Waste Management 56 (2016) 190–195

Contents lists available at ScienceDirect

Waste Management

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

Comparison of biogas recovery from MSW using different aerobic-anaerobic operation modes

Qiyong Xu [a], Ying Tian [a], Hwidong Kim [b], Jae Hac Ko [a,*]

[a] Key Laboratory for Eco-efficient Polysilicate Materials, School of Environment and Energy, Peking University Shenzhen Graduate School, Guangdong 518055, China
[b] Department of Environmental Science and Engineering, Gannon University, Erie, PA 16541, USA

ARTICLE INFO

Article history:
Received 18 March 2016
Revised 4 July 2016
Accepted 4 July 2016
Available online 12 July 2016

Keywords:
Bioreactor
MSW
Aeration pretreatment
Methane generation
Leachate quality
Oxygen consumption

ABSTRACT

Aeration pretreatment was demonstrated as an efficient technology to promote methane recovery from a bioreactor landfill with high food waste content. In this study, a short-term experiment was conducted to investigate the effects of aerobic-anaerobic operation modes on biogas recovery. Three landfill-simulated columns (anaerobic control (A1), a constant aeration (C1) and a gradually reduced aeration (C2)) were constructed and operated for 130 days. The aeration frequency was adjusted by oxygen consumption in an aerated MSW landfill. After aerobic pretreatment was halted, the methanogenic phase was rapidly developed in both the C1 and C2 columns, reducing the volatile fatty acid (VFA) concentrations and increasing pH. The methane volumes per dry MSW produced from the C1 and C2 columns were approximately 62 L/kg_{VS} and 75 L/kg_{VS}, respectively, while methane produced from the A1 column was almost negligible. The result clearly showed that aerobic pretreatment with gradual reduction of aeration rates could not only improve methane recovery from waste decomposition, but also enhance leachate COD and VFA removal.

1. Introduction

The bioreactor landfill has gained significant attention in recent years due to increased municipal solid waste (MSW) generation. The main advantages of bioreactor landfills over conventional landfills include a relatively short period of waste stabilization, high biogas production rates, and recovery of landfill space (Ahmadifar et al., 2015; Elagroudy et al., 2008; Mertoglu et al., 2006; Reinhart et al., 2002; Shao et al., 2008; Warith, 2002). However, despite the numerous advantages of bioreactor landfills, high food waste content in the MSW stream in developing countries may make it difficult to construct and operate bioreactor landfills that utilize traditional methods. Elevated concentrations of volatile fatty acids (VFAs) as a result of leachate recirculation may cause retardation of growth methanogenic bacteria, subsequently reducing methane production.

It has been reported that controlled aeration pretreatment could be a useful means to reduce the impact of VFAs on maintaining the balance between hydrolytic and methanogenic reactions (Hua et al., 2005). Favorable conditions for methane generation can be created through aeration by increasing leachate pH and decomposing organic acids generated from the waste hydrolysis process. Xu et al. (2014) demonstrated that the methanogenic phase was quickly established in aerobically pretreated bioreactors, while methane generation was inhibited in an anaerobic bioreactor. In addition to rapidly restoring the methanogenic phase, aerobic pretreatment was also applied to enhance biogas recovery. However, determining aeration rates or frequencies for pretreating MSW is complicated because the performance of aeration relies on the amount of aeration, air distribution in MSW (air permeability and moisture content), air-liquid contact area and reaeration, microbial growth conditions, biodegradable organic content of MSW, etc. In addition, due to the heterogeneous property of MSW and the dynamic changes of MSW with decomposition, it is difficult to formulate the aeration pretreatment parameters (aeration rates, modes, and frequencies) with MSW properties and/or leachate quality (Cossu et al., 2015; Nag et al., 2015; Xu et al., 2015).

Numerous studies have been conducted using various aeration positions, times and frequencies to improve the efficiency of biogas recovery (Botheju and Bakke, 2011; Sang et al., 2009; Wu et al., 2014). Gerassimidou et al. (2013) compared the total methane production from MSW (inoculated with aerobic sludge) by applying different durations of aeration pretreatment (0, 8, 45, and 90 days). The authors reported that the aerobically treated MSW reached the steady methanogenic phase faster than raw MSW. However,

* Corresponding author.
E-mail address: jaehacko@pkusz.edu.cn (J.H. Ko).

http://dx.doi.org/10.1016/j.wasman.2016.07.005
0956-053X/

excessive aerobic pretreatment might lead to the loss of organic matter and consequently the total volume of methane production could be reduced.

Therefore, it is critical to optimize the aeration pretreatment conditions to maximize biogas recovery from MSW. Xu et al. (2015) conducted a study to investigate the effects of two constant aeration frequencies on methane generation in simulated hybrid bioreactors. They argued that the use of high frequency aeration in a simulated bioreactor stimulated methane generation but reduced total methane production due to the loss of organic matter. Based on previous research, it was hypothesized that a gradual reduction in the frequency of aeration pretreatment could be helpful with respect to minimizing the loss of organic matter and increasing the efficiency of aeration pretreatment. Xu et al. (2015) determined the duration of aeration based on leachate pH by aerating MSW until the pH became 7. One of the drawbacks of the pH-based aeration controlling method was that leachate quality (pH) might not properly represent the physicochemical conditions of MSW decomposition. In this study, the aeration pretreatment conditions were determined by oxygen consumption from MSW decomposition; methane generations from MSW decomposition under these conditions were compared focusing on the effects of a constant aeration frequency and a gradual reduction in aeration frequency on landfill performance. To achieve this goal, a short-term experiment was conducted using three laboratory-scale lysimeters.

