Bio-stabilization of municipal solid waste prior to landfill: Environmental and economic assessment

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Abstract

A bio-stabilization was undertaken to pre-treat municipal solid waste (MSW), characterized by high moisture and organic matter, prior to landfill. The bio-stabilization included 16 days of active stage with enhanced aeration and 84 days of curing stage. The results showed that MSW weight was reduced by nearly 85% and MSW stability improved, with respiration activity (AT_4) and anaerobic gas production (GB_{21}) being reduced by 93% and 87%, respectively. The dramatic degradation of organic matter occurred in the active stage of bio-stabilization. Based on the bio-stabilization results, the economic and environmental analysis was conducted following 3 scenarios: the conventional landfill (CL), the combination of active stage of bio-stabilization and subsequent sanitary landfill (AL), and the combination of both active and curing stage of bio-stabilization and subsequent sanitary landfill (ACL). The results showed that AL could substantially save land resource and mitigate landfill pollutions, and the costs of AL would be the lowest as well.

Keywords

Municipal solid waste, Bio-stabilization, Landfill, Environmental and economic analysis

1 Introduction

Landfill is the most prevalent disposal method for municipal solid waste (MSW) management worldwide, as it is considered to be simple and low cost. Nevertheless, the amount of MSW is increasing dramatically these years. Considering the decreasing of valuable land resource, and long term environmental pollution such as leachate and landfill gas (LFG) (TCHOBANOGLOUS ET AL., 1993), raw MSW should not be landfilled directly (KOMILIS ET AL., 1999). This problem would be more critical in the developing countries, where MSW is often characterized by high moisture and organic matter content (MÜNNICH ET AL., 2006; NORBU ET AL., 2005). Bio-stabilization, an effective pretreatment prior to landfill, is regarded to be an environment friendly technology (ADANI ET AL., 2004; LORNAGE ET AL., 2007; SHAO ET AL., 2008).

Bio-stabilization involves enhanced biological degradation of organic matter, which can reduce MSW weight and volume, and decrease the environmental pollutions, such as leachate and landfill gas. On the other hand, bio-stabilization needs extra construction investment, operation and management (O&M) costs, which also have their own environmental impacts. However, the additional costs may be off-set by numerous economic advantages resulting from the combination of bio-stabilization and subsequent landfill, such as more efficient utilization of land space, leachate production and greenhouse gas emissions reduction, and post-closure costs savings.

Although the reduction of environmental impact through bio-stabilization has been reported quantitatively (MÜNNICH ET AL., 2006; NORBU ET AL., 2005; LORNAGE ET AL., 2007; ADANI ET AL., 2004; SHAO ET AL., 2008), there is still limited information about the time when shift the bio-stabilization period into subsequent landfill, oriented to minimum pollution potential and maximum benefits.

This paper presents the performance of bio-stabilization of MSW characterized by high moisture content and organic matter content, and environmental and economic analysis were conducted to optimize the combination of bio-stabilization and subsequent landfill are discussed.

2 Materials and Methods

The MSW used in this experiment was sampled from a residential area located in Shanghai, China. It comprised 60% ($w \cdot w^{-1}$, in wet weight, the same below) of kitchen waste, 23% ($w \cdot w^{-1}$) of paper, 11% ($w \cdot w^{-1}$) of plastics and 6% ($w \cdot w^{-1}$) of the others, which represents the typical MSW in developing countries. The whole bio-stabilization experiment was divided into two stages, i.e. active stage and curing stage. The active stage was carried out in the column reactor (1200 mm of height and 400 mm of internal diameter, described in detail by ZHANG ET AL. (2008)) for 16 days of enhanced aeration, with air-inflow rate fixed at 0.056 m^3 per kg wet wastes per hour, and the wastes were turned every 2 days. The following curing stage was performed in the column for 84 days and the wastes were turned every 7 days.

