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ORIGINAL ARTICLE

Biostabilization of municipal solid waste fractions from an Advanced Waste Treatment plant

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Abstract Controlling the safe disposal of Municipal Solid Waste (MSW), especially the biodegradable fraction, is an important goal of waste management. This study reports the effects of using composting to biostabilize the biodegradable fraction of MSW sourced from an Advanced Waste Treatment plant in Australia. The impact of biostabilization on the initial aerobic degradation of the material showed a reduction in oxygen consumption of 30% (230 g O_2/kg loss of ignition (LOI)) in immature compost and 45% (181 g O_2 kg^{-1} LOI) in mature compost when compared with the input material (330 g O_2/kg LOI). Anaerobic tests showed a reduction in biodegradability of 40% in the immature compost with biogas production 250 L/kg LOI compared with 50% in mature compost with biogas production of 218 L/kg LOI. The results confirm that the biostabilization of the biodegradable fraction of MSW diverted from landfill can result in a significant reduction of greenhouse gas emission.

1. Introduction

Modern landfills have been the principle method for disposing of Municipal Solid Waste (MSW) in many countries for over a century. However, recent decades have seen a change in attitudes towards landfills, caused by environmental issues surrounding the use of a landfill, including the production of landfill leachate, odour and methane (Ying et al., 2012; Farombi et al., 2012; Mor et al., 2006; Cossu et al., 2003). In addition, MSW disposal and treatment processes release substantial amounts of greenhouse gases which are considered as one of the most important anthropogenic sources of green-

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house gases (Tian et al., 2013). For example, in the United States, landfills contribute 17.5% of total methane gas emissions, representing the third-largest anthropogenic source of CH_4 emissions (USEPA, 2014).

Although, the issues associated with landfill are generally historic (Christensen and Kjeldsen, 1995), the legacy of the environmental issues from non-sanitary landfills has resulted in the development and use of alternative methods for the utilization of waste (Adani et al., 2000; Zhen-Shan et al., 2009). The aim of waste management of MSW has therefore been refocused to further reduce the environmental and health impacts of MSW. Legislation and regulations have reinforced the development of techniques for appropriate waste disposal, centred on waste minimization, recycling and recovery of materials, resulting in the minimization of MSW entering landfills (Leao et al., 2001). For example, decreasing allowances for landfilling the biodegradable fraction of the MSW (BMW) have been set in the UK under the National Landfill Allowance Schemes (DEFRA, 2006). Controlling the safe disposal of MSW, especially the biodegradable fraction, is an important goal of waste management. As leachate, odour and methane production represent the main environmental impacts of landfilling of MSW, studies have focused on the applications of processes such as composting that reduces these impacts. Compositing therefore represents an important component of an Advanced Waste Treatment (AWT) facility.

Composting has been proposed as a cost effective method that minimizes waste landfill impact using biological processes (Mohee and Soobhany, 2014; Ball et al., 2000b; Bernal et al., 2009). In AWT plants, waste minimization through recovery and recycling are capable of diverting around 80% of MSW away from landfills; composting of the BMW plays an important role in this diversion, typically converting around 10–15% (w/w) of the incoming MSW to compost and plant nutrient products. Generally in AWT plants, the initial shredding, mixing and composting is carried out in-shed or in-vessel in order to control odour and other environmental impacts while also maintaining optimal compost temperatures (55 °C) over the first 3–4 weeks; the maturation phases (typically lasting 8–12 weeks) normally occur outside due to decreased impacts and space restrictions.

During composting, aerobic biological treatment occurs resulting in a biostabilized product; the degree of the impact will depend on the level of stability reached (Scheelhaase and Bidlingmaier, 1997). To assess the potential impact of composting and the biostabilization process on the reduction in gaseous emissions such as carbon dioxide, respiratory measurements have routinely been used (Ball and Drake, 1998; Ball et al., 2000a). However, aerobic respiratory measurements do not provide information on any residual anaerobic biogas production which remains a key environmental factor associated with the landfilling of MSW. Therefore, residual biogas production tests have been developed, such as the Biochemical Biomethane Potential Test (BM100) (Wagland et al., 2009; Godley et al., 2005). These tests allow the measurement of biogas production that can potentially be produced from a known quantity of BMW (Godley et al., 2007).

