

Emission characteristics of odorous compounds during short-term pre-aeration of municipal solid waste prior to landfilling

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An important advantage of using a short-term pre-aeration of municipal solid waste (MSW) with high organic fractions prior to landfilling is that it intensively decomposes a part of organic matter, especially easily biodegradable fractions in waste, and thus regulates the subsequent anaerobic degradation of MSW under landfill conditions, meanwhile conserving the bio-methane potential as much as possible. However, this organic matter degraded during the pre-aeration process is converted by aerobic microorganisms into high concentrations of organic leachate and exhausted gases (e.g. NH_3 and volatile organic compounds), which are also potential pollution sources to the surrounding environment.

In this study, the emission characteristics of leachate and odorous gases generated during a short-term pre-aeration process of MSW are investigated in a laboratory reactor. It is found that MSW, pre-treated aerobically for 7 days, results in ~28.1% of weight loss and ~30.3% of capacity loss, respectively. Due to the initial hydrolysis, acidification and leaching of organic solids, TOC concentrations in leachate generated during the pre-aeration process increase rapidly at the beginning, and then are maintained at relatively stable levels, averaging from 16,700 to 26,000 mg/L. A certain amount of VFAs, mainly butyric acid (50-75%) and acetic acid (20-50%), is detected in leachate, with the concentration range of 1,000-18,000 mg/L, which can increase the odorous risk from leachate storage and treatment operation. NH_3 emission in the exhaust gases is highly consistent with the degradation of proteins and temperature evolution, with the maximum release capacity of ~37.6 mg/(kg DM.h) occurring at day 4. Compared to the initial untreated waste, the release strength of halocarbons and aromatic hydrocarbons from the pre-aerated waste is obviously decreased, whereas higher concentrations of organosulfurs, such as ethanethiol and dimethyl disulfide, and alkanes are observed (~10 times higher). This finding suggests that more attention should be paid to control the odorous charge during the subsequent storage, transportation and landfilling operation of the pre-aerated waste.

1. Introduction

Landfilling is the most prevalent method of municipal solid waste (MSW) disposal in the world, especially in developing countries. In order to minimize adverse impacts to the surrounding environment and improve the performance of MSW landfilling, multistage landfill modes are of increasing interest in recent landfill practice (Clarke et al., 2015; Cossu et al., 2015; Xu et al., 2014). Among these modes, a short-term pre-aeration of MSW prior to landfilling shows its advantages that allows, on the one hand, an abatement of landfill pollutant emissions and accelerated stabilization of MSW, and, on

the other hand, the conservation of a certain amount of biogas producible under anaerobic operation (Gerassimidou et al., 2013; Ni et al., 2016; Salati et al., 2013; Scaglia et al., 2013). Considering economic, environmental and social benefits, this short-term biological pre-aeration followed by anaerobic landfilling is effective to meet the recent requirements of MSW management in developing countries.

The operation of short-term pre-aeration may be used as a composting-like process, and a part of organic matter in waste, especially easily biodegradable fractions, can intensively be decomposed by aerobic microbes. During this process, it cannot be avoided to generate high concentrations of organic leachate and exhaust gases, such as NH_3 and volatile organic compounds (VOCs) (Kumar et al., 2011). It is reported that total non-methane organic compounds and total volatile sulfur compounds derived from food waste aerobic composting account for ~ 0.379 mg-C/dry g, and this value is comparatively higher than those emitted from paper, yard waste, and MSW decomposition (Staley et al., 2006; Zhang et al., 2013). MSW generated in developing countries is typically characterized by high moisture and high organic content, in which food waste is dominant, usually accounting for more than 50% by weight (Norbu et al., 2005; Zheng et al., 2014). These special characteristics of MSW can strengthen the pollution or health risk potential to the surrounding environment and people during the pre-aeration process, to some extent.

In this study, the emission characteristics of odorous charge, containing leachate and exhaust gases, generated during a short-term pre-aeration process of MSW, are investigated in a laboratory reactor. Based on the daily monitoring, the results obtained here can contribute to preventive recommendations for pollutant abatement during aerobic pre-treatment to help regulatory bodies.