The moisture was determined under 70°C for 2 days. The volatile solids (VS) content, assimilated to the ignition loss at 550°C, was estimated as the total organic content of a sample. Plastic was sorted before determination of VS as it is inert material in MSW. The leaching test, which can effectively estimate the leachate from a landfill, was performed at liquid/solid (L/S, $v \cdot w^{-1}$) =10 and the suspensions were filtered through 0.45μm membrane filter after centrifuging at 10,000 rpm. The total organic carbon (TOC) was determined by a TOC-VCPH (Shimadzu Co., Japan) and NH_4-N was determined by micro-Kjeldahl distillation methods.

The respiration activity (AT_4) was measured from the consumption of O_2 per unit of dry matter during 4 days, which was developed from the method described by HE ET AL. (2006). Briefly, air tight bottles were filled with 10 g collected samples (shredded into 2–3 mm particles) without inoculum and were cultivated at 35°C for 4 days. The cumulated O_2 consumption was measured every day. The gas production potential (GB_{21}) described the gas production under the anaerobic conditions during 21 days, which can predict the gas production potential after landfilling. The collected samples to be analyzed (50 g WM, wet matter) were incubated with digested sludge and water over a period of at least 21 days at 35°C. The gas was collected by air bag and determined volumetrically by drainage.

3 Result

3.1 MSW weight

The changes of total MSW weight, moisture content and organic matter were presented in Figure 1. As the results of the bio-stabilization showed, the reduction of MSW weight could be divided into three stages: 0-16 days was the fast degradation stage, corresponding to the period of the active stage and the MSW weight sharply reduced to 36% of initial weight; 16-58 days was the slowdown stage and the MSW weight decreased continuously to 20% of initial value; 58-100 days is the slack degradation stage with the MSW weight reduced to 13% at last.

During the bio-stabilization, the moisture reduction had the similar trend with weight reduction. During the active stage, the weight of water decreased to 23% of the original at day 16, which was a bigger ratio than the decrease of the total MSW weight. Compared with the weight loss of dry matter, the faster decrease of moisture content mainly contributed to weight reduction. Reduction in MSW weight during curing stage was relatively slow. The weight loss of water was faster than that of dry matter.

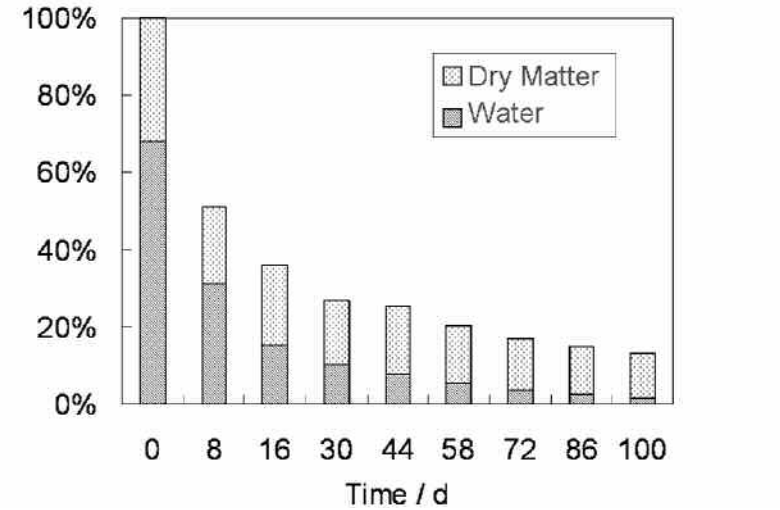

Figure 1 Evolution of MSW weight

3.2 Volatile solid

The evolution of VS content could reflect the reduction of biodegradable organic matter (Figure 2). The VS content decreased relatively fast, from 88.2% to 66.5%, during the active stage due to the degradation of liable organic matter. At day 100, the waste was stabilized and VS content achieved around 60%. The readily degradable organic matter was substantially reduced through aerobic degradation, which can abate the initial strong organic leachate generated during the acetogenic stage, leading to a more rapid onset of methanogenic conditions (ROBINSON ET AL., 2005).