The aim of this study was to assess the impact of biostabilization of the organic waste fraction through composting of MSW at a full scale AWT plant in Australia. Respiration and residual biogas production were determined during the process to provide a measure of the potential impact of the biostabilized products compared to the incoming material thereby assessing the environmental benefits of this treatment. To the best of the authors' knowledge, this is the first study which examines the impact of biostabilization of organic waste under both aerobic and anaerobic conditions using material from a full scale commercial Advanced Waste Treatment Plant.

2. Materials and methods

2.1. Sampling

Samples were collected, screened, weighed and prepared on-site at an Advanced Waste Treatment Facility in Australia. Advanced Waste Treatments are integrated systems designed to take the complex and varying mix of materials that make up what we know as waste and do three things: (1) recover useful products from the waste, (2) stabilize the waste to minimize environmental impacts, and 3) reduce material to landfill.

Fig. 1 shows the outline of the process for the conversion of MSW through to mature compost. The incoming MSW arriving on site was sampled immediately after the waste had passed through the pre-sort/bag opener, by random grab sampling. Unsuitable material (e.g. batteries, electronics) was manually removed during sorting prior to sampling. Immature compost was sampled from the end of the conveyor leaving the in-vessel composting tunnel, again using multiple grab sampling. Mature compost material was similarly taken from the most mature compost material (samples taken at 10–30 cm depth in the windrow) that was ready for screening in the outside compost rows. The volume of material collected at each stream varied from 14 kg (immature compost) to 26 kg (mature compost) (Table 1). Samples were transported to the laboratory via courier overnight on the day of sampling in sealed containers.

2.2. Analysis of sieved MSW material

Upon arrival samples were screened through 5 mm sieves and the contents separated according to the composition of the material (Table 1). The moisture content of each sample was determined following overnight drying in an oven at 70 °C. Loss on ignition was determined by placing dried material in a muffle furnace at 550 °C for 3 h. Total Kjeldahl nitrogen and total organic carbon content of dried and ground samples (using a pestle and mortar > 2 mm particles) of the three substrates were analyzed using standard laboratory protocols to provide additional data regarding the C:N ratio of the material (Table 1). All analyses were carried out in triplicate.

2.3. Testing of aerobic biostabilization

The aerobic biostabilization (DR4) test was adapted from the standard compostability ASTM D 5975–96 test (ASTM, 2004). Test organic waste material (BMW fraction from input MSW, immature compost and mature compost; 100 g dry matter) was mixed with commercially sourced mature compost (RICHGRO Organic Compost, used as a microbial inoculum; 100 g dry matter). The moisture content was adjusted and maintained at 50% (w/w) (Environment Agency, 2005). Ammonium chloride and sodium dihydrogen

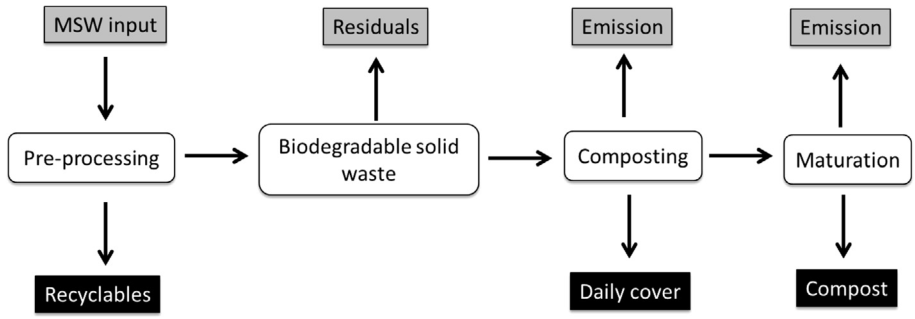

Figure 1 Overview of the processes involved in the separation and treatment of the biodegradable solid waste fraction at an Advanced Waste Treatment plant.

