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Utilization of stabilized wastes for reducing methane emission from municipal solid waste disposal

Wilai Chiemchaisri, Chart Chiemchaisri *, Jindaruch Boonchaiyuttasak

Department of Environmental Engineering, Faculty of Engineering, Kasetsart University, 50 Ngam Wong Wan Road, Chatuchak, Bangkok 10900, Thailand

HIGHLIGHTS

- Stabilized wastes could be utilized for reducing methane emission from landfill.
- Maximum methane oxidation rate of 34.1 g/m^3 d was obtained over 180 d.
- Methanotrophic activities of plastic and fine waste fraction were at same level.
- Plastic wastes facilitated oxygen supply for methane oxidation in the waste layer.
- Methanotroph type I was found predominant over the entire depth of waste layer.

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ABSTRACT

Stabilized solid wastes were utilized to mitigate methane emission from the landfill. Loose texture of plastic wastes encouraged air diffusion from the soil surface whereas fine organic fraction has good water holding capacity and nutrients to stimulate methane oxidation reaction. Biological methane oxidation capacity in stabilized waste layer was found to be up to 34.1 g/m^3 d. Microbial activity test revealed methanotrophic activities of plastic and degraded organic wastes were in the same order. The mixture of plastic and fine degraded organic waste matrix provided sufficient porosity for oxygen transfer and supported the growth of methanotrophs throughout 0.8 m depth of waste layer. Fluorescent in situ hybridization (FISH) analysis confirmed the presence of methanotrophs and their population was found varied along waste depth.

1. Introduction

Solid waste disposal on land is the most common method for managing municipal solid wastes in developing countries. The disposal of solid waste can either be performed in good sanitary condition like sanitary landfill or improper manner such as open dumping. In many developing countries, the latter could become predominant mode of operation due to limitation of budget, technical knowledge or awareness of their environmental impact such as leachate and gas formation (AIT, 2004). In term of gaseous pollution, the decomposition of organic solid wastes at solid waste disposal site leads to the formation of landfill gas which mainly composed of methane and carbon dioxide. Direct release of those greenhouse gases especially methane gas to atmosphere which is commonly practiced in many countries raised much concern to the global warming phenomena. In order to minimize this greenhouse gas emission, the produced gas can be generally captured and sent to flare or landfill gas power plant in many developed countries. However, those operations are rather limited in developing countries due to financial constraints. As an alternative option, natural methane oxidation reaction in landfill cover soil could be used to help reducing methane emission from these waste disposal activities (Huber-Humer et al., 2008). In sanitary landfill, provision of high porosity cover soil such as sandy loam and maintaining proper environmental conditions for methanotrophic bacteria enhances methane oxidation rate in landfill cover. The favorable environmental conditions for methanotrophic bacteria which are responsible for this methane oxidation reaction includes optimum moisture (10–15%) and temperature (25–30 °C), available nutrients through leachate irrigation and presence of vegetation (Visvanathan et al., 1999; Chiemchaisri et al., 2001; Tanthachoon et al., 2008). Most importantly, the loose structure of soil materials helps facilitating oxygen transfer and ensuring sufficient oxygen for microbial methane oxidation (Huber-Humer et al., 2008; Chiemchaisri et al., 2010a). Most of previous researches on methane oxidation at landfill cover soil were mainly focusing on its mechanisms and

* Corresponding author. Tel./fax: +66 25790730.
E-mail address: fengccc@ku.ac.th (C. Chiemchaisri).

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utilization of different types of landfill cover materials to enhance methanotrophic activities (He et al., 2008; Han et al., 2010). Potential cover materials such as compost and mechanical–biological treated (MBT) wastes have been investigated and applied in real practice (Jäckel et al., 2005; Powelson et al., 2006; Einola et al., 2008) but the utilization of stabilized solid wastes for such purpose is still very limited. In many developing countries, open dumps have been primarily used and they are later upgraded to sanitary landfills. During the remediation process, the stabilized wastes leftover within the sites need to be managed by disposal or utilization in a proper manner. The main composition in those stabilized wastes especially in developing country like Thailand are degraded organic wastes and plastic components and their composition varied with waste age (Chiemchaisri et al., 2010b). Currently their utilization is rather limited except only small fraction being converted to refuse derived fuel (Chiemchaisri et al., 2010b).

Utilization of stabilized wastes as cover material is one of the possible options for utilization of stabilized wastes from the dumpsite. The cover material can help mitigating methane emission from the landfill cell. Loose texture of stabilized wastes encouraged air diffusion from the soil surface whereas fine organic fraction available in the stabilized wastes has good water holding capacity and nutrients to stimulate methane oxidation reaction. This research is exploring a possibility to utilize those degraded organic wastes as biofiltration materials reducing methane emission at newly developed sanitary landfills once the operation those old waste dumping area are terminated.

