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Seasonal characteristics of odor and methane mitigation and the bacterial community dynamics in an on-site biocover at a sanitary landfill

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ABSTRACT

Landfills are key anthropogenic emission sources for odors and methane. For simultaneous mitigation of odors and methane emitted from landfills, a pilot-scale biocover (soil:perlite:earthworm cast:compost, 6:2:1:1, v/v) was constructed at a sanitary landfill in South Korea, and the biocover performance and its bacterial community dynamics were monitored for 240 days. The removal efficiencies of odor and methane were evaluated to compare the odor dilution ratios or methane concentrations at the biocover surface and landfill soil cover surface where the biocover was not installed. The odor removal efficiency was maintained above 85% in all seasons. The odor dilution ratios ranged from 300 to 3000 at the biocover surface, but they were 6694–20,801 at the landfill soil cover surface. Additionally, the methane removal efficiency was influenced by the ambient temperature; the methane removal efficiency in winter was 35–43%, while the methane removability was enhanced to 85%, 86%, and 96% in spring, early summer, and late summer, respectively. The ratio of methanotrophs to total bacterial community increased with increasing ambient temperature from 5.4% (in winter) to 12.8–14.8% (in summer). In winter, non-methanotrophs, such as *Acinetobacter* (8.8%), *Rhodanobacter* (7.5%), *Pedobacter* (7.5%), and *Arthrobacter* (5.7%), were abundant. However, in late summer, *Methylobacter* (8.8%), *Methylocaldum* (3.4%), *Mycobacterium* (1.1%), and *Desulviicoccus* (0.9%) were the dominant bacteria. *Methylobacter* was the dominant methanotroph in all seasons. These seasonal characteristics of the on-site biocover performance and its bacterial community are useful for designing a full-scale biocover for the simultaneous mitigation of odors and methane at landfills.

1. Introduction

Organic compounds in wastes are decomposed into methane and carbon dioxide by microbes under anaerobic conditions (Park and Shin, 2001). In this process, odorous compounds, such as hydrogen sulfide (H_2S), methyl mercaptan, dimethyl sulfide, ammonia, and volatile organic compounds (VOCs), are produced as byproducts (Park and Shin, 2001). Landfills are the most representative environmentally-obnoxious facilities because they emit diverse gases such as odors and methane (Both, 2001).

Approximately 50,000 tons of municipal solid waste are produced every day, and 15.1% of these are buried in landfills to be treated in South Korea (Korean Ministry of Environment, 2015a). A total of 289 landfills are located at various places in Korea, and the total capacity of these landfills was 59 million m^3 in 2014 (Korean Ministry of Environment, 2011). The Korean Ministry of Environment established the Offensive Odorant Prevention Law in 2005, and designated 22 odorous compounds as the representative odorous compounds that must be controlled (Korean Ministry of Environment, 2011). However, most odor-related policies have focused on food and sewage treatment plants, while there is a lack of policies for landfills (Both, 2001).

Methane, a significant greenhouse gas (GHG), has a global warming potential 28 times greater than that of carbon dioxide (IPCC, 2013), and it is mainly emitted from waste landfills (Moghbel and Fall, 2016). According to a report in 2015, methane accounted for 4% of the total GHG emissions in Korea; 25% of this methane was emitted from landfills, which was the second highest source of methane emission in Korea (Korean Greenhouse Gas

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Inventory and Research Center, 2015). Highly-concentrated methane can be collected and used as an alternative energy (Czyrnek-Delêtre et al., 2012). However, it is difficult to recover methane from landfills that are old or small in size because of the lack of proper energy recovery systems (Popov, 2005). Therefore, novel solutions for methane mitigation from landfills are required.

Biocovers can be used as a novel solution to simultaneously control the odor and methane emitted from landfills (Czyrnek-Delêtre et al., 2012; Huber-Humer et al., 2009). Biocovers are a landfill top cover soil that mitigate odor and methane from landfills by optimizing the environmental conditions for bacteria (Lou et al., 2011). There are many reports investigating the performance of biocovers, but most reports have focused on methane mitigation (Huber-Humer et al., 2009; Lee et al., 2014; Lou et al., 2011; Moghbel and Fall, 2016; Scheutz et al., 2014). We proposed the simultaneous removal of odor and methane by biocovers (Lee et al., 2017, 2014, 2013). Odor and methane were successfully removed with lab-scale biocovers (Lee et al., 2017, 2014, 2013). However, to design a full-scale biocover, the performance of on-site biocovers should be evaluated.

In this study, a pilot-scale biocover was designed and constructed on a sanitary landfill in Gwangyang, Korea. We evaluated the seasonal characteristics of the simultaneous mitigation of odors and methane in the on-site biocover for 240 days. In addition, the seasonal characteristics of bacterial community structures in the biocover were analyzed using high-throughput pyrosequencing based on the 16S rRNA-polymerase chain reaction (PCR).