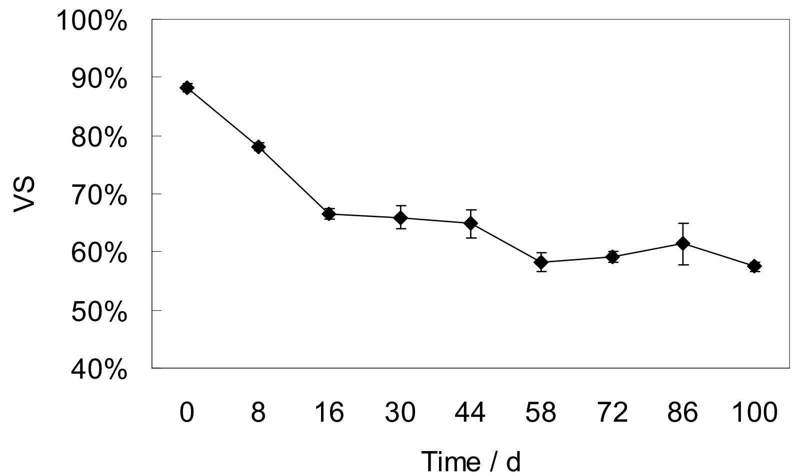

Figure 2 Evolution of VS

3.3 Leachate test

The potential loading of leachate pollution could be dramatically reduced by bio-stabilization as revealed by the leaching test. According to the results of leaching test (Figure 3), it was the first 8 days that the TOC concentration monotonously decreased to 10% of the initial peak value with the degradation of dissolved organics; after that, the TOC concentration almost kept steady.

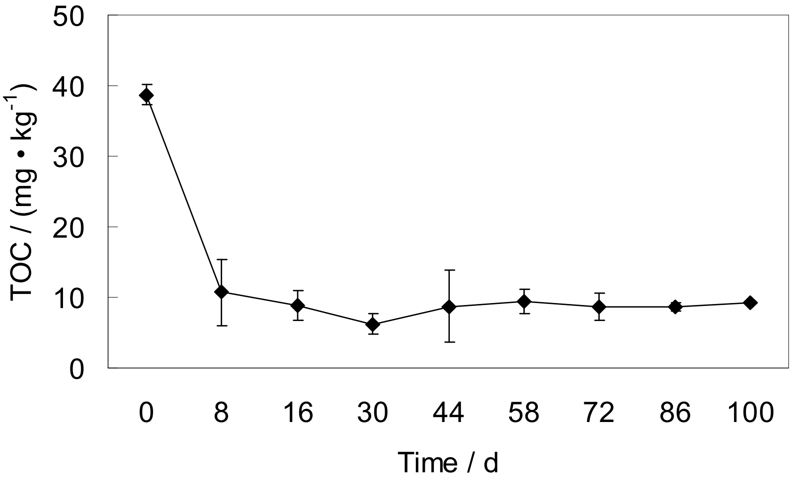

Figure 3 Evolution of TOC

3.4 Biological stability

The initial AT_4 index was 223.6 mg $O_2 \cdot g^{-1}$ DM. After 100 days treatment, the AT_4 index kept steady around 20 mg $O_2 \cdot g^{-1}$ DM, with a reduction of nearly 90%. The respirometric test had the advantage of giving both a quantitative response, related to the amount of organic matter, and qualitative information of its level of biodegradability. The dramatic decrease of AT_4 reflected the MSW's improvement in stability.

Landfill gas generation occurs mainly during the methanogenic phase of the landfill life cycle, and more than 90% of the gas is methane and carbon dioxide (ELFADEL ET AL., 1997). The associated environmental problems are odors, methane flammability, global warming. Methane also can be utilized as energy (MEHTA ET AL., 2002).

The GB_{21} test could provide information about the landfill gas production potential (Figure 4). The GB_{21} index decreased from 375.4 to 48.6 Nl/kg DM with a reduction of 87%.