2. Methods

2.1. Experimental system

Laboratory scale open-top lysimeters were used for evaluating methane oxidation capacity of stabilized wastes. The acrylic columns (Fig. 1) have a diameter of 0.15 m and a height of 1.0 m. They were filled with stabilized wastes obtained from a solid waste disposal site in Thailand which has been in operation for more than 20 years. Atmospheric oxygen can be facilitated into the waste layer through natural diffusion at the top of lysimeters. The solid wastes composed of 52.8% plastic wastes and 47.2% of fine fraction (stabilized organic wastes) and their chemical characteristics are shown in Table 1. Initial packing density of solid wastes was set at 270 kg/m^3 and 65% porosity, similar to the bulking density of original wastes placed at the disposal site. The columns were purged at the bottom with synthetic gas containing 60% methane and 40% carbon dioxide at different flow rates of 0.5, 1.0 and 1.5 ml/min, equivalent to actual methane loading rate of 8.32, 26.36 and 51.28 g/m^3 d respectively. The synthetic gas was used in this study to avoid any inference from other trace gases on methane oxidation reaction. These loading rates were set based on typical landfill gas emission rates from field measurements at the same solid waste disposal site (Chiemchaisri et al., 2006). During the experiment, moisture content of wastes was maintained at 10–15%, an optimum range for methane oxidation (Visvanathan et al., 1999). The experiment was conducted at room temperature (28–30 °C) for 187 d to determine long term oxidation capacities of the stabilized waste layer.

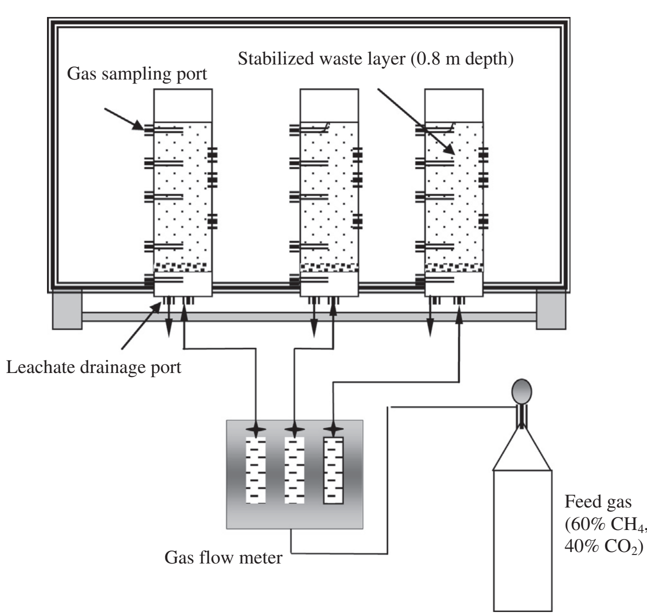

Fig. 1. Schematic of waste lysimeter experiment.

Table 1
Characteristics of stabilized solid wastes.

Parameter	Plastic wastes	Degraded organic wastes	Mixed wastes
pH	7.18	7.88	7.07
Moisture (%)	2.03	5.22	4.66
Bulk density (kg/m^3)	106.2	898.8	269.0
Porosity (%)	76.7	43.5	65.0
Volatile solids (%)	29.0	47.0	35.0
Total organic carbon (g/kg)	630.0	854.5	773.1
Ammonium nitrogen (mg/kg)	5.4	121.4	6.7
TKN (mg/kg)	390.9	2,389.8	965.7
Nitrate (mg/kg)	11.3	76.9	47.6
Total phosphorus (mg/kg)	140.8	1,394.5	428.4

Table 2
Oligonucleotide probes used for fluorescence in situ hybridization (FISH) analysis (Eller et al., 2001).

Probe	Target vbacteria	Formamide (%)	Probe and target sequence
Mγ705	Methanotroph type I	20	Probe: 3′-CTAGACTTCCTTGTGGTC-5′ target: 5′-GAUCUGAAGGAACACCAG-3′
Mγ84	Methanotroph type I	20	Probe: 3′-AGCCCGCGACTGCTCACC-5′ target: 5'-UCGGGCGCUGACG AGUGG-3'
Mα450	Methanotroph type II	20	Probe: 3′-CTATTACTGCCAT GGACCTA-5′ target:5′-GAUAAUGACGGUAC CUGGAU-3′

Methane oxidation rate (MOR) was evaluated at different segments of waste layer along the depth. The gas samples were collected at different depths of waste lysimeters, i.e. 0.1, 0.2, 0.3, 0.45, 0.65 and 0.80 m from the surface level of waste layer and they were analyzed for gas composition (CH_4, CO_2, O_2 and N_2) using a gas chromatography (GC6890, Agilent; TCD, carrier gas: helium (99.99%) 1.08 ml/s; packing material: CRT1, Alltech® in double-stainless steel columns). MOR can be determined from the following equation:

$$\mathrm{MOR}\ (\mathrm{mol/m^3\ d}) = Q[(CH_4)_{in} - (CH_4)_{out}]/V \quad (1)$$

where Q = gas flow rate (m^3/d); $(CH_4)_{in}$ = inflow methane concentration (g/m^3); $(CH_4)_{out}$ = outflow methane concentration (g/m^3); V = volume of waste (m^3).

By using Eq. (1), the observed methane concentrations in the inflow and outflow gas of each waste segment in the experimental column together with examined gas flow rate and volume of waste