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Effect of organic compositions of aerobically pretreated municipal solid waste on non-methane organic compound emissions during anaerobic degradation

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ABSTRACT

Odor pollution caused by municipal solid waste (MSW) treatment plants has become a growing public concern. Although aerobic pretreatment of MSW has advantages in accelerating landfill stabilization, the property of non-methane organic compound (NMOC) emissions from aerobically pretreated MSW (APMSW) during landfilling is unknown. To investigate NMOC emissions from anaerobic degradation of APMSW and to study the impact of organic compositions of APMSW and their decomposition stages, five simulative anaerobic bioreactors (R1–R5) were filled up with APMSW of different original organic compositions in a laboratory. For NMOC analysis, samples were collected from the gas that accumulated separately during two successive independent stages of the whole experiment. The results showed that the cumulative quantities of NMOCs from R1 to R5 were 1.11, 0.30, 0.18, 0.28, and 0.31 mg/kg DM, respectively, when volatile solid was degraded by 34.8–47.2%. As the organic content of the original waste was lower, the proportion of NMOCs generated in the early stage of anaerobic degradation became higher. Multiple linear regression analyses of the relationship between the quantities of degraded organics and generated NMOCs showed that lipid and protein have a strong effect on NMOC amount. The effect of lipid on NMOC quantity lasts longer than that of protein. This observation suggests that controlling the lipid and protein contents in MSW can reduce the odor from landfills.

1. Introduction

Conventional landfilling is a common method adopted worldwide to dispose of municipal solid waste (MSW). During the anaerobic degradation of MSW, most organic matter is broken down by microorganisms into simple compounds, leading to the formation of landfill gas. CO_2 and CH_4 are the dominant components in landfill gas. Trace species, such as mercury, arsenic, and some organic compounds, are often found abundantly in landfill gas relative to other environmental sources (Kim and Kim, 2002; Feng et al., 2004; Huang et al., 2009). Although non-methane organic compounds (NMOCs) comprise less than 1% (V/V) of landfill gas, they may create a disproportionate environmental burden and potential risk to human health (Allen et al., 1997). For example, emissions of carcinogens, such as benzene and vinyl chloride, pose a potential threat to workers and local inhabitants (El-Fadel et al., 1997; Durmusoglu et al., 2010). Furthermore, chloro- and fluorohydrocarbons emitted from landfills seriously corrode combustion engines that utilize landfill gas (Dernbach, 1985), deplete the ozone layer, and cause climate change (Molina and Rowland, 1974; Wallington et al., 1994).

The reported yields of NMOCs varied widely according to the nature of waste and the experiment condition (Thomas and Barlaz, 1999; Smet et al., 1999; Staley et al., 2006; Wang and Wu, 2008). The yield of total terpenes from orange wastes was up to 11,000 mg/kg DM (Wang and Wu, 2008), and the NMOC yields of refuse, paper, yard waste, and food waste were investigated to be 151, 16, 38, and 221 mg C/kg DM, respectively (Staley et al., 2006). It was also found that NMOC release during aerobic decomposition of refuse and yard waste was larger than that in anaerobic systems (Staley et al., 2006). However, Komilis et al. (2004) detected a VOC yield of food waste as low as 0.33 mg/kg DM under controlled aerobic conditions, approximately four orders of magnitude less than values reported by Staley et al. (2006).

Knox (1990) compared NMOCs released from three main phases of decomposition, and found that total NMOC concentration initially increases and then steadily decreases. Moreover, the author also investigated some categories of NMOC concentrations among waste degradation processes. Alcohols and halogenated hydrocarbons are the main components of NMOCs emitted from young refuse (Knox, 1990). Deipser and Stegmann (1994) found that the highest concentrations of volatile chlorinated and fluorinated hydrocarbons occur during the acid phase in a landfill. Kim (2006) similarly concluded that the proportion of reduced sulfur compounds is larger in young landfills than in old landfills.

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Aromatics and alkanes are the primary components emitted from middle-aged and old refuses (Knox, 1990).

Sources of NMOCs in landfill gas include the anaerobic biodegradation intermediates and the volatilization of hazardous organic compounds present in MSW (Thomas and Barlaz, 1999). The decomposition by-products of readily degradable organic matter are oxygenated compounds, alkanes, and alkenes (Smet et al., 1999). Aromatics may also be present in food waste because most aromatics are lipophilic compounds that can be absorbed by lipids (He et al., 2010). Yard waste, fruit peels, and vegetable leavings are particularly high in terpenes (Wang and Wu, 2008). According to Allen et al. (1997), domestic waste releases more alkanes, alcohols, and ketones than trade waste. Consumer products from the chemical industry contain chlorinated compounds that are directly volatized in landfills (UK Environment Agency, 2004). Young and Parker (1983) found that the gas evolved by industrial landfills is considerably richer in hydrocarbons and solvents, including halocarbons, than that from landfills receiving only domestic waste.

