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Comparison of static, in-vessel composting of MSW with thermophilic anaerobic digestion and combinations of the two processes

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ABSTRACT

The biological stabilisation of the organic fraction of municipal solid waste (OFMSW) into a form stable enough for land application can be achieved via aerobic or anaerobic treatments. To investigate the rates of degradation (e.g. via electron equivalents removed, or via carbon emitted) of aerobic and anaerobic treatment, OFMSW samples were exposed to computer controlled laboratory-scale aerobic (static in-vessel composting), and anaerobic (thermophilic anaerobic digestion with liquor recycle) treatment individually and in combination. A comparison of the degradation rates, based on electron flow revealed that provided a suitable inoculum was used, anaerobic digestion was the faster of the two waste conversion process. In addition to faster maximum substrate oxidation rates, anaerobic digestion (followed by post-treatment aerobic maturation), when compared to static composting alone, converted a larger fraction of the organics to gaseous end-products (CO_2 and CH_4), leading to improved end-product stability and maturity, as measured by compost self-heating and root elongation tests, respectively. While not comparable to windrow and other mixed, highly aerated compost systems, our results show that in the thermophilic, in-vessel treatment investigated here, the inclusion of a anaerobic phase, rather than using composting alone, improved hydrolysis rates as well as oxidation rates and product stability. The combination of the two methods, as used in the DiCOM® process, was also tested allowing heat generation to thermophilic operating temperature, biogas recovery and a low odour stable end-product within 19 days of operation.

1. Introduction

Historically, strategies for the management of municipal solid waste (MSW) included burial, burning and ocean dumping; practices which are now known to lead to contamination of land, air and sea (Earle et al., 1995). Until recently landfill was the main waste treatment method utilised. Waste management has become one of the largest environmental concerns in recent decades, with the problems in disposal compounded by the ever-increasing quantity of refuse to be managed. The scarcity of land and the uncontrolled contamination with gas and leachate emissions have made landfill, particularly of organics, no longer a sustainable option (Hartmann and Ahring, 2006). It is now accepted that no single solution exists for the management of MSW, with an integrated approach most likely to succeed (Earle et al., 1995).

Approximately 50% of MSW consists of organic matter, with the composition of the organic fraction of MSW (OFMSW) being an important parameter in determining the most appropriate method for its treatment. Typically, food waste, which is too wet and lacks the structure for composting, is treated via anaerobic digestion whereas green waste (plant material) is composted (Edelmann and Engeli, 1993; Braber, 1995).

Both composting and anaerobic digestion have their own specific advantages and disadvantages (Table 1), with composting generally accepted as being a more rapid process than anaerobic treatment (Lopes et al., 2004; Mohaibes and Heinonen-Tanski, 2004). However, based on an energy balance, anaerobic digestion has an advantage over composting, incineration, a combination of composting and digestion (Edelmann et al., 2005) or land-filling (Haight, 2005), with anaerobic digestion capable of being energy sufficient if only one quarter of the biogenic waste is digested to biogas (Edelmann et al., 2000).

One recognised disadvantage of anaerobic digestion is the fact that the solids produced are not typically suitable for direct land application as they tend to be odorous, too wet and too high in volatile fatty acid (VFA) concentration, which are phytotoxic. In addition, if the digestion is not performed under thermophilic conditions, the solids are not sanitised. Consequently, a post treatment of these solids is required (Poggi-Varaldo et al., 1999) with composting providing an appropriate management solution (Fricke et al., 2005; Meissl and Smidt, 2007).

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Table 1
Advantages and disadvantages of composting and anaerobic digestion. References: (a) Edelmann and Engeli (1993); (b) Braber (1995); (c) De Baere (1999); (d) Edelmann et al. (1999); (e) Smet et al. (1999); (f) De Baere (2000); (g) Edelmann et al. (2000); (h) Mata-Alvarez et al. (2000); (i) Edelmann et al. (2005) and (j) Hartmann and Ahring (2006).

Composting		Anaerobic Digestion		References
Advantage	Disadvantage	Advantage	Disadvantage	
Simple Inexpensive			More complex More expensive	a, b, f, h
	Larger area	Smaller area		a, b
	Odour pollution	Reduced odour via biogas combustion		a, b, c, e
	Uncontrolled leachate emission		High strength wastewater formed	j
	Uncontrolled CH_4 production			b, c, g, i
	Net energy consumer	Net energy producer		d

Providing aerobic maturation for the solid digestate obtained from anaerobic treatment of solid waste has been found to improve the quality of the end-product (Edelmann and Engeli, 1993) and reduce odour emission (De Baere, 1999) by reducing the emission of volatile compounds (Smet et al., 1999). Recent years have seen the development of numerous integrated waste treatment systems (Six and De Baere, 1992; Kayhanian and Tchobanoglous, 1993; Kübler and Schertler, 1994; ten Brummeler, 2000; Müller et al., 2003; Teixeira et al., 2004; Walker et al., 2006a) utilising post-anaerobic digestion composting to mature anaerobic digestate.

