leachate quality during the degradation of the organic solid waste. The leachate quality and the gas composition in each of the reactors were measured during the experimental period (408 days). The aeration process entailed the injection of air into plexiglass cylinders (200 cm height × 10 cm diameter), filled with fresh organic solid waste collected from a composting plant. Different aeration routines were applied, namely, continuous aeration (aerobic reactor A), aeration for three days/week (aerobic–anaerobic reactor B), aeration for 6 h/day (aerobic–anaerobic reactor C), and no aeration (non-aerated reactor D). It was found that aerobic reactor A produced the best results in terms of reduction of GHGs and improvement of the leachate quality. The aerobic–anaerobic reactor C was found to be more effective than reactor B in respect of both the emission of GHGs and the leachate quality; moreover, compared with aerobic reactor A, energy costs were reduced by operating this reactor. The transition period phenomenon was investigated during an intensive seven-day experiment conducted on the discharged leachate obtained from aerobic–anaerobic reactors B and C. The experiment concerned the differences in the composition of the gas during the aeration and the non-aeration periods. It was found that the transition period between the aeration and non-aeration cycles, which followed the simultaneous nitrification–denitrification had a considerable effect on the leachate quality of both the reactors. The results indicated that AALM has the potential to reduce leachate pollutants and the emission of GHGs. Furthermore, the occurrence of simultaneous nitrification–denitrification presents the prospect that intermittent aeration could reduce landfill aftercare and energy costs.

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1. Introduction

The majority of developing countries have adopted the anaerobic type of landfilling as a municipal solid waste (MSW) disposal method. However, increasing attention is being given to the environmental problems associated with such landfills. These problems are high concentrations of total organic carbon (TOC) and total nitrogen (T-N) in the leachate, an extended stabilization period, and the emission of high levels of greenhouse gases (GHGs).

It is desirable that a landfilled solid-waste layer be maintained under an aerobic condition, which accelerates the decomposition of the organic matter (Hanashima et al., 1981, 1983; Mitchell et al., 2003, 2004). Moreover, relative to anaerobic decomposition, aerobic decomposition of organic matter could reduce the emission of methane gas, which has 28 times (no climate-carbon feedbacks) the global warming potential (GWP 100) of carbon dioxide (IPCC, 2013). In addition, the aerobic decomposition of organic matter could bring about the rapid stabilization of landfilled solid waste (Cossu et al., 2003; Bilgili et al., 2007). Furthermore, a worldwide considerable attention is currently being given to the reclamation of the aged landfill sites, or to reduce the period of post-closure management of the landfills. In this regard, applying the aerobic–anaerobic landfill method (AALM) of hybrid conditions may create biostabilized landfills, thereby, reducing the need for expensive perpetual landfill aftercare (Wu et al., 2014).

The AALM is a novel approach to MSW management that could solve the problems associated with anaerobic landfills in both

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developing and in developed countries, as it combines the advantages of the aerobic type of landfill with reduced operational costs (Shimaoka et al., 2011a,b). The AALM is based on the nitrification of solid waste under aerobic conditions and denitrification under anaerobic conditions (Shimaoka et al., 2011b). The AALM could enable the development of simultaneous nitrification and denitrification processes in only one landfill cell (Berge et al., 2006), rather than in two separate anoxic and aerobic cells. Moreover, provided that the temperature is properly controlled (Raga and Cossu, 2013), efficient nitrogen turnover could be achieved. In the AALM, a certain proportion of air is injected into an anaerobic landfill at a certain rate for a period of time to create a partially aerobic atmosphere in the landfill. In this way, aerobic and anaerobic atmospheres are stratified in the landfill, and the leachate from a solid waste layer is alternately exposed to aerobic and anaerobic conditions as it percolates down through the layer. Moreover, the position of the aerobic layers is controlled to achieve the optimum decomposition of the MSW by dynamically changing the air injection parameters, based on the consideration of air injection position, rate, and period, as well as the phase of decomposition of the landfilled solid waste. In this manner, the AALM could shorten the landfill aftercare period and lower the environmental loads derived from the landfill.

Based on large-scale lysimeter experiments and numerical simulations, it has been reported that air injection at a greater depth, or at the bottom layer of a landfill, was beneficial in terms of the improvement in the leachate quality, the reduction of GHGs, and the enhancement of solid waste stabilization (Shimaoka et al., 2011a; Wu et al., 2014). Previous studies have focused on aerobic and anaerobic conditions that are alternately created along the vertical direction of a landfill by applying continuous air injection. However, intermittent aeration, which results in a single landfill layer alternating temporally between aerobic and anaerobic conditions, has not been discussed. The application of intermittent aeration is also expected to reduce the operational costs, compared with continuous air injection, because surplus aeration can reduce microbial activity and increase energy consumption (Sang et al., 2009).