Table 1 Compositional analysis of the incoming MSW fraction, the immature compost fraction and the mature compost fraction from an Advanced Waste Treatment Facility.

Parameter	MSW fraction		Immature compost		Mature compost	
	Weight (kg)	(% w/w)	Weight (kg)	(% w/w)	Weight (kg)	(% w/w)
Total sample weight (kg)	19.66	100	14.38	100	26.51	100
Plastics	3.5	17.80	3.51	24.40	1.14	4.30
Metal	0.8	4.10	0.33	2.30	0.046	0.20
Inerts	1.23	6.30	0.83	5.80	0.24	0.90
Glass	1.27	6.50	0.35	2.40	2.82	10.60
Non biodegradable MW	6.8	34.59	5.02	34.91	4.246	16.02
Biodegradable MW	12.86	65.41	9.36	65.09	22.264	83.98
> 5 mm biodegradables	11.6	59	7.04	49.00	4.422	16.80
< 5 mm biodegradables	1.05	5.30	1.67	11.60	14.15	53.40
TOC (% dry matter)	42		45		35.5	
Total N (% dry matter)	0.89		1.06		1.25	
Moisture content% (w/w)	48.54 (±1.0)		37.53 (±0.7)		46.98 (±0.2)	
Loss on ignition (LOI) (% d wt in BMW)	51.47 (±3.4)		62.48 (±3.0)		53.02 (±3.1)	
Loss on ignition (LOI) (% d wt in total)	33.67		40.67		44.53	

phosphate were added to amend the C:N ratio to 15 and the N:P ratio to 45.

The test mixtures (in triplicate) were placed in an aerated reactor vessel and incubated at 35 °C for 4 d. The O_2 consumed during the 4 d was estimated from the amount of CO_2 liberated and expressed in terms of the loss on ignition (LOI) content of the test material (mg/kg LOI). CO_2 emissions were measured daily using the NaOH Titration Method described previously (Environment Agency, 2005). Control vessels (one vessel remained empty, one contained compost only, one where the sample material was replaced by cellulose) were routinely included.

2.4. Testing of anaerobic degradation

The anaerobic BM100 test (Environment Agency, 2005) used in this study was adapted from a sewage sludge digestion test method (Standing Committee of Analysts, 1997). Laboratory scale anaerobic digesters adapted from Schott bottles (500 mL) were set up and kept at a constant temperature of 35 °C. In all test digesters, prepared sample BMW fractions (in triplicate) from input MSW, immature compost and mature compost, equivalent to 22 g loss of ignition (< 10 mm) were mixed with a nutrient medium (222 mL) and digested sewage sludge was added (50 mL) as microbial inoculum (Environment Agency, 2005).

Mesophilic inoculum (seed sludge) was collected from a working mesophilic anaerobic digester at a wastewater treatment plant in Adelaide, South Australia. The inoculum was stored at 4 °C before use. Prior to anaerobic digestion tests, the inoculum was incubated for 48 h at 35 °C to allow stabilization. This mixture was then de-oxygenated by sparging with N_2 gas for 5 min before incubation at 35 °C. Each digester was equipped with one port to transfer the biogas to the collection cylinder, fitted with gas opening valves. An air suction pump was used to fill the collection cylinder with acidified (pH 4) water. The mixture was incubated anaerobically at 35 °C and the biogas (CH_4 + CO_2) collected and measured until no more biogas was produced (100 d) and the results were expressed as L/kg LOI. Cellulose (Sigma, Australia) that was used as a positive control was used in the same LOI volume and tested in duplicate. Mesophilic inoculum alone was used as a baseline negative control to determine biogas production resulting from the inoculum alone. Biogas production was determined daily by measuring the headspace of each digester by an acidic water displacement volumetric method as previously described (Environment Agency, 2005). In brief, the cumulative biogas production was calculated each day and then adjusted to give the cumulative test substrate biogas production.