Aerobic pretreatment of MSW can not only reduce mass of waste but improve landfill behavior. When aerobically pretreated MSW (APMSW) is buried in a landfill, the leachate pollution load and the biogas production potential will be diminished (Kuruparan et al., 2003; Lornage et al., 2007; Scaglia et al., 2010; Tambone et al., 2011), the stabilization process will be enhanced (Leikam and Stegmann, 1999; Zach et al., 2000), and the intensity of the NMOC emissions will be reduced (Zhang et al., in press). To our best knowledge, however, little information is available on the effect of organic compositions of APMSW on NMOC characteristics at different degradation stages. This information is important because it is helpful for determining the way and the extent of pretreatment from perspective of odor control. The objectives of this study are as follows: (1) to investigate the NMOC emissions from APMSW with various original organic contents by measuring NMOC yields and components at two different stages of the anaerobic process and by analyzing emission intensities, and (2) to correlate the degraded organic contents with the NMOC yields.

2. Materials and methods

2.1. Materials

The original waste A1, approximately 500 kg of MSW was obtained from a landfill in Beijing, China. The waste was aerobically treated to various extents, obtaining five waste samples of different organic compositions (Table 1). The detailed aerobic pretreatment process for the five wastes is introduced in literature (Zhang et al., in press).

2.2. Experimental setup

The reactors, made up of high-density polyethylene, each had an internal diameter of 500 mm and a height of 750 mm (Fig. 1). The operation modes are shown in Table 2. The reactors R1–R5 were filled with A1–A5, respectively.

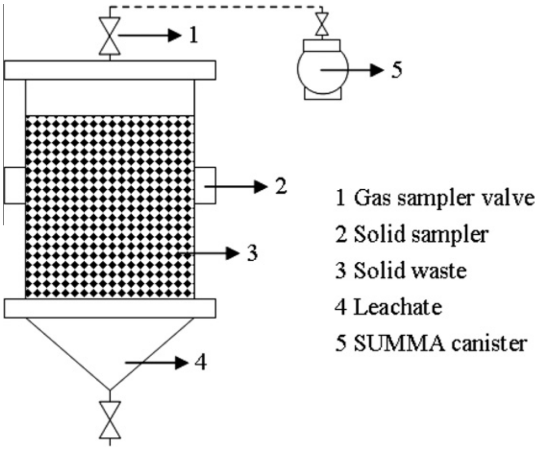

Fig. 1. Scheme of the reactor.

Table 2
Operation modes of the five reactors.

Reactors	Materials	Weight (kg)	Height (cm)	Time (d)	
				Stage I	Stage II
R1	A1	77.5	53.5	1st–127th	128th–359th
R2	A2	63.2	41.0	1st–97th	98th–329th
R3	A3	61.2	37.5	1st–77th	78th–309th
R4	A4	58.2	36.5	1st–77th	78th–309th
R5	A5	57.0	33.5	1st–77th	78th–309th

2.3. Sampling and analytical methods

The gas accumulated in the reactors was collected separately at the end of stage I or II using a previously evacuated SUMMA canister and then analyzed for the determination of its NMOC composition. Solid samples were obtained immediately after gas sampling from the two side samplers and the top of the reactors.

Moisture content (wet basis) was determined by heating the ground sample at 105 °C for 24 h. Volatile solid (VS) was determined by ashing the dry samples at 550 °C to a constant weight in a muffle furnace (SX2-8-10; NuoJi Instrument Co. Ltd., Changzhou, China). Before the organic components were analyzed, the waste sample was first dried at 105 °C, and then shredded using a shredding machine (LK-500; Nongfeng Instrument Co. Ltd., Zhongshan, China). Protein was determined as Kjeldahl *N* times a factor of 6.25 (APHA, 1998). Lipid was determined through extraction using ether (AOAC, 1990, method no. 920.39). The remaining organics were called "others," which were calculated by subtracting the sum of lipid and protein from VS.

Total carbon (TC) and total nitrogen (TN) were measured using a carbon–hydrogen–nitrogen analyzer (Equipment CE 440; EAI USA).

Table 1
Characteristics of the five kinds of waste for anaerobic degradation.[a]

Waste	Moisture (%)	VS (%)	TC (%)	TN (%)	Lipid (%)	Protein (%)	Others[b] (%)
A1	61.8	65.1	34.9	2.1	7.8	13.1	44.2
A2	70.2	49.6	22.6	1.8	0.6	11.1	37.9
A3	70.0	45.2	20.5	1.5	0.3	10.2	34.7
A4	71.0	38.2	18.4	1.2	0.3	9.8	28.1
A5	70.0	30.2	15.1	1.1	0.1	9.4	20.7

[a] A1 indicates the original waste obtained from a landfill site; A2, A3, A4, and A5 represent the waste produced from aerobic pretreatment of A1.
[b] Others are determined by subtracting lipid and protein from VS.