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Compositional analysis of excavated landfill samples and the determination of residual biogas potential of the organic fraction

J. García [a], S. Davies [b], R. Villa [a], D.M. Gomes [a], F. Coulon [a,*], S.T. Wagland [a,*]

[a] School of Energy, Environment and Agrifood, Cranfield University, Cranfield, Bedfordshire MK43 0AL, UK
[b] Viridor Waste Management Ltd, Viridor House, Priory Bridge Road, Taunton, Somerset TA1 1AP, UK

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ABSTRACT

The objectives of this study were to assess the biogas potential of landfilled materials and to further validate the suitability of the enzymatic hydrolysis test EHT as a valuable alternative to substitute the standardised test currently in use (BMP). Both tests were applied to a range of landfill waste samples. The waste composition and volatile solids content (VS) profile together with the BMP test results showed that the biogas potential of the waste samples was directly related to their VS content, as expected. The positive correlation between the VS and the BMP test ($r = 0.67$) suggests that the first could be used as a primary indicator of biogas potential of waste samples. Nevertheless, it should be validated against the BMP test because, occasionally, the VS content does not equate to the biogas production. This was mainly due to the paper content of the samples which also correlates positively ($r = 0.77$) with the BMP biogas production. The EHT results showed a higher correlation with the BMP test ($r = 0.91$) than in previous studies which used a wider mixture of enzymes containing cellulase, hemicellulase and carbohydrase. This finding positions the EHT as a quick assessing method for the biodegradability of waste samples in future sample regimes.

1. Introduction

Landfill disposal in the United Kingdom dominated as a method of managing municipal wastes in the past. However, this practice has declined since the introduction of the European Landfill Directive [LFD] (European Commission, 1999). As an example, in 2008, 55% of the total municipal solid waste (MSW) was still directly landfilled (Laner et al., 2012). In 2014, this was reduced to 28% (Eurostat, 2015). After the LFD, the EU Waste Framework Directive 2008/98/EC was implemented to prioritise waste management practices. This directive contributed to minimise waste disposal on landfills and increase the reuse, recycling and recovery of waste (European Commission, 2008).

Soon after waste is deposited, landfill gas [LFG] production commences, progressing through a number of biochemical stages (Christensen et al., 2001; Emkes et al., 2015; Kjeldsen et al., 2002). LFG consists mainly of methane (45–60%) and carbon dioxide (40–60%) (Barlaz et al., 1990; Emkes et al., 2015; Harrison et al., 2000; Kjeldsen et al., 2002). LFG's harmful impacts on the environment are well-known and are mainly due to its high greenhouse gas effect (Adu-Gyamfi et al., 2009; Donovan et al., 2011).

LFD requires operators to capture and treat landfill gas. This has directly decreased the number of MSW operating sites in the UK with a Landfill Directive Compliance permit, from 2000 sites in April 2000 to 465 in 2009 (EA, 2013). Modern engineered landfill sites mechanically compact the waste to eliminate voids and seal them with low impermeability capping layers, usually clay (Environmental Change Institute, 2013). These landfill sites have gas capture systems which enable the collection of methane-rich LFG that can be used to produce electricity. Landfills accepting untreated MSW with high content of biodegradable waste have a high potential of producing large amounts of LFG. The high calorific content of methane allows LFG to be recovered and used to produce a renewable source of energy (Emkes et al., 2015; Krook et al., 2012). Electricity production from landfill sites is an important source of renewable energy (Qasaimeh et al., 2016) in a time when European member states work towards their renewable energy targets (European Commission, 2009). Thus, converting this gas into energy and selling it to the grid is the main source of revenue for landfill sites (Donovan et al., 2011).

LFG production can be estimated by mathematical modelling. Commercial models such as LandGem of US-EPA, GasSim and the IPPCs landfill gas models have been developed to inform landfill

* Corresponding authors.
E-mail addresses: f.coulon@cranfield.ac.uk (F. Coulon), s.t.wagland@cranfield.ac.uk (S.T. Wagland).

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site operators on LFG collection and its potential for energy conversion (Oonk, 2010). Currently, they rely on the amount of waste landfilled, its composition, the moisture content and landfill gas collection efficiency among other factors (Amini et al., 2012) assuming that landfills contain mostly biodegradable waste fraction. However recent studies showed that diversion of biodegradable municipal waste (BMW) from landfills considerably resulted in lower methane generation (Donovan et al., 2010, 2011). Thus the reliance of these LFG generation models on highly biodegradable waste fractions may have reduced their performance and increased their uncertainty (Raco et al., 2010; Scheutz et al., 2011). This, in turn contributes to the increment of the discrepancies between on-site LFG data performance and mathematical models estimations. Scheutz et al. (2011) studied the amount of biogas obtained from sites treating different low organic waste streams using GasSim model. The author showed that GasSim largely overestimated the LFG production, especially for the landfill cells containing lower biodegradable waste content (LFG production measured on site ranging between 0.52 and 2.02 kg CH_4/kg waste/day and GasSim prediction ranging between 27 and 83 kg CH_4/kg waste/day). The limitations of GasSim model when describing the organic content and biodegradability in different waste fractions were also highlighted (Scheutz et al., 2011). Thus, validation of these models against actual data is needed.