2. Methods

2.1. Packing materials for the pilot-scale biocover

Soil, perlite, earthworm cast, and compost were prepared as packing materials for the prototype biocover. Landfill cover soil was utilized. Perlite (Kyungdong One Co. Ltd., Seoul, Korea) and earthworm cast (Kumhosilup, Naju, Korea) were commercially purchased. Compost was obtained from the Gwangyang food waste recycling facility (Gwangyang, Korea). The physicochemical characteristics of these four raw materials are shown in the supplementary material. The four raw materials were mixed using an excavator at a ratio of 6:2:1:1 (v/v, soil:perlite:earthworm cast:compost) for the packing material. The earthworm cast also functioned as an inoculum for the bacterial complex.

2.2. Construction of the pilot-scale biocover

The pilot-scale biocover was constructed in a sanitary landfill located in Gwangyang, Korea (latitude 34°58′0″ and longitude 127°38′35″, Fig. 1a). The total disposal capacity of the landfill is 3,145,291 m^3, and it is planned to be operated until 2037. Every year, 172,425 tons of waste have been buried in the landfill site, and most of this waste consists of municipal waste (78%) including paper (29%), wood (21%), food waste (16%), and plastic (12%) (Korean Ministry of Environment, 2015a). The biocover was installed within the landfill surface with a volume of 2.5 W × 5.0 L × 1.0 H m^3 (Fig. 1b). The pilot-scale biocover was constructed as shown in Fig. 1c; this is described in detail in the supplementary material. The site view of the completed biocover is shown in Fig. 1d and e. After installation, the biocover was monitored for 240 days (January 2016 – September 2016).

2.3. Gas analysis

A total of 22 representative odorous compounds were monitored from the landfill and biocover surfaces. These 22 representative odorous compounds were designated based on the Offensive Odorant Prevention Law by the Korean Ministry of Environment and include two nitrogen compounds, four sulfur compounds, five aldehydes, seven volatile organic compounds, and four organic acids (Korean Ministry of Environment, 2011). Gas analysis of the compounds was conducted according to the Korean Standard Odor Analysis Method, as described in the supplementary material (Korean Ministry of Environment, 2014). Gas samples were collected on the 25th, 54th, 88th, 131st, 145th, 178th, 214th, and 240th days during the operation period.

The odor dilution ratio is the number of dilutions required to render the odor undetectable (Dravnieks and Jarke, 1980). The odor dilution ratio was derived as an odor index using the olfactory method according to the Korean Standard Odor Analysis Method (Korean Ministry of Environment, 2014).

The sum of the odor activity value (SOAV) was calculated based on the concentrations of the 22 representative odorous compounds, which were measured by the instrumental analysis described in the supplementary material. The OAV and SOAV were calculated using Eq. (1) (Kim and Park, 2008):

$$\mathrm{SOAV} = \sum (C_i/C_{OTi}) \quad (1)$$

C_i is the concentration of the ith component, and C_{OTi} is the threshold of the ith component.

Methane was analyzed using a biogas check analyzer (Geotechnical Instruments, Chelmsford, UK) at the field site.

Based on the values of the odor dilution ratios, SOAVs, and methane concentrations, two concepts of the removal efficiency were calculated. Firstly, "the removal efficiency compared to the biocover inlet ($RE_{BS/BI}$,%)" was calculated by comparing the values at the biocover inlet and biocover surface (outlet). This value was used to evaluate the odor or methane removal efficiencies of the biocover itself. Secondly, "the removal efficiency compared to the landfill soil cover surface ($RE_{BS/LS}$,%)" was calculated by comparing the values at the landfill soil cover surface (control) and the biocover surface (outlet). This value indicated the effectiveness of the biocover at removing odor or methane compared with the existing control landfill. The removal efficiencies were calculated according to Eqs. (2) and (3):

$$RE_{BS/BI}(\%) = (BI - BS)/BI \times 100 \quad (2)$$

$$RE_{BS/LS}(\%) = (LS - BS)/LS \times 100 \quad (3)$$

BI is the value at the biocover inlet, BS is the value at the biocover surface, and LS is the value at the landfill soil cover surface.

2.4. Packing material sampling and physicochemical characteristics analysis

The biocover soil samples were collected at a depth of 10–20 cm from the surface of the biocover. The sampling was conducted on the 5th (January 14th, 2016), 88th (April 6th, 2016), 178 th (July 5th, 2016), and 240th (September 5 th, 2016) days. After sieving through a 2 mm mesh, the samples were stored at 4 °C before use.

The pH and water content were measured based on the Korean Standard Soil Analysis Method (Korean Ministry of Environment, 2015b), and the organic content was measured based on the Korean Standard Wastes Analysis Method (Korean Ministry of Environment, 2010). A two-tailed test was conducted to evaluate the statistical significance of the physicochemical values at a level of 0.05, and it was classified as statistically significant ($p < 0.05$) and nonsignificant ($p > 0.05$).

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