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# A comparative study of leachate quality and biogas generation in simulated anaerobic and hybrid bioreactors

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A B S T R A C T

Research has been conducted to compare leachate characterization and biogas generation in simulated anaerobic and hybrid bioreactor landfills with typical Chinese municipal solid waste (MSW). Three laboratory-scale reactors, an anaerobic (A1) and two hybrid bioreactors (C1 and C2), were constructed and operated for about 10 months. The hybrid bioreactors were operated in an aerobic–anaerobic mode with different aeration frequencies by providing air into the upper layer of waste. Results showed that the temporary aeration into the upper layer aided methane generation by shortening the initial acidogenic phase because of volatile fatty acids (VFAs) reduction and pH increase. Chemical oxygen demand (COD) decreased faster in the hybrid bioreactors, but the concentrations of ammonia–nitrogen in the hybrid bioreactors were greater than those in the anaerobic control. Methanogenic conditions were established within 75 d and 60 d in C1 and C2, respectively. However, high aeration frequency led to the consumption of organic matters by aerobic degradation and resulted in reducing accumulative methane volume. The temporary aeration enhanced waste settlement and the settlement increased with increasing the frequency of aeration. Methane production was inhibited in the anaerobic control; however, the total methane generations from hybrid bioreactors were 133.4 $L/kg_{vs}$ and 113.2 $L/kg_{vs}$. As for MSW with high content of food waste, leachate recirculation right after aeration stopped was not recommended due to VFA inhibition for methanogens.



## 1. Introduction

The treatment of municipal solid waste (MSW) has become a big challenge for many developing countries, due to industrialization and urbanization. As the largest MSW generation country, China annually generates about 29% MSW of the world (Dong et al., 2001; The World Bank, 2005). Major MSW management options include landfilling, incineration, and composting (Bai and Sutanto, 2002; Cheng and Hu, 2010; Zhang et al., 2010). Among those options, bioreactor landfill technology has gained a lot of attention recently (Erses and Onay, 2003; Erses et al., 2008; Hettiaratchi et al., 2014; Liu et al., 2014; Warith, 2002; Wu et al., 2014).

The main advantages of bioreactor landfills over conventional landfills generally include facilitating waste degradation, accelerating landfill gas generation, and reducing landfill post-closure maintenance periods (Reinhart et al., 2002). Leachate recirculation is one of the most commonly used techniques in bioreactor landfills, which could create a favorable environment for waste biodegradation (Bilgili et al., 2012; Jiang et al., 2007; Šan and Onay, 2001). However, if MSW contains a large portion of food waste with high moisture content, especially for MSW in developing countries, leachate recirculation can accelerate waste acidification due to the accumulation of hydrolytic products. As a result, the acid inhibition for methanogens can delay the waste decomposition in the landfill (Brummeler and Koster, 1990; Shao et al., 2005; Valencia et al., 2009).

It was reported that aerobic bioreactor with air injection could increase the pH of leachate by decomposing acid products quickly (Bilgili et al., 2007; Sang et al., 2009). Different aspects of operating landfills with air addition, such as landfill gas composition, leachate quality, economic evaluation, and operation strategy, have been examined in many studies (Chong et al., 2005; Ko et al., 2013; Powell et al., 2006; Stessel and Murphy, 1992; Tolaymat et al., 2010). Operating an aerobic bioreactor can effectively improve leachate quality and facilitate waste degradation, but it takes out an opportunity of biogas-energy conversion. Stessel and Murphy (1992) observed the enhancement of waste degradation in the landfill with aerobic operation and proposed the application of a hybrid management system. Hybrid bioreactor landfill utilizing both aerobic and anaerobic modes could adopt the advantages of aerobic bioreactor (fast improvement of leachate quality)

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as well as anaerobic bioreactor (recovery valuable biogas) (He and Shen, 2006; Suchowska-Kisielewicz et al., 2013; Zhang et al., 2009). Previous research showed that operating a hybrid system could effectively remove ammonia nitrogen from leachate by biological nitrification–denitrification processes (Long et al., 2008, 2009; Shao et al., 2008). However, these studies mainly focused on in situ nitrogen removal from leachate, little information is available for waste degradation and gas generation in hybrid bioreactor landfills. Recent research suggested that, by temporary aeration, leachate pH of hybrid bioreactors increased faster than that in anaerobic control and methane generation phase was established (Xu et al., 2014). Hasegawa et al. (2000) found that sludge with pre-aeration increased the accumulative biogas production by 150% compared with sludge without this process. However, Brummeler and Koster (1990) showed that the excess aeration could lead to the loss of organic matters. Gerassimidou et al. (2013) observed the maximum methane production in the bioreactor with 8-day's aeration. However, the impact of aeration modes on the performance of hybrid bioreactor has not been examined.

With the increasing attention on hybrid bioreactor technology, it is necessary to understand the characteristics of waste degradation, leachate quality, as well as gas generation of hybrid bioreactor under various operational conditions. In this study, the characteristics of leachate quality and biogas generation in anaerobic and hybrid bioreactors with different aeration frequencies were compared.