2. Materials and methods

2.1 Substrate and experimental equipment

Based on the typical MSW compositions in Beijing city (Sun et al., 2014), synthetic MSW is used in the present study to minimize variability and guarantee the comparability between the reactors. A detailed breakdown of the initial waste composition was shown in a previous report (Ni et al., 2016). The initial water content and biodegradable VS content of the synthetic MSW are 55.7% (w/w) and 48.7%TS, respectively. The MSW is manually shredded and well mixed with a uniform size of 20–40 mm.

Two laboratory-scale Plexiglas columns are used as pre-aeration reactors in the present research. Each reactor has an internal diameter of 240 mm and a height of 1,100 mm. To channel air into the waste body, a vertical stainless steel pipe with side perforations is installed at the centre of the reactors. The ventilation rate is regulated by a LZB-12 flowmeter. A thermo-regulated insulation system is designed to cover all the reactor lateral surfaces and to maintain a constant temperature at $35 \pm 1^\circ\text{C}$. The waste mass temperature is monitored using three Pt100 temperature sensors installed in the side of each reactor (upper, middle and lower layers, respectively). Additionally, a 10-cm thick gravel layer is placed at the bottom of the reactors for leachate discharge.

2.2 Methodology

Before pre-aeration, ~ 16 kg MSW is filled into each reactor, resulting in a density of ~ 0.5 t/m³. While loading, approximately 800 g of sludge compost (5% inoculation rate) is mixed in the waste to enhance the aerobic degradation process. The airflow rate is

fixed at 0.5 L/min/kg waste at room temperature in both reactors, with a frequency of 10 min every 20 min, to maintain a favourable aerobic condition. The pre-aeration time lasts for 7 days, which is considered a reasonable and effective duration to regulate the subsequent performance of landfilling operation (Ni et al., 2016). Additionally, no leachate recirculation is used during the pre-aeration process.

2.3 Analytical methods

The physical and chemical characteristics of the substrate before and after aerobic pre-treatment are measured according to the methods reported by Ni et al. (2016). Leachate samples from the pre-aeration process are tested for the following analytical parameters daily, according to APHA methods (2005): pH, TOC, TN, $\text{NH}_4^+\text{-N}$, and VFA. The CO_2 content emitted on this stage is measured by a GC-2014 gas chromatographer equipped with a thermal conductivity detector. Exhaust air is bubbled through a 250 ml 2 N H_3BO_4 solution to capture NH_3 , and this solution is tested every 12 h to determine the amount of NH_3 stripping. All the analysis on solid and liquid samples is conducted in duplicate.

VOCs emitted from the waste mass at the beginning and the end of the pre-aeration process is grabbed using summa canister and analyzed according to the TO-15 method, using a GC-MS system. This method was also used in a previous study to determine the VOC emissions from the actual landfill site in Beijing city (Duan et al., 2014).

3. Results and discussion

3.1 Evolution of temperature and CO_2 concentration during the pre-aeration process

The temporal evolution of the temperature and CO_2 content in the free space of the reactors before ventilation is shown in Fig. 1. Pre-aeration of 7 days enables the waste mass to undergo the complete stage of temperature rise ($29.8 < T < 45^\circ\text{C}$) and thermophilic stage ($T > 45^\circ\text{C}$), with the maximum temperature of 58.5°C . It was reported that the thermophilic temperature is beneficial for the decomposition of easily degradable components in waste, while a mesophilic condition can accelerate the degradation of lignocelluloses (Ni et al., 2016). Based on this reason, it is advisable to interrupt the pre-aeration process before the waste mass temperature entering into the cooling stage to give way to anaerobic treatment, with the purpose of conserving the fraction of lignocelluloses in the waste as much as possible for the subsequent methane production. This is also assumed to support the reason why a pre-aeration of 7 days is used in this study. At the end of the pre-aeration of 7 days, the temperature of the pile mass decreases to less than 50°C . Liu et al. (2009) reported that the pile temperature, if it remains above 55°C for 24 h, will result in an almost complete destruction of human and animal pathogens. In this study, the pile average temperature remains above 55°C around 3 days, it infers that the post-sorted waste is free from pathogens after this short-term pre-aeration.

