Waste Management 55 (2016) 12–21

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Rapid digestion of shredded MSW by sequentially flooding and draining small landfill cells

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ARTICLE INFO

Article history:
Received 22 July 2015
Revised 29 November 2015
Accepted 30 November 2015
Available online 21 December 2015

Keywords:
Anaerobic digestion
Flood and drain
Landfill cell
Leachate
Municipal solid waste

ABSTRACT

This paper compares the digestion of a packed bed of shredded municipal waste using a flood and drain regime against a control digestion of similarly prepared material using a trickle flow regime. All trials were performed on shallow (2 m) beds of the sub-8 cm fraction of shredded mixed MSW, encapsulated in a polyethylene bladder. The control cell (Cell 1) was loaded with 1974 tonnes shredded municipal waste and produced $76 \pm 9\ m^3$ CH_4 dry t^{-1} ($45 \pm 2\ m^3$ CH_4 'as received' t^{-1}) over 200 days in response to a daily recirculation of the leachate inventory which was maintained at $60\ m^3$. The flood and drain operation was performed on two co-located cells (Cell 2 and Cell 3) that were loaded simultaneously with 1026 and 915 tonnes of the sub-8 cm fraction of shredded mixed MSW, with a third empty cell used as a reservoir for $275\ m^3$ of mature landfill leachate. Cell 2 was first digested in isolation by flooding and draining once per week to avoid excessive souring. Gas production from Cell 2 peaked and declined to a steady residual level in 150 days. Cell 3 was flooded and drained for the first time 186 days after the commencement of Cell 2, using the same inventory of leachate which was now exchanged between the cells, such that each cell was flooded and drained twice per week. Biogas production from Cell 3 commenced immediately with flooding, peaking and reducing to a residual level within 100 days. The average CH_4 yield from Cells 2 and 3 was $123 \pm 15\ m^3$ dry t^{-1} ($92 \pm 2\ m^3$ 'as received' t^{-1}, equal to 95% of the long term (2 month) BMP yield.

1. Introduction

A widely practised method of accelerating the digestion of municipal solid waste (MSW) in landfills is to irrigate the waste with leachate to overcome moisture limitations and to distribute buffered leachate flushed from stabilised layers to fresh, reactive waste. Landfills with this practice are commonly referred to as bioreactor landfills. The goal of bioreactor landfill operation is to achieve more rapid stabilisation of MSW rather than high rate digestion, primarily because digestate is left in-situ in bioreactor landfills while the space in high rate anaerobic digesters is re-used. Minimum time to arrive at peak CH_4 generation in a bioreactor landfill is predicted to be 1.5–2 years (Pohland and Al-Yousfi, 1994).

In contrast, it is well established that the batch digestion of static MSW beds can be completed within one month using in-vessel processes, by recirculating and trickling leachate over the waste bed. For example, Chynoweth et al. (1992) developed a sequential batch digestion method where leachate from a mature bed was used to flush acidic leachate from a fresh bed, to accelerate the establishment of methanogenic conditions. CH_4 yields as much as $200\ m^3$ CH_4 t^{-1} VS (equivalent to $200\ m^3$ biogas t^{-1} for their waste) were achieved in 21 days at 55 °C in 675 L batches of OFMSW (organic fraction of MSW) that was hand sorted and hammer-milled to less than 8 cm particle size (Table 1). Chugh et al. (1998) verified this process in repeated trials on shredded MSW in 200 L reactors operated at 38 °C and found the rate of digestion increased with the volume of leachate used in the recirculation circuit (Table 1).

At a commercial in-vessel scale, ten Brummeler et al. (1992) and ten Brummeler (2000) degraded source separated household organic waste, achieving $70\ m^3$ of biogas per tonne in 21 days in $480\ m^3$ cells using the BIOCEL process, where digestate from previous batches was mixed with fresh waste, optimally at a 1:1 ratio and leachate was recirculated through the bed, nominally at a rate relative to the working volume of $0.3\ m^3\ m^{-3}\ d^{-1}$. Similar commercialised static leach-bed processes such as the BEKON process have produced higher yields from source separated OFMSW, with typical CH_4 yields of $80\ m^3\ t^{-1}$ in 28 to 35 days.

Complete biogas records from the batch digestion of waste in landfill settings are rare. Barlaz et al. (2010) conducted a survey

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http://dx.doi.org/10.1016/j.wasman.2015.11.050
0956-053X/

Table 1
Performance of some pilot and full scale landfill bioreactors.

