Bioresource Technology 222 (2016) 66–74

Contents lists available at ScienceDirect

Bioresource Technology

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

Stimulation of waste decomposition in an old landfill by air injection

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HIGHLIGHTS

- Stabilisation of old landfill by air injection was investigated.
- Bottom aeration facilitates homogenous distribution of oxygen in waste matrix.
- Substantial TOC decomposition and methane generation reduction.
- Nitrogen was effectively removed by simultaneous nitrification and denitrification.
- A slight mass reduction (around 4.0%) of aged MSW after 4.5 years of aeration.

ARTICLE INFO

Article history:
Received 7 July 2016
Received in revised form 13 September 2016
Accepted 17 September 2016
Available online 21 September 2016

Keywords:
Landfill lysimeter
Aeration modes
Spatiotemporal distribution
In situ nitrogen removal
Methane production inhibition

ABSTRACT

Three pilot-scale lysimeters were operated for 4.5 years to quantify the change in the carbon and nitrogen pool in an old landfill under various air injection conditions. The results indicate that air injection at the bottom layer facilitated homogeneous distribution of oxygen in the waste matrix. Substantial total organic carbon (TOC) decomposition and methane generation reduction were achieved. Considerable amount of nitrogen was removed, suggesting that in situ nitrogen removal via the effective simultaneous nitrification and denitrification mechanism is viable. Moreover, material mass change measurements revealed a slight mass reduction of aged MSW (by approximately 4.0%) after 4.5 years of aeration. Additionally, experiments revealed that intensive aeration during the final stage of the experiment did not further stimulate the degradation of the aged MSW. Therefore, elimination of the labile fraction of aged MSW should be considered the objective of in situ aeration.

1. Introduction

Biological stabilisation of old landfills by in situ aeration is one of the most promising landfill remediation measures, especially in cases where energy recovery is no longer economically viable. The technical and economic feasibility and the advantages of in situ aeration, e.g. reduction of greenhouse gas (GHG) emissions and acceleration of organic carbon degradation, have been demonstrated via several laboratory and field tests (Leikam et al., 1999; Heyer et al., 2005; Bilgili et al., 2006; Rendra et al., 2007; Jun et al., 2007; Rich et al., 2008; Erses et al., 2008; Sang et al., 2008; Berge et al., 2009; Bartholameuz et al., 2016; Ni et al., 2016).

Numerous technologies have been proposed, developed and examined to optimise the environmental conditions of aerobic landfills. For example, use of an aerobic bioreactor that operates through a combination of aeration and leachate recirculation is one of the most extensively documented methods. This landfill strategy can stimulate microbial activity because moisture and air are supplied simultaneously. The organic matter degradation rate was demonstrated to be markedly improved using this strategy compared with using anaerobic decomposition (Stessel and Murphy, 1992; Onay and Pohland, 1998; Borglin et al., 2004; Berge et al., 2006). However, leachate recirculation has many disadvantages. First, it can hinder the air distribution in the waste matrix (Jain et al., 2005; Yazdani et al., 2010), thereby reducing aeration efficiency. Second, ammonia, the most significant long-term pollutant in landfills (Barlaz et al., 2002), tends to accumulate in this scenario with or without landfill aeration because leachate recirculation increases the ammonification rate (Long et al., 2008a, b; Xu et al., 2014). Although previous studies have demonstrated that ammonium can be removed from the leachate by in situ nitrification, the low C/N ratio of the leachate from landfills with

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http://dx.doi.org/10.1016/j.biortech.2016.09.078
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leachate recirculation is a significant factor in limiting denitrification (Chung et al., 2015).

Given that anaerobic conditions favour nitrogen removal via denitrification, interest in hybrid landfill bioreactors has recently increased. The results of that research indicate that the hybrid conditions created by cyclic/intermittent aeration might reduce the high cost of continuous air injection and that cyclic aeration is beneficial for ammonium and total nitrogen (TN) elimination (He and Shen, 2006; Shao et al., 2008; Nikolaou et al., 2010; Chung et al., 2015). In addition, hybrid reactors are expected to surpass either anaerobic or aerobic reactors in terms of total organic carbon (TOC) reduction (Ziehmann and Meier, 1999). However, the stage/age of the applied landfill, negative impact on methane generation and practical performance at the pilot/full-scale field are issues that must be addressed before hybrid reactors can be deployed in field (Ziehmann and Meier, 1999; Lee et al., 2002; Sang et al., 2009). As an alternative to the cyclic/intermittent aeration method, hybrid conditions can also be created inside landfills using a phase separation approach. In this approach, several reactors/units perform different functions (e.g. nitrification, denitrification, methanogenesis). Schematics of such phase separation systems are readily available elsewhere (Okeefe and Chynoweth, 2000; He and Shen, 2006; Long et al., 2008a,b, 2009). The ammonium and chemical oxygen demand (COD) removal efficiencies are dramatically enhanced in this system. In addition, energy recovery from methane generation can be achieved. Nevertheless, this landfill strategy is difficult to implement because of the complexity and high costs of the systems. Therefore, a more practical landfill aeration strategy that has low operating costs, is easily applied and is highly effective is desired.