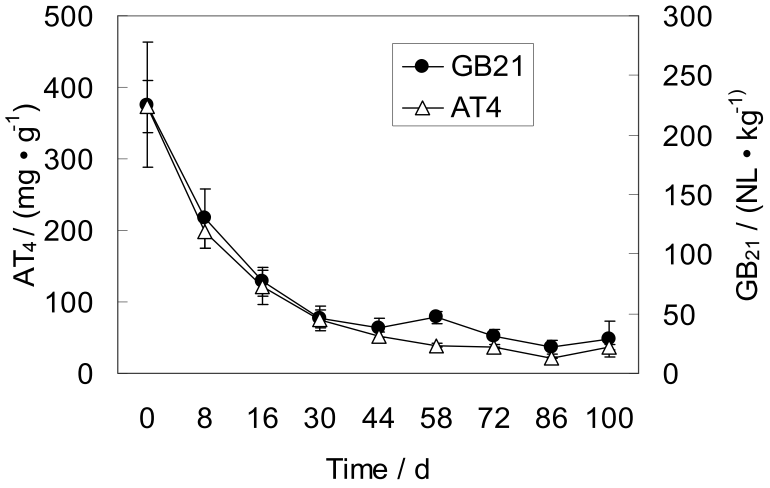

Figure 4 Evolution of biological stability indicators

4 Environmental and Economic Analysis

4.1 Scenarios

During the bio-stabilization, the marked time of the evolution of MSW, characterized by high moisture and organic matter content, was day 16, namely when the active stage ended, and day 58, which was consisted of the active stage and 42 days of curing stage.

Based on the marked time of the evolution of MSW during bio-stabilization, this study compared 2 scenarios constructed for handling MSW from conventional sanitary landfill (Table 1). The 2 scenarios for the combination of bio-stabilization and subsequent land-fill are: active stage treatment prior to landfill (AL); active stage plus curing stage prior to landfill (ACL). The conventional sanitary landfill (CL) was included as the baseline as usual scenario for comparison. Considering the different characteristics of bio-stabilization products, the adopted landfill technologies were different: CL and ACL, the landfill follows the prescriptive sanitary landfill in local standard; AL, similar as CL and ACL without the construction, O&M related to landfill gas collection. In order to test the hypotheses, the MSW production scale was assumed as 500 $t \cdot d^{-1}$, the active landfill time of bio-stabilization plant were both 20 years.

Table 1 The Scenarios

Scenarios	Bio-stabilization		Landfill
	Active Stage	Curing Stage	
CL	--	--	Sanitary landfill
AL	16 d	--	Sanitary landfill
ACL	16 d	42 d	Sanitary landfill (without LFG collection)

4.2 Land area saving

In all the scenarios, the unit area necessary for MSW landfill is 0.2 $m^2 \cdot t^{-1}$. The land needed for landfill of 3 scenarios is 6.9×10^5 m^2, 1.4×10^5 m^2 and 9.1×10^4 m^2. The land area for landfill was substantially saved in AL and ACL with the reduction of MSW weight, which potentially constitutes a major source of benefit. Although the bio-stabilization plant needs additional land involved construction and O&M, the land used for bio-stabilization could be off-set by the advantages of subsequent land source saving in landfill. The land area for bio-stabilization in ACL could be calculated according to the current local composting construction standard, and the AL would be assumed to take its half because of the elimination of curing stage. The actual land needed in each scenario is 6.9×10^5 m^2, 1.7×10^5 m^2 and 1.5×10^5 m^2.

4.3 Environmental pollutions estimate

The MSW in developing countries was characterized by high moisture content, which greatly affected the quantity of leachate generation. During the bio-stabilization, there was no extra leachate generated as the moisture reduced mainly via evaporation. As a result, the leachate generated only during landfilling. After MSW landfilling, water flows out as leachate when the moisture content exceeds the field capacity. At day 16, the shifting time of the active stage and the curing stage, the moisture had reduced to 43%, which is lower than the field capacity, approximately ranging from 48% to 52% (DE VELÁSQUEZ ET AL., 2003). Meantime, the organic matter content was at such a low level that it could not produce more water by its own degradation any more. As a result, the leachate from MSW itself would be 0.18 $t \cdot t^{-1}$ MSW, -0.07 $t \cdot t^{-1}$ MSW and -0.23 $t \cdot t^{-1}$ MSW ("-" means that the MSW could absorb water from other sources).