The CO_2 concentration can indicate the degradation efficiency of organics by aerobic microorganisms under the given ventilation modes, to some extent. Coinciding with the temperature evolution, the CO_2 concentration in the free space of the reactors before ventilation gradually increases from 130 mL/L and peaks at 730 mL/L at day 4, then decreases rapidly. At the end of the experiment, the CO_2 level slightly increases and remains at a high level (> 470 mL/L), possibly implying that mesophilic organisms are

activated again, especially fungi and actinomycetes, which can consume lignocelluloses in waste as carbon source further. Finally, the pre-aeration of 7 days results in ~28.1% of weight loss of substrates and ~30.3% of capacity loss, respectively.

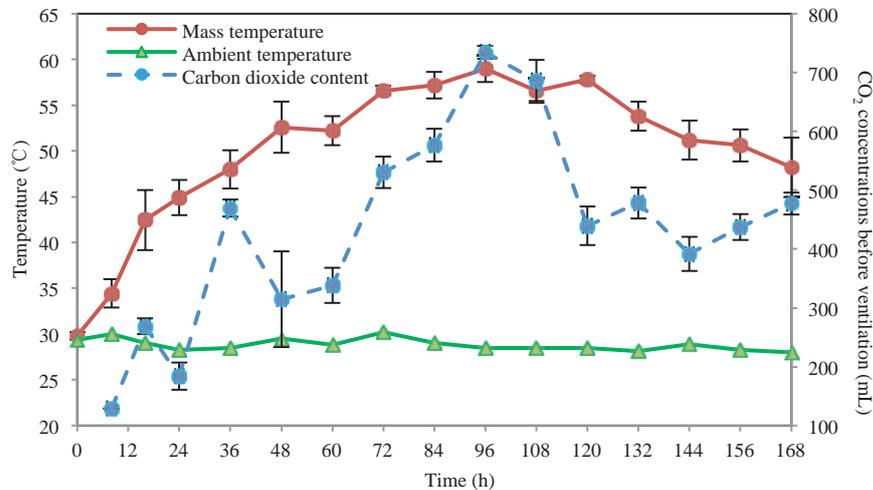


Figure 1: Temporal evolution of temperature and CO₂ concentration before ventilation.

3.2 NH₃ and VOC emissions during the pre-aeration process

NH₃ emissions from the exhaust gas are of utmost concern for the odorous nuisance during the pre-aeration of MSW. Coincident with the temperature increase, NH₃ generation from the degradation of proteins is evidently accelerated. It gradually increases from almost 0 mg/(kg DM·h) and peaks at ~37.6 mg/(kg DM·h) at the end of day 4, and then decreases rapidly due to consumption of substrates. This generation rate of NH₃ is also impacted by the pH of the system. In this study, it is observed that the pH values of leachate generated daily gradually increase from 4.7 to 7.5 during the same period. This finding is in agreement with Charles et al. (2007) who also found that the high protease exoenzyme activities during the thermophilic stage and high pH were responsible for the high NH₃ volatilization.

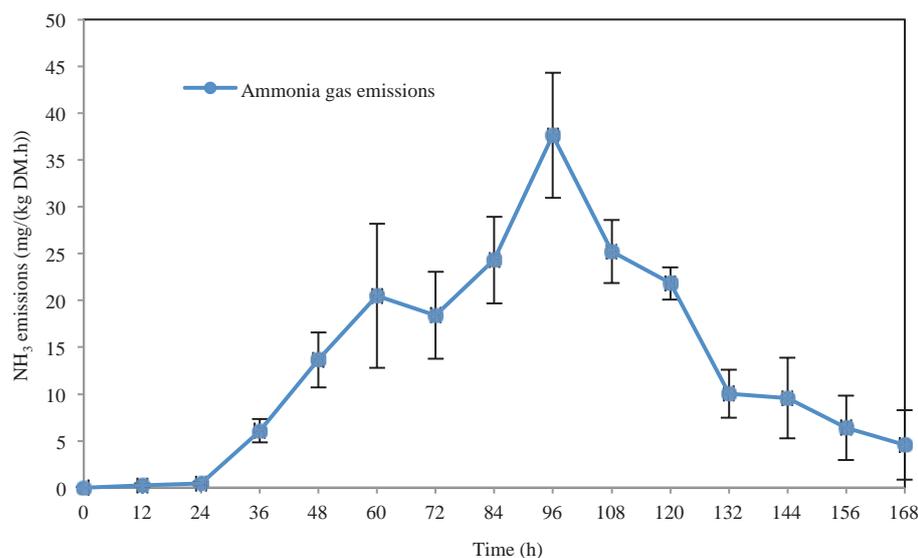


Figure 2: Ammonia emission during short-term pre-aeration of MSW.