In this study, we have developed a hybrid landfill method that uses a spatial phase separation strategy. Specifically, air is injected into an anaerobic-type landfill at appropriate depths to create aerobic zones, whereby alternative aerobic–anaerobic conditions (i.e. hybrid conditions) are created vertically in the landfill. In this method, the leachate is not recirculated for the following reasons. First, landfill aeration is generally used to remediate old landfills, where the liner may be broken or absent; therefore, leachate recirculation might cause secondary contamination. Second, one of the objectives is to improve the aeration efficiency. Third, leachate recirculation is expensive. To ascertain the optimum aeration strategy for this method, the influence of different aeration modes (i.e. different combinations of air injection depths and flow rates) on the spatiotemporal distribution of gases and pollutants (e.g. TOC, NH_4^+-N, NO_x^--N) was investigated. Moreover, the mass change of carbon and nitrogen in the solid, liquid and gas phases was calculated. The results obtained here may lay a foundation for the optimal design of landfill aeration systems and provide a scientific basis for further study.

2. Materials and methods

2.1. Characteristics of refuse

The solid waste used for lysimeter experiments was collected from Laogang landfill, a sanitary landfill located southeast of Shanghai city, China. The Laogang landfill is home to China's (and Asia's) largest landfill and is being operated since 1989. It currently serves as Shanghai's main disposal site for municipal solid waste (MSW), accepting between 8000 and 10,000 tons of trash daily from 11 districts of Shanghai. This landfilled waste was subjected to anaerobic biodegradation for approximately 5–8 years before our experiments. Solid waste samples were collected from several random pits (at a depth of approximately 1 m), which were excavated by a digger, and then mixed so that the most representative sample could be obtained. The excavated waste was manually sieved to a particle size of less than 10 cm, thoroughly homogenised and placed into lysimeters under tight compaction. The mass composition of the processed solid waste was as follows: ceramics and stone (28.6%); glass (6.7%); wood, bamboo and straw (6.6%); kitchen waste (6.0%); plastics (4.7%) and particles of size 5 mm or less (43.0%). The physicochemical characteristics of the processed solid waste are listed in Table 1.

2.2. Experimental setup and operation

Three pilot-scale lysimeters (Lys. A, B and C) were constructed to simulate hybrid landfills and an anaerobic landfill. As shown in Fig. 1, the lysimeters were 3 m in height and 1 m in diameter, and were constructed using iron. A 0.1 m thick layer of coarse gravel was placed at the bottom of each column as a drainage layer. The manually segregated fraction of aged MSW (~3.1 t in wet weight) was loaded into each lysimeter, resulting in a bulk density of 1.4 t/m^3. A 0.1 m thick layer of soil was placed on top of each of the lysimeters. Each lysimeter had with six ports for leachate collection, six ports for gas collection and another six ports for solid waste collection. Each port contained a tube that extended to the centre of the lysimeter for gas and leachate collection. Each lysimeter contained three air injection ports at depths of 0.5, 1.5 and 2.5 m. To prevent asymmetrical distribution of air, two separate

Table 1
Waste characteristics from lysimeter A, B and C on different days. The data presented in this table represents the averaged values of six solid sample collected from different depth at particular points in time.

	0 d	586 d	1050 d	1625 d	0 d	586 d	1050 d	1625 d	0 d	586 d	1050 d	1625 d
Moisture content (%)	40.4	37.5	34.4	36.2	43.0	34.1	34.3	34.7	43.0	34.1	31.6	36.6
Packing density (t-wet/m^3)	1.4	N.D.	N.D.	1.1	1.4	N.D.	N.D.	1.1	1.4	N.D.	N.D.	1.1
C (%, d.b)[a]	10.8	10.3	11.5	10.7	11.0	10.1	11.5	10.8	11.2	10.6	N.D.	11.2
N (%, d.b)[a]	0.7	0.6	0.6	0.5	0.7	0.7	0.6	0.5	0.8	0.7	0.6	0.5
LOI (%)	24.4	23.0	16.3	16.2	24.1	19.9	17.5	16.4	25.8	25.7	19.1	17.3
Settlements (cm)	0.0	4.8	6.7	8.6	0.0	6.4	8.3	10.1	0.0	7.8	9.8	11.5
pH (–)[b]	7.6	7.7	7.6	7.8	7.5	7.6	7.6	7.9	7.4	7.7	7.5	8.2
EC (ms/cm)[b]	2.9	3.0	1.5	N.D.	2.9	3.4	1.5	N.D.	2.8	2.8	1.0	N.D.
ORP (mv)[b]	138.8	273.7	168.0	N.D.	142.6	185.7	169.0	N.D.	142.8	164.3	142.0	N.D.
Extractable OC (mg/kg-dry)[b]	719.8	N.D.	529.2	505.0	730.2	N.D.	650.5	567.9	655.0	N.D.	575.8	620.8
Extractable NH_4^+-N (mg/kg-dry)[b]	535.7	22.7	8.0	0.0	548.7	22.6	7.5	0.0	543.0	37.0	15.7	75.2
Extractable NO_2^--N (mg/kg-dry)[b]	459.8	26.9	9.3	0.0	532.1	36.4	13.8	0.0	196.7	123.3	4.7	0.0
Extractable NO_3^--N (mg/kg-dry)[b]	177.5	74.2	72.6	202.2	204.7	60.9	83.5	277.7	267.2	67.9	107.6	127.5
Extractable Cl^- (mg/kg-dry)[b]	3361.5	2089.2	961.0	894.2	3525.9	1880.8	767.1	484.4	3407.0	1549.1	482.8	487.0
Extractable SO_4^{2-} (mg/kg-dry)[b]	9887.5	12234.8	7430.0	976.4	10287.5	14621.9	7491.6	786.6	9959.9	11128.6	4543.4	496.6

LOI: Loss on Ignition; EC: Electrical Conductivity; ORP: Oxidation Reduction Potential.

[a] Were represented for the solid samples whose particle size was less than 5 mm.

[b] Were measured after the leaching test which was authorized by Japanese Environmental Agency, JLT-46.