The carbon dioxide content of the biogas produced was also analysed weekly using the Kitagawa tubes (5–50% CO_2-Tube 126UH, Komyo Rikagaku Kogyo, Kawasaki, Japan) by following the manufacturer's instructions. The methane content of the biogas was analysed weekly using a Geotech Biogas Analyser (Geotechnical Instruments UK Ltd) following the manufacturer's instructions. Each digester had a pH of 7.5 which was regularly measured (Eutech PH510) and maintained via the addition of Na_2CO_3. Temperature was measured using a standard portable thermometer and each digester was mixed daily to ensure contact between bacteria/enzymes and substrates.

2.5. Data analysis

The data obtained from replicates were analysed using Analysis of Variance (ANOVA) or T test by IBM SPSS (version 21). The relationship between the aerobic and anaerobic experiments were calculated using Microsoft excel 2010.

3. Results and discussion

3.1. Impact of treatment on composition of MSW

Analysis of the composition of the MSW revealed similar data to that recently published; for example BMW fractions of around 60% (w/w) were reported in the UK (Resource Futures, 2011). In this current study, 65% of the material present in the incoming MSW was classified as BMW. In terms of plastic, almost 18% of the incoming waste was plastic. This compares to a value of around 10% for the recent UK study (Resource Futures, 2011).

A comparison of the initial feed material and the resultant composts formed through an AWT system showed that the plastic contamination of the final product was significantly reduced during treatment, particularly during the final preparation of mature composting through sieving. The plastic content within the immature compost remained high at 24% (w/w) (Table 1). The main-non-biodegradable fraction remaining in mature compost from MSW was glass, representing a significant fraction (6.5% w/w) of the compost. Clearly, contamination of the final compost product with glass remains an issue and the influence of source separation is important prior to the AWT process. The ability of the resulting compost fractions to be used in a range of applications including the use of the material for daily landfill cover as well as mature compost which can attain an accredited level of quality is crucial in maintaining financial viability of the composting process.

As the compost process continued there was significant decomposition of the biodegradable material during treatment, resulting in an increase in the biodegradable fraction below 5 mm (Table 1) from approximately 12% (w/w) in the immature compost to over 53% (w/w) in the mature compost. The presence of finer particles in compost is generally desirable as this will increase the surface area to volume ratio of the bioavailable fraction, allowing faster degradation. The C:N ratio of the samples decreased significantly from over 48:1 in the original material to 28:1 in the final compost (Table 1). This reduction is presumably as a result of volatilization of mineralized carbon in the form of CO_2 during composting. Volatilization of nitrogen may also occur but in this study, the rate of nitrogenous gas emission was lower than that of carbon (Table 1).

Both the N content (1.25%) and the C:N ratio (28:1) of the mature compost are comparable to those found in peat-based composts (1.30% and 33:1, respectively) (Ball et al., 2000b) suggesting that amount of N present in the mature compost (but not the original BMW or the immature compost) was at an appropriate level for a good plant growth medium.

3.2. Aerobic degradation study

Examination of the impact of stabilization on the initial aerobic degradation of the material, as assessed by oxygen consumption and expressed in terms of Kg LOI shows a reduction in oxygen consumption of around 30% (23 g/kg LOI) in immature compost samples and 45% (18 g/kg LOI) in mature compost samples when compared with the input material (76 g/kg LOI) (Fig. 2). Assessment of the oxygen consumption of compost is recognized as a good indicator of compost maturity/stability (Gómez et al., 2006). Compost stability can be defined as the extent to which biodegradable materials have decomposed (Barrena et al., 2014). If unstable, compost may contain significant amounts of biodegradable material that enable a highly active microbial community to flourish. When applied to a soil, this immature material containing a large, active microbial community may compete with plants for nutrients (particularly nitrogen) and oxygen resulting in poor plant growth and yields.

