



Targeted modification of organic components of municipal solid waste by short-term pre-aeration and its enhancement on anaerobic degradation in simulated landfill bioreactors



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HIGHLIGHTS

- Short-term pre-aeration effectively enhanced anaerobic degradation of MSW.
- MSW with 6-day pre-aeration performed the highest methane yield with 123.4 NL/kg DM.
- Accelerated proteins degradation by pre-aeration neutralized excessive VFAs.
- Pre-aeration was ceased before its cooling stage to switch to anaerobic landfilling.

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ABSTRACT

Pre-aeration is effective on regulating subsequent anaerobic degradation of municipal solid waste (MSW) with high organic fractions during landfilling. The strength of pre-aeration should be optimized to intentionally remove some easily biodegradable fractions while conserve bio-methane potential as much as possible. This study investigates the evolution of organic components in MSW during 2–14 days pre-aeration process and its impacts on subsequent anaerobic degradation in simulated landfill bioreactors. Results showed that a 6-day pre-aeration enabled to develop a thermophilic stage, which significantly accelerated biodegradation of organics except lignocelluloses, with removal rates of 42.8%, 76.7% and 25.1% for proteins, carbohydrates and lipids, respectively. Particularly, ammonia from accelerated ammonification in the thermophilic stage neutralized VFAs generated from anaerobic landfilling. As a result, the MSW with 6-day pre-aeration obtained the highest methane yield 123.4 NL/kg dry matter. Therefore, it is recommended to interrupt pre-aeration before its cooling stage to switch to anaerobic landfilling.

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1. Introduction

Municipal solid waste (MSW) generated in Asia developing Countries has been characterized typically by high moisture content and high organic content. Food waste is usually the dominant composition accounting for more than 50% by weight (Norbu et al., 2005; Zheng et al., 2014a). Landfilling is the prevalent method of MSW disposal in developing Countries, especially in China (Zhang et al., 2010). However, due to its physical-chemical characteristics, direct landfilling of raw MSW, which is commonly applied in China, is easy to cause a series of complex environmental prob-

lems, e.g. complex leachate generation, odorous charge, fugitive GHG emissions, undesirable land uses and long-term health hazards (Cai et al., 2015; O'Keefe and Chynoweth, 2000; Reinhart et al., 2016).

Under this scenario, aiming at better minimizing adverse environmental impacts, some in-situ landfill modes (generally including anaerobic bioreactor landfill, aerobic bioreactor landfill, hybrid bioreactor landfill, facultative bioreactor landfill, flushing bioreactor landfill and flooding/draining landfill cells) and multi-stage landfill modes (e.g. ex-situ pre-treatment prior to anaerobic bioreactor landfill) are of increasing interest in recent landfill management schemes (Clarke et al., 2015; Cossu et al., 2015; Mali et al., 2012; Siddiqui et al., 2012; Slezak et al., 2015; Xu et al., 2014). Among the multifarious alternatives, aerobic biological

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pre-treatment has been shown to be effective and became an important landfilling practice, especially in European Countries (Montejo et al., 2013; Scaglia et al., 2010). When applying a long-term aerobic biological pre-treatment, the goal is to produce stabilized residuals that can be safely disposed of to minimize the pollutant emissions, but almost renouncing the opportunity to collect a good amount of biogas to be converted into energy. Meanwhile, waste management costs increase significantly when this process is used (Reinhart et al., 2016).

After considering a balance between environmental and economic benefits, a short-term aerobic biological pre-treatment (2–4 weeks or less) prior to landfilling was proposed (Gerassimidou et al., 2013; Salati et al., 2013; Scaglia et al., 2013). This method would enable to obtain semi-stabilized products, allowing, on one hand, landfill pollutant emissions abatement, and, on the other hand, the preservation of a certain part of biogas producible under anaerobic treatment (Tambone et al., 2011). Gerassimidou et al. (2013) reported that 8-day aerobic biological pre-treatment was very effective for improving the performances of landfill bioreactors which accepted MSW with a high content of putrescibles. In this regard, considering the reasonable pre-treatment costs and specific characteristics of generated MSW, this short-term biological pre-aeration followed by anaerobic landfilling is of great economic, environmental and social importance to effectively meet the recent requirements of MSW disposal in developing Countries.

