Environmental Research 166 (2018) 516–528

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Odor mitigation and bacterial community dynamics in on-site biocovers at a sanitary landfill in South Korea

Jeonghee Yun[a], Hyekyeng Jung[a], Hee-Wook Ryu[b], Kyung-Cheol Oh[c], Jun-Min Jeon[c], Kyung-Suk Cho[a,*]

[a] Department of Environmental Science and Engineering, Ewha Womans University, 52, Ewhayeodae-gil, Seodaemun-gu, Seoul 03760, Republic of Korea
[b] Department of Chemical Engineering, Soongsil University, Seoul 06978, Republic of Korea
[c] Green Environmental Complex Center, Suncheon 57992, Republic of Korea

ARTICLE INFO

Keywords:
Landfill
On-site biocover
Deodorization
Bacterial community
Network analysis

ABSTRACT

Unpleasant odors emitted from landfills have been caused environmental and societal problems. For odor abatement, two pilot-scale biocovers were installed at a sanitary landfill site in South Korea. Biocovers PBC1 and PBC2 comprised a soil mixture with different ratios of earthworm casts as an inoculum source and were operated for 240 days. Their odor removal efficiencies were evaluated, and their bacterial community structures were characterized using pyrosequencing. In addition, the correlation between odor removability and bacterial community dynamics was assessed using network analysis. The removal efficiency of complex odor intensity in the two biocovers ranged from 81.1% to 97.8%. Removal efficiencies of sulfur-containing odors (hydrogen sulfide, methanethiol, dimethyl sulfide, and dimethyl disulfide), which contributed most to complex odor intensity, were greater than 91% in both biocovers. Despite the fluctuations in ambient temperature (−8.2 to 31.3 °C) and inlet complex odor intensity (10,000–42,748 of odor dilution ratio), biocovers PBC1 and PBC2 displayed stable deodorizing performance. A high ratio of earthworm casts as an inoculum source led to high odor removability during the first 25 days of operation, but different mixing ratios of earthworm casts did not significantly affect overall odor removability. A bacterial community analysis showed that *Methylobacter*, *Arthrobacter*, *Acinetobacter*, *Rhodanobacter*, and *Pedobacter* were the dominant genera in both biocovers. Network analysis results indicated that *Steroidobacter*, *Cystobacter*, *Methylosarcina*, *Solirubrobacter*, and *Pseudoxanthomonas* increased in relative abundance with time and were major contributors to odor removal, although these bacteria had a relatively low abundance compared to the overall bacterial community. These data contribute to a more comprehensive understanding of the relationship between bacterial community dynamics and deodorizing performance in biocovers.

1. Introduction

Odor emission is a major environmental issue and societal concern (Barbusinski et al., 2017; Capanema et al., 2014). Odors are emitted from various industrial areas such as waste water treatment plants, disposal facilities, chemical industries, food industries, paper mills, and livestock activities (Barbusinski et al., 2017; Capelli et al., 2008). Landfills are representative environmental facilities that release unpleasant odorous gases (Fang et al., 2012; Sakawi et al., 2011). Landfill gas is a complex gas generated from biodegradation of organic waste by microorganisms under aerobic or anaerobic conditions and is mainly composed of methane and carbon dioxide (Cho and Ryu, 2009; Park et al., 2017). It also includes a small amount of odorous volatile organic compounds (VOCs) such as hexane, toluene, and xylene as well as odorous gases such as hydrogen sulfide (0–0.2%), methanethiol (0–0.2%), dimethyl sulfide (DMS; 0–0.2%), and ammonia (0.1–1%) (Gebert et al., 2008; Nikiema et al., 2007). The emission of hydrogen sulfide, which is a major contributor to landfill odors, has been estimated to be approximately 0.3–633.5 $mg\,m^{-2}{\cdot}h^{-1}$ (Muezzinoglu, 2003; Parker et al., 2002). Jeon et al. (2014) characterized odor emission at nine landfills in South Korea, and they reported that hydrogen sulfide was the primary contributor to odor intensity. Fang et al. (2012) reported that concentrations of ammonia, hydrogen sulfide, methanethiol, DMS, *n*-butylaldehyde, and acetic acid were as high as 70,000, 109, 79.2, 78, 88.6, and 2250 ppb, respectively, in a landfill in Shanghai, China. These malodorous gases are not only unpleasant, but they can induce potential public health concerns. Consequently, odor control in landfills is an important issue and appropriate technologies

---

* Corresponding author.
E-mail address: kscho@ewha.ac.kr (K.-S. Cho).

https://doi.org/10.1016/j.envres.2018.06.039
Received 5 April 2018; Received in revised form 4 June 2018; Accepted 19 June 2018

are needed.