3.3. Anaerobic degradation study

Determination of the biostabilization effect during anaerobic degradation of the input material and the mature and immature compost is shown in Fig. 3 which shows the mean cumulative biogas production from each sample throughout the incubation period. After an initial lag period lasting up to 20 d, a period of rapid biogas production occurred (Fig. 3). After

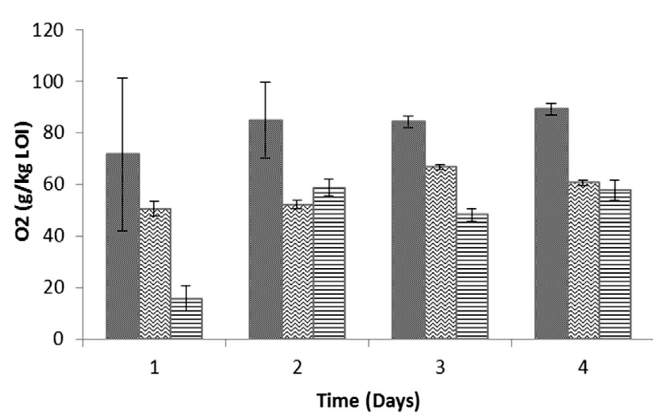

Figure 2 Daily O_2 consumption (mg/kg LOI) during aerobic incubation of Municipal Solid Waste feed (▆), immature compost (≋) and mature compost (☰) for 96 h at 35 °C.

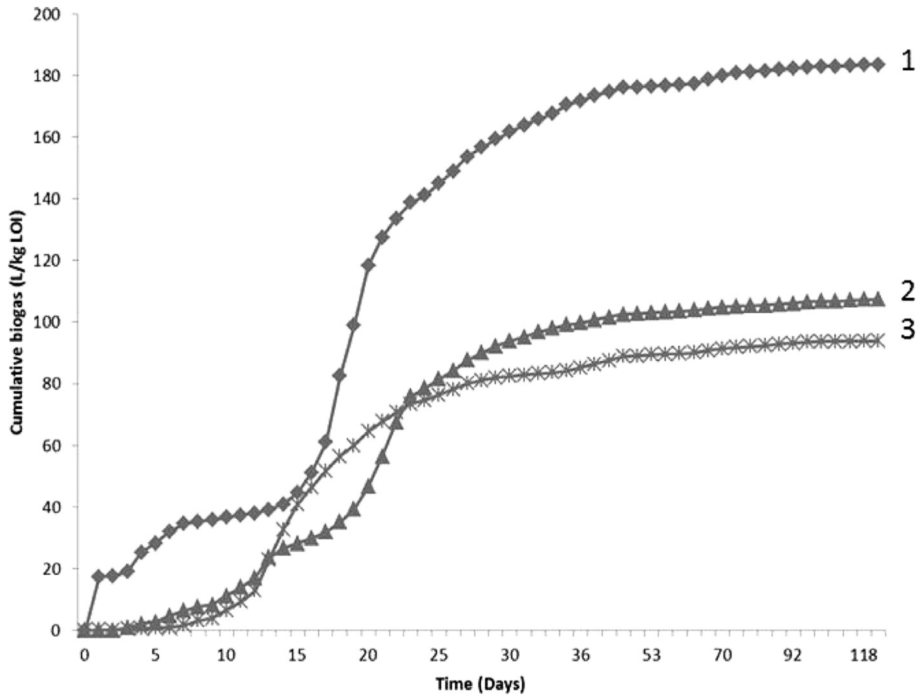

Figure 3 Daily production of anaerobic biogas per day (cumulative) for three samples L/kg LOI from an Advanced Waste Treatment facility (1: feed; 2: immature compost; 3: mature compost) over 116 d incubation at 35 °C.