During pre-aeration, a mass of VOCs is inevitably generated and emitted to the surrounding environment. Most VOC emissions are generally responsible for odorous nuisance and health risks due to their relatively low olfactory thresholds and potential toxicity. In this study, the VOC emissions detected contain mainly alkanes, halocarbons, aromatic hydrocarbons, organic sulfur compounds and oxygenated compounds (Fig. 3). For the initial untreated waste, ethanol is the largest category of VOC emissions, accounting for 36.1% (w/w) of the total VOCs tested, followed by esters, sulfur compounds, halocarbons, alkanes and aromatic hydrocarbons. To investigate the olfactory nuisance related to the solid waste treatment, organosulfurs are consistently considered to be the main contributors, although aerobic processes are sometimes applied (Ni et al., 2015). Four representative organosulfurs are identified in this study, mainly containing methanethiol, dimethyl sulfide, carbon disulfide and dimethyl disulfide, and their concentrations are in the range of 0.003~0.3 mg/m³.

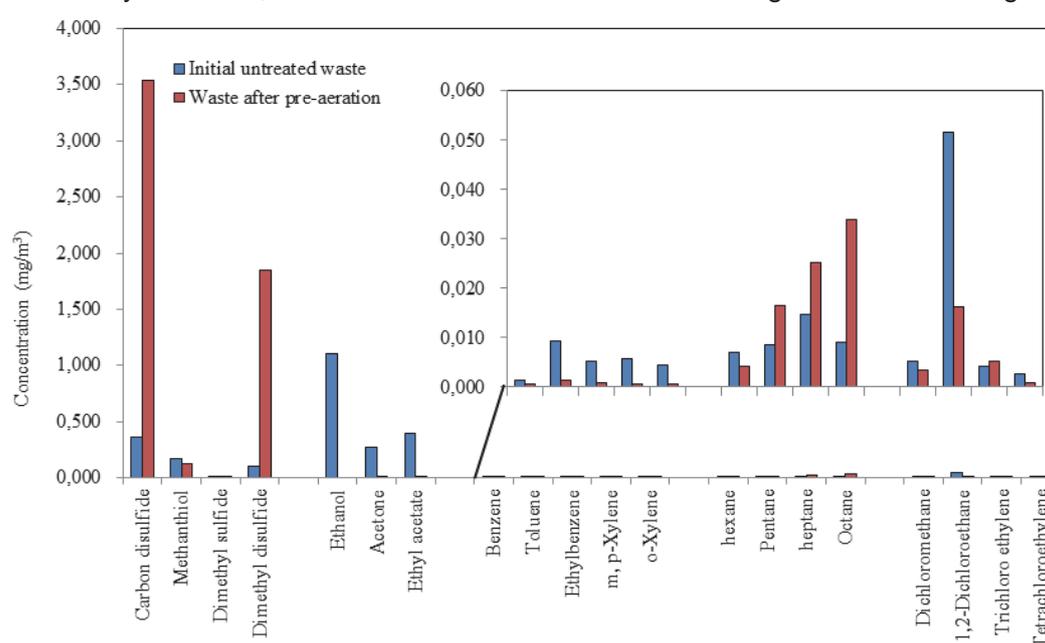


Figure 3: Dominant VOC emissions detected from waste mass before and after pre-aeration.

Compared with the VOCs emitted from the untreated waste, higher emission concentrations of alkanes and organosulfurs are detected from the waste after pre-aeration (~10 times higher), but less halocarbons and aromatic hydrocarbons are detected (Fig. 3). The decomposition of organic sulfur, mainly from the proteins contained in waste, under aerobic conditions, result in mercaptanes (Organic group -SH), and dimethyl sulphide, tending to be generated under conditions of anoxic circumstances, predominates (Fang et al., 2015); meanwhile, alkanes are more likely generated from decomposition of lipids in waste. These two kinds of VOCs are commonly considered as biogenic compounds, which are generated due to biodecomposition during the short-term pre-aeration process. On the contrary, halocarbons and aromatic hydrocarbons are usually considered as abiogenic compounds in waste (Powell et al., 2005) rather than as intermediate products of waste biodegradation, thus pre-aeration is beneficial for eliminating their contents through air stripping. Due to the low odour threshold value of organosulfurs, the above findings suggest that, from the perspective of odour control, more attention should be paid to

the subsequent storage, transportation and landfilling operations of the pre-aerated waste.