In general, the technologies for controlling odor include chemical methods such as ozonation, physical methods such as adsorption, and biological methods such as biofilters and biocovers (Barbusinski et al., 2017; Kennes and Veiga, 2010; Nanda et al., 2012). Among these methods, biocovers are suited to control odors emitted from area sources including landfills (Capanema et al., 2014). Most previous studies on biocovers have focused on removal efficiencies of target odor compounds and optimization of system parameters such as type of packing material, system configuration, temperature, pH, moisture content, and organic matter content (Barbusinski et al., 2017; Heaney et al., 2011; Scheutz et al., 2009). Majdinasab and Yuan (2017) reported that maintenance of the optimal temperature in landfill biocovers was important because it affected microbial activity directly and indirectly via modulating evaporation. Majdinasab and Yuan (2017) also reported that moisture content affected bio-reaction and microbial activity by interfering with the flow of nutrients and gases within biocover soils. pH is another important factor due to its influence on bacteria activity. The optimal pH values for landfill biocover were between 6.6 and 7.0 (Majdinasab and Yuan, 2017). In a case study on the removal of sulfur-containing odors in landfill biocovers with different organic matter content, the biocover with the greatest organic matter content achieved the lowest odor emissions (Capanema et al., 2014). There is, however, little information available on the removal properties of odor with complex intensity as well as individual odorous compounds in field-scale biocovers at landfills.

Bacteria play important roles in deodorization in biocovers and biofilters (Li et al., 2012; Slezak et al., 2015). In a full-scale biofilter where the removal efficiency of hydrogen sulfide was over 90%, *Pseudomonas* and *Lysinibacillus* were dominant and survived over an operating period of nine months (Li et al., 2012). Ho et al. (2008a) observed that *Pseudomonas* was a predominant and stable organism during long-term operation (415 days) of a biofilter. In another biofilter used to control trimethylamine, researchers identified trimethylamine degraders such as *Bacillus*, *Arthrobacter*, *Aminobacter*, *Paracoccus* and *Nitrosospira* (Ding et al., 2008). *Acinetobacter*, *Pseudomonas*, and *Comamonas* were found to be sulfur-utilizing bacteria in the biocover that removed hydrogen sulfide (Xia et al., 2015). In a biocover that simultaneously removed odor and methane, *Acinetobacter*, *Rhodanobacter*, *Pedobacter* and *Arthrobacter* were abundant in winter, but, in late summer, *Methylobacter*, *Methylocaldum*, *Mycobacterium* and *Desulviicoccus* were the dominant bacteria (Lee et al., 2018). In most studies of full-scale and pilot-scale biological processes, dominant species were considered key contributors to deodorization. Thus, there is a need to comprehensively interpret the complex relationships between biocover performance and bacterial community structure through new approaches such as network analysis.

In this study, two biocovers were constructed with a mixture of soil, earthworm casts, perlite, and compost at different ratios and were established at a sanitary landfill in Gwangyang, South Korea. The specific objectives of this study were (1) to evaluate the removal performance of complex odor intensity and 22 representative odors in the on-site biocovers, and (2) to characterize bacterial community dynamics through long-term (240 days) monitoring of the biocovers. In addition, a comprehensive view of the complex interactions between bacterial communities and removal efficiencies of the odors was interpreted using network analysis. The data obtained from the on-site biocover system can contribute to the development of a more reliable and efficient odor-elimination strategy in landfills.