To determine an appropriately short but effective pre-aeration duration is still challenging. Previous researches have been directed towards the evaluation of the effects of aerobic pre-treatment on subsequent anaerobic landfilling, taking into account different aeration modes and aeration time, and many advantages have been already proven (Cossu et al., 2015; Mansour et al., 2012; Xu et al., 2015). Data in the references suggests using VS and carbon losses as criteria to determine the right time to start subsequent anaerobic treatment (Gerassimidou et al., 2013; Mansour et al., 2012). Even so, there are still gaps in understanding what level of pre-aeration is actually required, especially for MSW with high organic fractions, as these parameters does not provide much information about the specific components remaining. It is well known that the types of organic components in waste significantly influence its anaerobic degradation behaviours (Kobayashi et al., 2012; Wang and Barlaz, 2016; Zheng et al., 2014b). This means that, in order to optimize pre-aeration process, targeted removal of organic components in waste should be extremely considered. However, little attention has been paid to systematically evaluate the temporal change of organic components in MSW (e.g. carbohydrates, proteins, lipids and lignocellulose) during short-term pre-aeration process and its correlations with subsequent anaerobic treatment. Owing to deficiencies in consistent pre-aeration intensity, previous reports (Gerassimidou et al., 2013; Mansour et al., 2012; Scaglia et al., 2013) achieved yet cannot definitely provide the sound evidences on how short-term pre-aeration could modify the organic components in MSW, consequently failing to present the right time switching between pre-aeration process and subsequent anaerobic landfilling.

In this study, a series of short-term pre-aeration durations, namely 2, 4, 6, 8, 11 and 14 days, was applied before anaerobic degradation of MSW in simulated landfill bioreactors. In line with different pre-aeration durations, the associations with leachate emissions and methane production from anaerobic landfilling phase, as well as comprehensive organic components characterization during the whole combined process were investigated. The overall objectives of this study were (1) to evaluate the modification of organic components achieved during short-term pre-aeration and compare its subsequent impacts on leachate quality and methane yield from anaerobic landfilling; (2) to discuss mechanisms

of short-term pre-aeration to enhance anaerobic degradation; and (3) to identify potential process indicators to determine switching point between pre-aeration and subsequent anaerobic treatment.

2. Materials and methods

2.1. Substrate - Synthetic municipal solid waste

On the basis of the typical MSW composition in Beijing (Sun et al., 2014), a synthetic MSW was prepared using a mixture of food waste (FW), office paper (OPF), plastic (P) and inorganic materials (I) such as stones, glasses and metals. The mixture ratio of these components was fixed at 63% (FW), 13% (OPF), 5% (P) and 19% (I) on a wet weight basis. The initial water content and biodegradable VS content of the synthetic MSW were 57.5% (w/w) and 47.3%TS, respectively. The chemical components are showed in Table 1. Synthetic MSW is preferred to real MSW in order to better understand the reactor inputs and to ensure a reliable comparison between the outputs of short pre-aeration intensities specially arranged in this study. The MSW was manually shredded and well mixed with a uniform size of 20–40 mm.

2.2. Experimental equipment

Six laboratory-scale Plexiglas columns were used as bioreactors to compare the effects of different short-term pre-aeration durations on anaerobic landfilling. Another column without pre-aeration was arranged as control (AN bioreactor). Each reactor had an internal diameter of 180 mm and a height of 320 mm. A perforated plate was fixed approximately 50 mm above the bottom of each reactor to support the waste and facilitate aeration. The upper end of each column was equipped with two valves to allow gas extraction and leachate recirculation. The lower end was equipped with a valve for leachate collection. The ventilation rate was regulated by a LZB-10 flowmeter (Shanghai Instrument Co.). A thermo-regulated insulation system was designed to cover all the reactor lateral surfaces and to maintain a constant temperature at 35 ± 1 °C. The waste mass temperature was monitored and recorded using a Pt100 temperature sensor installed in the centre of each reactor, and the data were logged with a two-minute interval using a data collector (Meikong CO.). The reactor sketch is illustrated in Fig. 1.

2.3. Methodology

2.3.1. Pre-aeration phase

Three kilos of MSW was filled into each column. While loading, approximately 150 g of sludge compost (5% inoculation rate) was mixed in the waste to enhance the aerobic degradation process (Mali et al., 2012). The short-term pre-aeration duration was the sole variable. Each bioreactor had its own pre-aeration duration: 2, 4, 6, 8, 11 and 14 days (i.e. R1–R6 bioreactors, respectively), in order to evaluate its effects. The initial airflow rate was fixed at

Table 1
Chemical components of synthetic MSW used in this study

Parameter	Values ^b
Carbohydrates (g/g TS) ^a	0.174 ± 0.013
Crude proteins (g/g TS)	0.229 ± 0.003
Crude lipids (g/g TS)	0.155 ± 0.001
Lignocelluloses (g/g TS)	0.363 ± 0.024
Total carbon (g/g TS)	0.454 ± 0.001
Total nitrogen (g/g TS)	0.030 ± 0.001

^a Results were tested after plastic and inorganic materials removal.

^b Data are the means of triplicate measurements ± standard deviations.

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