3.3 NH₃ and VOC emissions during the pre-aeration process

Due to the initial hydrolysis by aerobic organisms and leaching of organic solids, TOC concentrations in leachate generated during the pre-aeration process increase rapidly at the beginning, and then are maintained at relatively stable levels (~20,000-26,000 mg/L) (Fig. 4). A certain amount of VFAs is also detected in leachate generated during the pre-aeration process. Some species of VFAs, such as butyric acid and valeric acid, possess the pungent smell, which is, thus, an important source of odour emission (Fang et al., 2015). In this study, the concentrations of VFAs in leachate increase evidently from the initial value ~1,000 mg/L to 18,000 mg/L at the end of the pre-aeration (Fig. 4). The rapid increase of VFA concentrations, occurring at the end of day 3, may be attributed to the accelerated decomposition of proteins in waste, which is consistent with the increase of NH₃ emissions (Fig. 2); meanwhile, the settlement of pile mass can increase the difficulty of the oxygen transmission. This results inevitably in the locally anaerobic condition of the system, which can enhance the yield of VFAs. Among the VFAs detected, butyric acid (50-75%) is dominant, followed by acetic acid. The presence of these VFAs can aggravate the odorous risks from the leachate storage and treatment units.

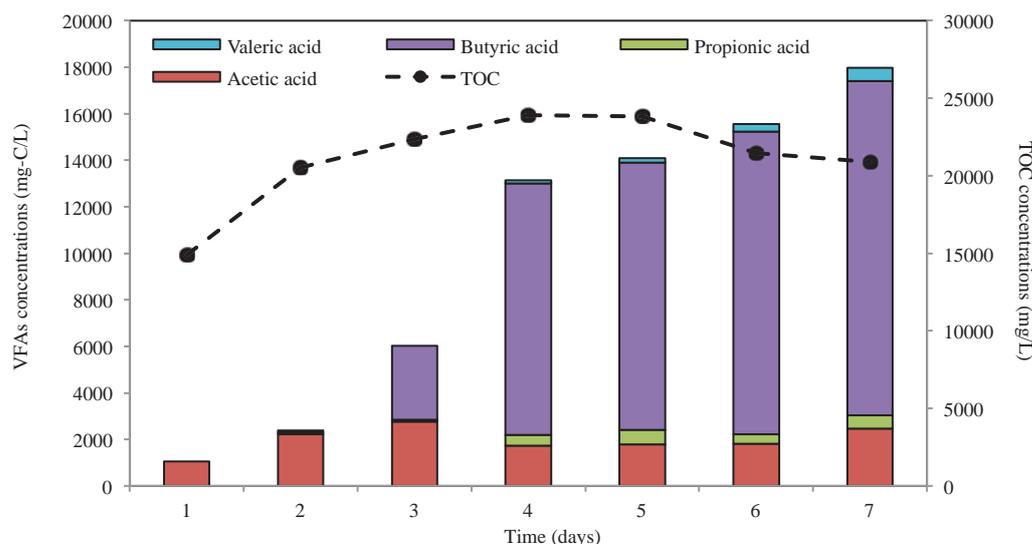


Figure 4: Evolution of VFAs in leachate during the pre-aeration process.

4. Conclusions

Short-term pre-aeration is effective in reducing the amount and volume of waste prior to its disposal. However, intensive pre-aeration could generate high concentrations of leachate and odorous gases, which make it a potential source of odorous nuisance. During the pre-aeration process, the NH₃ emission in exhaust gases is highly consistent with the temperature evolution and the degradation of proteins, with the maximum value detected in this study of ~37.6 mg/(kg DM.h). Compared to the initial waste, the release strength of halocarbons and aromatic hydrocarbons from the pre-aerated waste is decreased, whereas higher concentrations of organosulfurs and alkanes are observed, suggesting that more attention should be paid to the subsequent

storage, transportation and landfilling operations of the pre-aerated waste. Additionally, the presence of VFAs in leachate, mainly butyric acid and acetic acid, aggravate the odorous risks from the leachate storage and treatment units.

Acknowledgements

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