The leachate in 3 scenarios could be calculated mainly according to 2 sources, namely the infiltration of precipitation and MSW itself. Given that the leachate from CL was 100%, those of AL and ACL would decrease to 14% and 3%, respectively.

During the bio-stabilization, the MSW was stabilized and the released odors could be collected and removed. Only in CL did the landfill generated odor pollutions. Utilization of LFG, in controlled combustion for the purpose of producing energy and thereby displacing fossil fuel and abating emissions of pollutants, is an added global environmental benefit. 40% of generated methane was assumed to be collected, while 60% of methane generated was not captured. The alternative option to minimize methane emission is that of encouraging methane oxidation in the soil covering in landfill. The IPCC suggested the oxidation factor in landfill to be 0.1 in developing countries for their management. By this, the methane emissions in CL, AL and ACL are 4.9×10^7 m^3 and 1.6×10^7 m^3 and 3.6×10^6 m^3, respectively.

4.4 Economical benefit and cost

The bio-stabilization is much like composting of MSW, such as the in-vessel system method regarding to the process of forced aeration, periodic turning and so on. The cost involved in the bio-stabilization constituted of land use, equipment, construction and O&M. Since the compost should meet the certain quality demands of markets and the additional process, such as screening and bagging, also increase the costs, so the bio-stabilization would be less expensive than composting. The costs of bio-stabilization in ACL can be estimated according to the threshold of composting costs listed in local standards (Table 2). The cost of bio-stabilization in AL is 60% of that in ACL because of the absence of curing stage.

Table 2 Construction and O&M costs

	Construction		O&M	
	Items	**Costs**	**Items**	**Costs**
Bio-stabilization	--	9.0 - 15.0× 10^3 $\$\cdot t^{-1}\cdot d^{-1}$	--	3.0 - 4.4 $\$\cdot d^{-1}$
Landfill	Site Establishment Leachate System Equipment Purchase Site Office+Compound facility Investigation, design and engineering	2.4 - 14.4 $\$\cdot m^{-3}$	Gas Collection Laborer(s) Cover material Equipment Fuel/Oil Cost Road Maintenance Other Materials	2.9 - 6.6 $\$\cdot d^{-1}$

Typical sanitary landfill costs are incurred in site construction and O&M, which cost 6.5 $USD\cdot t^{-1}$ and 6.6 $USD\cdot t^{-1}$ according to local standard (Table 2). The costs associated with landfill gas management (including piping) in ACL are saved. As to CL and ACL, utilizing captured methane to generate electricity presents potential revenue. The electricity production efficiency is assumed to be 4.86 kWh/kg CH_4 combusted. JOHANNESSEN

ET AL. (1999) found that the private breakeven price of electricity for the Landfill-Gas-to-Energy projects is lower than US$0.04/kWh. In China, the price for electricity power to local power grid is US$0.062/kWh. In addition, in order to ensure the social environmental benefits from the clean energy, the current social subsidy of US$0.037/kWh would be appropriate for the LFG-to-Energy project.

Table 3 Costs and Benefits (×10^7 USD)

Scenarios	Costs		Benefits	Total
	Bio-stabilization	landfill		
CL	0.0	-4.6	1.5	-3.1
AL	-0.8	-1.6	0.5	-1.9
ACL	-1.4	-0.7	0.0	-2.1

By the environmental and economic analysis (Table 3), it was found that AL and ACL could substantially save land resource and minimize landfill pollutions regarding to leachate quality and quantity as well as methane emission, and their costs would be lower than that of conventional sanitary landfill.

5 Conclusion

1) Through bio-stabilization, the weight of MSW was reduced by nearly 85% and the VS content decreased to approximately 60%. It was observed that MSW was relatively stabilized after 58 days, with AT_4 and GB_{21} index decreased by 93% and 87%. However, the fastest degradation was occurred during active stage.

2) By the environmental and economic analysis, it was found that ACL (active stage and curing stage prior to landfill) and AL (active stage treatment prior to landfill) could substantially save the costs of conventional landfill. However, the AL was characterized by lowest cost and the ACL has lower pollution potential.

6 Literature

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