During composting, readily degradable substrates (which include residual VFA from anaerobic solids) are rapidly consumed with the significant energy released heating up the material. Depending on the degradability of the organic substrate, the oxygen (O_2) supply and heat loss, the temperature of the material can rise to 70 °C or more which contributes to eliminating pathogens from the material (Neklyudov et al., 2006). It is therefore logical and advantageous to develop processes which combine anaerobic digestion and composting to provide improved waste processing. The DiCOM® process (Walker et al., 2006a,b; DiCOM, 2009), developed and patented by AnaeCo Ltd. (Perth, Western Australia), is one such process. It exposes OFMSW to 5 days of pressurised aeration, followed by 7 days of thermophilic anaerobic digestion (with liquor transfer and recirculation) and 7 days of aerobic maturation within a single completely sealed reactor. The final products of this process are a composted end-product and renewable energy in the form of biogas.

The aim of this paper is to compare rates of degradation of OFMSW under static, in-vessel aerobic composting and thermophilic anaerobic digestion conditions and a combination of the two processes. As an example of a full-scale process that combines aerobic composting and thermophilic anaerobic digestion, the treatment regime of the DiCOM® process was also investigated. Data produced are expected to be helpful in designing the most efficient combination of the two methods for the degradation of OFMSW.

2. Methods

2.1. Experimental design

Mixed MSW collected in the metropolitan area of Perth, Western Australia in March, 2005 was mechanically sorted using a screen aperture of 50 mm. Larger inert objects (plastic, metal and glass) in the sorted OFMSW were removed by hand before the organics were further shredded (<25 mm). Portions of the well mixed batch of OFMSW were combined with shredded paper (Hygenex® 2187951) and Jarrah wood chips (trapped between 1 and 5 mm screens) in the ratio of 1000:17:67 (w/w) (to replace that removed during the mechanical sorting process and provide a solid matrix) and frozen (−20 °C) to provide an identical starting material for all trials and reproducible outcomes. Prior to use, samples (2.4 kg; wet bulk density 578 kg/m^3; free air space 55%; C:N was 18:1; 55% moisture content; 56% total volatile solids content (VS); 8.3% protein; 4.3% fat and 45% carbohydrate) were thawed at room temperature and deionised water (≈400 mL) added to provide a positive 'fist test', as described in Australian Standard 4454 (2003).

The OFMSW was treated in an insulated cylindrical, 7 L high temperature PVC computer controlled laboratory-scale reactor as described previously by Walker et al. (2006a). The reactor was operated as a sequencing batch reactor capable of providing in-vessel composting, anaerobic digestion or combinations of both.

Trials consisted of at most 12 days of treatment (aerobic, anaerobic or a combination of both) followed by 7 days of aerobic maturation (Table 2). During aerobic operation, pressurised air was introduced into the reactor until the internal pressure was raised to a predetermined level. The internal pressure was maintained (10 min) before being released and the aeration regime repeated. This aeration regime was used to prevent channelling of air through the essentially unmixed material. Small scale composting trials typically underperform due to limited heat build-up (high surface to volume ratio causing increased heat loss). To prevent the heat loss typical for small scale composting experiments, a highly insulated vessel (heat loss coefficient 0.0912 h^{-1}) was used and the external reactor temperature controlled, by means of a heat tape, to that of the reactor core, but not beyond 60 °C.

For those trials where a thermophilic anaerobic phase was present (Trials A, B and C; Table 2), digestion was initiated by sealing the reactor and allowing aerobic microbial metabolism to consume residual oxygen and establish an anaerobic environment. Once anaerobic conditions had been established, the reactor was flooded with 4.1 L liquid (anaerobic inoculum obtained from a laboratory-scale DiCOM® reactor) (NH_4^+–N = 1400 mg/L). Then the liquor was re-circulated (70 mL/min (max)) from the reactor top to its base and maintained at 55 ± 2 °C. At the conclusion of digestion, the anaerobic liquid was drained and the solids mechanically squeezed (to remove excess moisture and provide a positive "fist test" (AS 4454, 2003)).

Aerobic post-digestion maturation consisted of 7 days of aeration as described above. Again, to limit heat loss from this small scale reactor, external heating was used to ensure the core reactor temperature did not fall below 35 ± 2 °C.

Table 2
Phase lengths of trials.

Trial description	Length of initial aeration (days)	Length of anaerobic treatment (days)	Length of final aeration (days)
Thermophilic anaerobic digestion (B)	0	12	7
Combined aerobic and thermophilic anaerobic digestion (C)	1	10	7
DiCOM® (A)	5	7	7
Static in-vessel composting (D)	12	0	7
Thermophilic static composting (E)	12	0	7