In this study, column experiments were conducted to determine the effectiveness of applying intermittent aeration, as is done in the AALM. The experiments, in which aerobic and anaerobic conditions were alternately created in a specific layer of a column by means of intermittent air injection, entailed examining the effect of intermittent aeration on the leachate quality and the emission of GHGs. Furthermore, the occurrence of nitrification and denitrification during the transitional periods between the aerobic and anaerobic conditions was also investigated by means of these column experiments.

2. Materials and methods

2.1. Column experiment

The research was conducted using four laboratory-scale column reactors (A, B, C, and D). The schematic diagram of the column reactor can be found elsewhere (see supplementary material, Fig. S1). Each column was a plexiglass cylinder (200 cm height × 10 cm diameter) in which 15 cm of gravel, 170 cm of solid waste, and 10 cm of cover soil were layered from the bottom to the top, respectively. Top 5 cm was kept as open space in the column reactors; therefore, there was possibility of the atmospheric air penetration in the reactors. An aeration pipe was installed at the bottom of the column to introduce air. Gas sampling points were set up at every 40 cm depth interval in the column reactors.

Each column reactor was filled with organic solid waste, collected from a composting plant, with a dry density of 0.32 t/m^3 and a wet density of 0.67 t/m^3 that had been shredded to pieces of less than 1 cm (1/10 of the column's internal diameter to avoid the air paths from the glass void space). The composition of the waste was primarily kitchen waste from restaurants, households, and food industries along with wood chips.

Table 1 presents the operating conditions of the column experiments. Column A was operated with continuous aeration (7 days/week), columns B (3 days/week) and C (6 h/day) were operated with intermittent aeration, and column D (no aeration) was operated without aeration. The durations of air injection for columns B and C were set to three days/week (3 days continuous aeration and 4 days without aeration) and 6 h/day, respectively. The air injection rate during aeration was 7.1 l/kg dry mass (DM) h for aerobic (A) and aerobic–anaerobic (B and C) columns in stage-1 (0–302 days). All columns were covered with electric blankets and insulation materials to maintain the ambient temperature at approximately 30 ± 1 °C, in winter (the experimental period was October 15, 2012 to November 28, 2013) and in other seasons kept at 30 ± 1 °C room temperature. Temperature probes (Em50, Decagon Devices, Inc.) were placed in the middle of each column and were connected to a data logger (Em50, Decagon Devices, Inc.) to record the internal temperature. A total of 360 ml of distilled water was added weekly until 150 days of the experiment and later the amount was reduced to 280 ml to each column to simulate precipitation and generation of leachate. There was no leachate recirculation in this study.

Gas samples were collected from five-gas sampling points (25, 65, 105, 145 and 185 m depth) in each column for analysis of the O_2, CO_2, CH_4, and N_2O concentrations at 2-weeks intervals (in case of reactor B and C, sampling was before start the aeration). Leachate was collected weekly from the bottom of the each reactor and each sample was filtered using 0.45 μm pore filter paper to analyze the pH, electric conductivity (EC), oxidation–reduction potential (ORP), TOC, T-N, NH_4^+–N, NO_3^-–N, and NO_2^-–N concentrations.

An intensive seven-day experiment was conducted from day 302 to day 309 to investigate the phenomena taking place during the transitional periods between the aerobic and non-aerobic conditions, with the same aeration rate (7.1 l/kg DM h) for reactor B and C. The sampling interval of gas and leachate was shortened during this experiment. Micro-tubing pumps (Masterflex C/L, Cole-Parmer, USA) were used to sprinkle distilled water evenly to maintain the continuous leachate outflow. Leachate samples were collected by using fraction collector (CHF121SA, Cole-Parmer; USA).

Table 1
Conditional and operational parameters of column experiment.

Parameters	Reactor A	Reactor B	Reactor C	Reactor D
Moisture content (%)	50			
Packing density (t/m^3)	0.32 (Dry), 0.67 (Wet)			
Volumetric ratios (m^3/m^3)	0.23 (Solid), 0.36 (Liquid), 0.41 (Gas)			
Ambient temperature (°C)	30 ± 1°[a]			
Water supply as rainfall (mL/week)	360[b], 280[c]			
Duration of continuous air injection	7 days/week[d]	3 days/week[e]	6 h/day[f]	No aeration
Air injection rate l/kg DM h	7.1[g] and 4.2[h]			0.0

[a] Started from 15th day of operation.
[b] (0–150 days).
[c] (156–408 days).
[d] 168 h continuous/week (5040 L/week).
[e] 72 h continuous/week (2160 L/week).
[f] 42 h/week (1260 L/week).
[g] Stage-1 (0–302 days).
[h] Stage-2 (325–408 days).

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