2. Materials and method

2.1. Experiment setup

Waste components were collected from the Shenzhen University Town (Shenzhen, China) and synthesized to represent the typical MSW composition in China. The compositions of MSW are shown in Table 1. Each component of MSW was shredded to less than 2 cm and mixed well before it was loaded into each reactor. The initial moisture content of the synthesized waste was 44%; a total of 800 mL of deionized water was added to generate initial leachate for recirculation.

Three reactors (A1, C1, C2) were constructed to simulate bioreactors under different operational conditions in one anaerobic and two aerobically pretreated bioreactors. All columns were made of transparent polyacrylic material with a diameter of 10 cm and height of 60 cm. A schematic diagram of those bioreactors is shown in Fig. 1. Each bioreactor was loaded with 2 kg of mixed MSW with a thickness of 40 cm. The final bulk density of the compacted waste was 640 kg/m^3. A 5-cm thick gravel layer was placed on top of each bioreactor for even distribution of recirculated leachate. Another gravel layer was placed at the bottom of the column for leachate drainage. For the aerobically pretreated bioreactors (C1 and C2), a 5-cm thick gravel layer was placed as a separated aeration layer at the 2nd/3rd height of MSW layer (Fig. 1b). Air was introduced to the aeration layer through the 0.5-cm diameter tube connected to the aeration layer. Two ports were installed on top of each bioreactor for leachate recirculation and gas collection. An additional port was installed at the bottom of the column for leachate collection.

Table 1
Component of MSW used in simulated bioreactors.

Waste component	Weight percent (%)	Moisture content (%)	Wet mass (kg)	TS (kg)	VS/TS[a]
Food waste	55.0	76	1.10	0.26	0.94
Paper	10.0	8	0.20	0.18	0.86
Plastics	10.0	<1	0.20	0.20	0.92
Sand	20.0	3	0.40	0.38	0.03
Glass	4.50	<1	0.09	0.09	<0.01
Metal	0.50	<1	0.01	0.01	0.08
Total	100	44	2.00	1.12	0.70

[a] The ratio of volatile solid to total solid.

In the aerobically pretreated bioreactors (C1 and C2), air was intermittently introduced into each reactor by a compressor (HAILEA, China, 25 W) connected to the aeration pipes, with a flow rate of 150 mL/min (134 mL/kg dry mass/min) for the first 50 days. During each aeration, air was injected for two hours. The aeration frequency in C1 was maintained at a constant frequency of 4 times/d, while C2 was aerated in a gradually reduced mode based on the change of oxygen concentration. All simulated bioreactor landfills were covered by insulation material and operated for 130 days; the temperature was maintained at 30 ± 2 °C using heating tapes with temperature controllers. Leachate collected from each column was recirculated with a flow rate of 150 mL/d. The aeration was stopped at day 50; at this point reactors C1 and C2 were operated under anaerobic conditions. Leachate recirculation was suspended when aeration was ceased in order to avoid the potential inhibition of methanogenic bacterial growth caused by abrupt changes in landfill conditions. Leachate was recirculated again at day 84, when the leachate pH in the pretreated bioreactors was stabilized at approximately 7.

In this research, several different levels of aeration rates (frequencies) were applied to the C2 column to explore the effects of variable aeration rates changed by oxygen demands on biogas recovery. A total of three different levels of aeration frequencies were applied two, three and four times a day. The oxygen demands were estimated by oxygen depletion for 30 min after aeration was halted, assuming that the oxygen levels (% in volume) in landfill gas would be reduced by waste decomposition. The change in oxygen levels within 30 min (ΔO_2/30 min) was calculated using the O_2 concentration between two points: right after aeration was stopped and 30 min after stopping aeration. ΔO_2/30 min was used to determine the time to change the aeration frequency; if ΔO_2/30 min was 2% less than in the previous observations, the aeration frequencies were reduced to the lower level. Detailed operations of each bioreactor landfill are shown in Table 2.

2.2. Sampling and analysis

The gas and leachate of each reactor were sampled regularly. The gas samples were analyzed for O_2 and CH_4 using a gas chromatograph (FULI GC 9790, Hangzhou, China) with a current of 110 mA. The temperatures of the thermal conductivity detector (TCD), sample injection port and capillary column were set at 100 °C, 70 °C and 50 °C, respectively. Leachate samples were analyzed for pH (Sartorius, PB-10, Germany). COD was measured according to the Environmental Protection Industry Standard of the People's Republic of China (HJ/T 399-2007). VFA was determined by spectrophotometry at the wavelength of 500 nm, according to routine analysis of biogas fermentation. A more detailed method description can be found elsewhere (Siedlecka et al., 2008). Blanks and calibration check samples were performed as appropriate.

3. Results and discussion

3.1. Controlling aerobic pretreatment based on oxygen consumption rate

The changes in ΔO_2/30 min over time are presented in Fig. 2. In general, the changes in oxygen levels in landfill gas within 30 min decreased over time from 6% to below 3%, indicating that a lower amount of oxygen is required for MSW decomposition. In other