2. Materials and methods

2.1. Landfill site

Pilot-scale biofilters were established in a landfill in Gwangyang, South Korea (latitude: 34.97528°N, longitude: 127.58917°E, Fig. Sla). The sanitary landfill site began operation in 1996 and has a total disposal capacity of 3145,291 m^2. It receives 172,425 t of municipal waste per year, containing 29% paper, 21% wood, 16% food waste, and 12% plastics (Korean Ministry of Environment, 2014a).

2.2. Construction of pilot-scale biocovers and packing materials

Pilot-scale biocovers were 2.5 m in width × 5.0 m in length × 1.0 m in depth and were constructed on a sanitary landfill site containing buried domestic waste deposited starting in 2014 (Figs. S1b and S1c). The solid waste was covered with a 0.25-m layer of gravel that had a diameter of 2–5 cm, and that was covered with a polypropylene nonwoven textile sheet (Kyungdong One Co. Ltd., Seoul, South Korea). A 0.5-m-deep soil layer was placed on top of the textile cover. A perforated pipeline was installed at the bottom of the biocover and was connected to polyvinyl chloride (PVC) pipes for pumped landfill gas and biocover inlet gas sampling.

Soil, perlite, compost, and earthworm casts were used as packing materials for the prototype biocovers. Earthworm casts were utilized as a major inoculum source due to their high microbial diversity (Moon et al., 2010). The soil had a pH of 7.0 ± 0.1, water content of 9.1 ± 0.2%, and organic matter content of 2.6 ± 0.2%. The pH, water content, and organic matter content of perlite were 6.7 ± 0.1, 0.1 ± 0.0%, and 0.4 ± 0.0%, respectively. Those of earthworm casts were 7.2 ± 0.1, 47.5 ± 0.3%, and 30.0 ± 0.4%, respectively. The compost had a pH of 8.6 ± 0.0, water content of 43.4 ± 0.9%, and organic matter content of 69.3 ± 1.3%. Based on the preliminary results of lab-scale test (data not shown), the mixture ratios of the packing materials were determined as follows: The PBC1 biocover was packed with a mixture of soil, perlite, compost, and earthworm casts at a volume ratio of 7:3:1:1. The PBC2 biocover was packed with a mixture of soil, perlite, compost, and earthworm casts at a volume ratio of 4:3:1:3. A perforated pipeline was installed at the bottom of the biocovers and connected to a PVC pipe for landfill sampling (biocover inlet gas sampling). A flux chamber (acryl, 1.00 m W × 1.50 m L × 0.15 m H) was installed on the surface of the biocovers for gas sampling from the biocover surface (biocover outlet gas sampling). The installed biocovers are shown in Fig. Sld. To analyze odorous compounds, gas sampling at the biocover inlet was collected from an inflow pipe of the landfill gas at the biocover bottom, and biocover outlet gas sampling was collected on the biocover surface. The chamber for gas sample analysis as a control was set on a landfill soil cover surface where the biocover was not installed. The biocover performances were monitored for 240 days from January 2016 to September 2016.

2.3. Gas analysis

Gas analysis of 22 representative odorous compounds and methane emitted from the biocovers was conducted using the Korean Standard Odor Analysis Method (Korean Ministry of Environment, 2014b), as described in Yun et al. (2017). These representative odorous compounds consisted of nitrogen compounds (ammonia and trimethylamine), sulfur compounds (hydrogen sulfide, methanethiol, DMS, dimethyl disulfide), aldehydes (acetaldehyde, propionaldehyde, butyl aldehyde, *i*-valeric aldehyde, *n*-valeric aldehyde), volatile organic compounds (methyl ethyl ketone, methyl isobutyl ketone, butyl acetate, *i*-butyl alcohol, styrene, toluene, xylene), and organic acids (*n*-butyric acid, propionic acid, *i*-valeric acid, *n*-valeric acid) (Korean Ministry of Environment, 2011). Gas collection was sampled at the 25th, 54th, 88th, 131th, 145th, 178th, 214th, and 240th days of the operation period. Detailed methods for the analysis of the odorous compounds have been described in Lee et al. (2018). The odor dilution ratio (ODR) and the sum of the odor activity value (SOAV) were used as odor indices to evaluate the removal efficiency of the complex odors (Lee et al., 2013, 2018; Wenjing et al., 2015). The ODR indicated the dilution number required to reach an undetectable level, and the SOAV was