Feedstock composition and mass	Inoculation	Bioreactor	Flow regime/rate	Operational parameters	Methane yield	References
• Organic fraction of MSW (less than 10 cm particle size) • (180 kg per batch)	Sequencing with mature, digested beds of MSW	675 L batch laboratory reactor	Recirculating, trickling leachate over the waste bed Rate: unknown	SRT 21 days $T = 55\ ^\circ C$	200 $m^3\ t^{-1}$ VS (200 m^3 biogas t^{-1})	Chynoweth et al. (1992)
• Shredded MSW, average particles size ~ 10 cm • 50 kg per batch	Sequencing with mature, digested beds of MSW	200 L batch laboratory reactor	Recirculating, trickling leachate over the waste bed, at rates of 0.02, 0.1, 0.3 $m^3\ m^{-3}\ d^{-1}$	SRT 60 days $T = 38\ ^\circ C$	120, 160 and 190 $m^3\ t^{-1}$ VS (from lowest to highest recirculation rates)	Chugh et al. (1998)
• Source separated household org. waste • ~400t of total waste (fresh + digestate)/batch	Mixing of fresh waste and digestate at a ratio of between 1:1 and 1:1.5.	480 m^3 concrete batch digester	Recirculating, trickling leachate at a rate of 0.3 $m^3\ m^{-3}\ d^{-1}$	SRT 21–30 days $T = 35\ ^\circ C$	70 m^3 biogas t^{-1}	ten Brummeler et al. (1992), ten Brummeler (2000)
• Source separated OFMSW • ~370 t per batch	Mixing of fresh waste and digestate at unknown ratio	Concrete containers	Recirculating, trickling leachate Rate: unknown	SRT 28–35 days $T = 37\ ^\circ C$	80 $m^3\ t^{-1}$	BEKON process
• MSW • 0.1–15.6 million t	No Inoculation	Full-scale landfill based bioreactors with area between 1.4–40.0 ha	Recirculating, trickling leachate at a rate of 0.015–0.4 m yr^{-1}	SRT 6–20 years No temperature control	59–120 $m^3\ t^{-1}$	Barlaz et al. (2010)
Green waste (1718t) and aged horse manure (118t)	Mixing with aged horse manure	3500 m^3 truncated pyramid shaped polyethylene lined landfill cell	Recirculating, trickling leachate at a rate of $2 \times 10^{-3}\ m^3\ m^3\ d^{-1}$, or 1.8 m yr^{-1}	SRT 366 days No temperature control, average temperature $T = 46.5\ ^\circ C$	27.3 $m^3\ t^{-1}$ (60 m^3 biogas t^{-1})	Yazdani et al. (2012)

of biogas production and leachate composition trends in 5 bioreactor landfills across the USA, including a landfill cell (69,240t) that was rapidly filled and sealed. That cell was operated with a leachate recirculation rate of approximately 0.4 m yr^{-1}. The waste degradation rate, according to a fit of the US EPA LandGem model to biogas data and an assumed ultimate methane yield of 59 $m^3\ t^{-1}$ was 0.35 yr^{-1}, which equates to 80% methane yield in 4.6 years.

Most recently, Yazdani et al. (2012) digested green waste (1718t) and aged horse manure (118t) in a truncated pyramid shaped polyethylene lined cell that was approximately 3500 m^3. They applied trickle flow irrigation and recirculation, at a normalised rate of $2 \times 10^{-3}\ m^3\ m^{-3}\ d^{-1}$, equal to 1.8 m yr^{-1} for their cell geometry. This is orders of magnitude lower than that applied in the above mentioned laboratory studies and commercial leach-bed processes. Without any heating, the cell maintained an average temperature of 46 °C during digestion with a cumulative CH_4 yield after 366 days of 27.3 $m^3\ CH_4\ t^{-1}$ (60 m^3 biogas t^{-1}). A further 7.2 $m^3\ CH_4\ t^{-1}$ was produced from anaerobic pockets that persisted over a subsequent 66 day aeration phase. Subsequent BMP assays by Yazdani et al. on digestate at the end of the 366 day period indicated 60% of the ultimate BMP yield was realised during the anaerobic phase. A conclusion cannot be drawn from these few trials of the potential to match in-vessel digestion rates in landfill cells. There are numerous effects such waste type, particle size reduction, leachate application and temperature that can be manipulated to enhance degradation.

The aim of this paper is to isolate the effect of leachate application. It is hypothesised in this paper that digestion in field scale leach-beds is slow primarily because of poor distribution of leachate through the bed. Infiltrating flow will only distribute evenly if the waste particles are fine enough to retard and distribute flow by capillary and friction forces. In reality, waste particles are not uniformly sized or shaped. Particles can block flow and can be rigid and large enough for trickle flow to occur. This is less significant at the laboratory scale where high flow rates can be applied to narrow columns. In contrast, flow can deviate and by-pass pockets of waste in broad beds such as landfill cells.

Poor liquid–solid contact can be overcome by completely submerging the waste. Flooding and draining cycles have been previously used by Rees-White et al. (2011) on a 25,000 tonne 5 m deep bed of MSW for the purpose of flushing leachable metals and other hazardous components from the waste bed. The superficial velocity applied during flooding was 0.6 mm hr^{-1}. The extent of leachate hold-up in the bed increased with the number of flood and drain cycles. In contrast, complete and rapid exchange of leachate is required to implement strategies such as sequential batch digestion where the time to flood and drain should be insignificant compared to the overall degradation time. This paper presents flood and drain digestion trials on small landfill based 2 m deep beds of the sub-8 cm fraction of shredded MSW. A control bed of the same depth and similarly sourced material was operated in a trickle flow regime.

2. Material and methods

Three landfill cells were constructed at the Swanbank landfill, Ipswich, Queensland. Cell 1 was operated between October 2010 and April 2011 using a trickle flow regime. Cell 2 and Cell 3 were operated between August 2012 and May 2013 using a flood and drain flow regime. The exact dates of operation are shown in Table 2.

2.1. Description of the waste and leachate used in the cells

All cells were loaded with the sub-8 cm fraction of shredded kerbside collected MSW. A 750 DK Hammel shredder and a Komptech Farwick trommel with an 80 mm mesh was used to shred and screen the waste for all cells. The chosen mesh size was estimated to be large enough to pass organic particles but fine enough to reject materials that survived the shredding processes such as metal, timber and plastic sheets. The sub-8 cm fraction ranged between 46% (Cell 3) and 51% (Cell 2) of the total MSW fed to the shredder. Cell 1 was loaded almost 2 years prior to the flood and drain cells (Table 2), which brings into question the comparability of the waste