## 2. Materials and methods

### 2.1. Materials

MSW was synthesized using waste components shown in Table 1. Each waste component was collected from Shenzhen University Town (Shenzhen, China). The composition of synthesized MSW represented a typical MSW in Shenzhen. The size of each waste component was manually reduced, if needed, smaller than 5 cm before mixing all components. The synthetic waste was comprised of (by wet weight) food waste (55%), paper (10%), plastics (10%), glass (4.5%), metal (0.5%) and inert material (20%, sandy soil). The initial moisture content of the synthesized waste was 42.4%. The sum of volatile solid (VS) from waste components in each bioreactor was 64% of total solid (TS). One thousand milliliter deionized water was added in each column for moisture content adjustment and initial leachate generation.

**Table 1**
Composition of MSW in simulated bioreactors.

| Waste component | Weight percent (%) | Moisture content (%) | Wet mass/kg | TS/kg | VS (%) ($\frac{VS}{TS} \times 100$) |
|---|---|---|---|---|---|
| Food waste | 55.0 | 75.07 | 2.20 | 0.55 | 82.65 |
| Paper | 10.0 | 7.69 | 0.40 | 0.37 | 87.45 |
| Plastics | 10.0 | 0.24 | 0.40 | 0.40 | 91.44 |
| Sand | 20.0 | 1.55 | 0.80 | 0.79 | 0.44 |
| Glass | 4.5 | 0.02 | 0.02 | 0.02 | 0.05 |
| Metal | 0.5 | 1.44 | 0.18 | 0.18 | 2.92 |
| Total | 100 | 42.40 | 4.00 | 2.31 | – |

### 2.2. Experimental design and operation

Three laboratory-scale columns were constructed to simulate an anaerobic control (A1) and two hybrid bioreactors (C1 and C2). Fig. 1 shows the structure of the laboratory bioreactors. Each bioreactor was constructed using 15-cm-diameter polyacrylic plastic pipe. The total height of each column was 65 cm. The working volume was about 11.5 L with a head space of 8% v/v.

In each reactor, a gravel layer was first placed at the bottom as a drainage layer. Then, a total 4.0 kg of synthesized MSW (40 cm thickness) was placed. Cobblestone was used for gravel layer placement. The bulk density of the compacted waste was 570 kg/m$^3$. A 10-cm thickness layer of gravel was placed on the top of the waste layer to facilitate the even distribution of recirculated leachate. In hybrid bioreactors, a 5-cm thickness gravel layer was located below a 13-cm-depth waste as an aeration layer. A 0.5-cm diameter of polyacrylic plastic tube was installed into the aeration layer through the center of the upper waste layer (Fig. 1b). A port was installed at the bottom of each column for collecting leachate. At the top of each column, two ports were installed to collect gas and add leachate.

All simulated bioreactors were operated for about 10 months. The reactors were covered insulation material and maintained at 30 °C using heating tapes. In the hybrid bioreactor, air was injected intermittently for two hours by a compressor (HAILEA, China, 25 W) connected to the aeration pipes, with a flow rate of 170 mL/min-kg$_{VS}$ (about 250 mL/min). The air injection frequency was twice per day in C1 and 4 times per day in C2. The intermittent air injection was conducted until leachate pH reached 7.0. Once leachate pH reached 7.0, the aeration was stopped to convert the hybrid bioreactor to anaerobic conditions for biogas generation.

Leachate collected from each column was recirculated with a 250 mL per recirculation. After aeration stopped at day 75, no recirculation was performed for C1 from day 76 to day 115. For

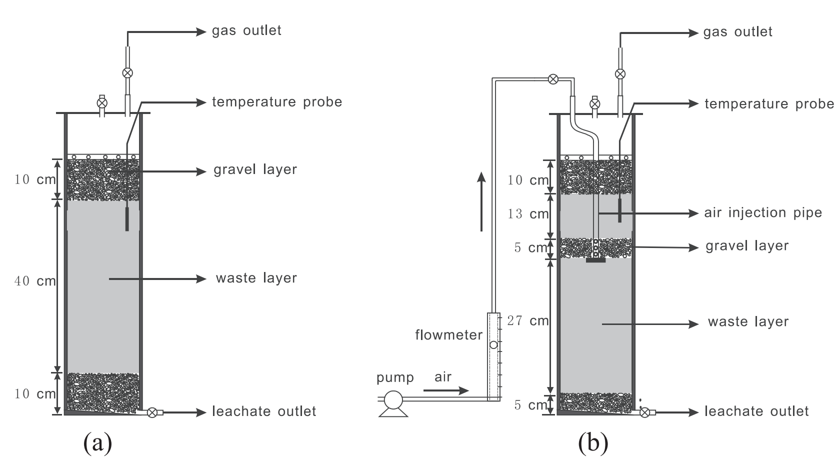


**Fig. 1.** Schematic of bioreactor landfills: (a) anaerobic bioreactor (A1) and (b) hybrid bioreactors (C1 and C2).