Day 40 this rapid gas production had significantly declined for all incubations. Table 2 summarizes the results of the anaerobic digestion assessment. Biogas production (expressed per Kg LOI) was significantly decreased in immature and mature compost compared with the input MSW. The results show a reduction in biogas production of around 40% in the immature compost sample with biogas production of 250 L/kg LOI and around 50% in the mature compost sample with biogas production of 218 L/kg LOI (Table 2). Analysis of the methane content throughout the incubation revealed average methane content of 44% for all three substrates throughout the incubation (data not shown). Methane gas is an important greenhouse gas due to the fact that its global warming potential is more than 20 to 21 times that of carbon dioxide (Abushammal et al., 2010; USEPA, 2014). Methane production under anaerobic conditions is influenced by a number of factors including nutrient availability. Anaerobic systems generally require less nitrogen and therefore high C:N ratios along with a readily degradable form of C. During the composting process an increase in the C:N ratio occurs as the carbon is mineralized, leaving less available carbon. This reduces microbial activity and methanogenesis, resulting in significantly reduced greenhouse gas emissions.

Table 2 Biogas production (L per kg LOI in BMW), corrected by hydrostatic head pressure and standard temperature and pressure for MSW during stabilization at an Advanced Waste Treatment facility.

Sample	MSW fraction	Immature compost	Mature compost
Total mean biogas production (L per kg LOI)	427.5	250.3	218.7
Standard error (±)	7.6	38.7	7.4
Biodegradability, % feed	100%	58.5%	51.2%

3.4. Relationship between biostabilization of waste in aerobic and anaerobic reactions

Fig. 4 shows the relationship between the aerobic and anaerobic test for the BMW for the feed, mature and immature compost samples. A linear relationship can be observed between biogas production and O_2 consumption for the three samples

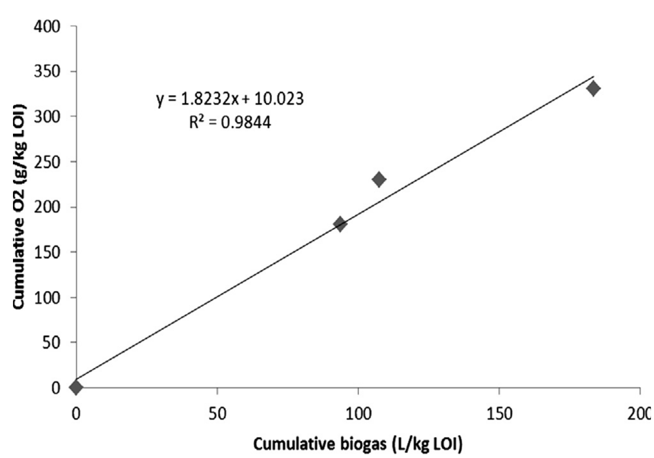

Figure 4 Comparison of final (4 d) production of O_2 test result (g/kg LOI) values to final (116 d) anaerobic biogas test values (cumulative) of three samples (feed; immature compost; mature compost).

(r^2 = 0.984) (Fig. 4). This observed correlation between the aerobic and the anaerobic tests for a range of MSW derived mixed BMW samples has been previously shown (Godley et al., 2007), although the authors cautioned against the use of these tests for other waste streams. The slope of line between the aerobic and anaerobic tests is specific to each waste feed, making it difficult to compare with other data (Environment Agency, 2005). However previous data collected using similar approaches confirm that the results presented here fall within the range previously determined. Often a plateau is observed in the relationship at higher values (Godley et al., 2005); this was not observed in the present study, presumably because the biodegradability of the material even in raw material was not sufficient to reach this point. The results confirm that the value of these tests in assessing the impact of biostabilization protocols at AWT facilities. For any given mixed MSW these tests enable assessment of the impact of treatment on the potential reduction in greenhouse gas emission, providing an important management tool.

4. Conclusion

The results from this study have shown that the biostabilization of the BMW fraction of MSW that is diverted from landfill can result in a significant reduction of greenhouse gas emission potential for this material. Further, the biostabilized product can either be used as a landfill capping material or if suitable, potentially as a high quality compost.

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