Considering this context, providing updated values on the biodegradable content of landfill waste would allow refining the sensitivity of the models. It would also provide landfill operators with better LFG production estimations. Moreover, this information could also help to establish possible issues with the landfill site that may lead to lower LFG production, or slower production rates (Emkes et al., 2015).

Several aerobic and anaerobic methods are currently available to assess the biodegradability of waste. The aerobic tests, such as the DR4 and ASTM are used to assess the stability of compost. The anaerobic tests include the GB21, GS90 and BM100 (Wagland et al., 2009). All methods have their own strengths and weaknesses. The aerobic tests offer a relatively short timescale for test completion (on average 4 days for DR4 and ASTM) but they do not measure the whole biodegradability. The anaerobic tests include the standardised BM100 currently used to assess the biodegradability of waste in protocol published by the Environment Agency [EA] for England and Wales. The BM100's weakness stems from its inconvenient routine testing which can last for more than 30 days. Thus, developing a rapid low cost method that can assess the biodegradability of waste with enough accuracy will be a highly valuable tool for the aforementioned monitoring purposes.

Previously, an enzymatic hydrolysis test [EHT] method was investigated as a novel, rapid alternative to assess the biodegradability of waste (Wagland et al., 2011, 2008, 2007a,b). This method considered that LFG is released mostly from the biodegradation of hemicellulose and cellulose materials. Results showed a good correlation between the EHT and the standardised biochemical methane potential [BMP] test when applied to a variety of organic waste samples ($r = 0.77$). These results position EHT as a good alternative to aerobic tests when assessing short term biodegradability of organic waste materials. The EHT method was also used by Chatelet (2012) to predict the residual biomethane potential (RBP) of anaerobic digestion (AD) digestate.

In this study, the UK accepted version of the BMP protocol was used as control and as a reference method to compare both EHT and BMP methods and to assess the correlation obtained between them. A new range of enzyme mixture consisting of crude cellulase, crude hemicellulase, endo-carbohydrase and lipase were used to assess waste biodegradability and residual biomethane potential. The objective of this study was to determine the physical composition and the residual biogas potential of landfilled materials and to further validate the suitability of the EHT as a valuable alternative to the BMP protocol.

2. Materials and methods

2.1. Origin of waste

The waste samples analysed in this study were comprised of MSW from a landfill site, Site A, located in the South of England in the county of Sussex.

Site A is a closed site with its capping works completed in 2009. Between 2004 and 2006, the site received over a million tonnes of waste. Recently, gas wells were drilled and installed.

Fourteen waste bags containing approximately between 2 and 5 kg were extracted at Site A. These were collected every 2 m until reaching the clay layer at 30 m.

Table 1 shows the weight of the waste fractions collected at the different layers.

2.2. Waste samples preparation and composition analysis

Waste sample bags were stored in a cold room prior to manual sorting and analysis. Non-biodegradable waste including plastics, inert, and metals were removed by manual sorting. The weight of the collected fractions including fine organics, inert, wood, metal, textile paper/cardboard and plastic is shown in Table 1.

Dry matter (DM or TS) and volatile solids (VS) of the BMW samples were determined in triplicate following the procedure EN 12879:2000 (Wagland, 2008). This was done to calculate the amount of moisture present in the waste and the amount of volatile solids (VS). The samples were dried during 24 h for the DM determination at 105 °C and 4 h at 505 °C for the VS determination.

According to Wagland (2008) there is not apparent benefit to reducing the particle size from <10 mm to <2 mm when undertaking the enzymatic hydrolysis test. Thus, in this study, the dried waste samples were shredded to a particle size of 8 mm. Before shredding, the bulk of the waste samples were dried overnight.

2.3. Biochemical methane potential test (BMP)

Different articles have been reported over the years to define a common BMP testing protocol (Angelidaki et al., 2009; Raposo et al., 2011), the test in this work were carried out following the RBP protocol for the digestates (Walker and Wilson, 1991). In addition to waste samples analysed, control tests with samples containing inoculum (blanks) and a mixture of inoculum and cellulose (reference material) were all done in triplicate.

The reference material should be able to produce in excess of 0.5 L of biogas per gram volatile solids (L/g VS) within the time of the test. The test was carried out in batch reactors of 1 L. Sewage digestate from the local wastewater treatment plant was used as active inoculum. The BMP test was run for a minimum of 21 days or until biogas had reached a stable plateau (over 30 days for our samples). Biogas production was measured daily by water displacement and methane content using a SERVOPRO1400 CH4 gas analyser (Servomex, UK). The measurements were monitored daily during the first 7 days, and every 3 days after that.

20 g of VS of each material, 350 g of inoculum, 1 mL of concentrated nutrient solution and water were added to 1 L batch reactors to a final volume of 800 mL. The bottles were sealed and the headspace flushed with nitrogen. The mixture was incubated under anaerobic conditions at 38 °C.