



RESEARCH ARTICLE

Assessing pretreated municipal solid waste degradation by BMP and fibre analysis

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ABSTRACT

Landfill continues to be the major method of Municipal solid waste (MSW) disposal in the UK and many other countries despite considerable efforts to limit its use. The EU Landfill Directive requires, amongst other things, that waste is treated to reduce its biodegradability prior to disposal to landfill. This pre-treatment is often achieved through what is generically termed mechanical-biological treatment. Predicting the biodegradability or degradation potential of these pre-treated wastes is important for the long term management and aftercare of landfill sites. To address this, a series of biochemical methane potential (BMP) tests have been undertaken to characterize the anaerobic biodegradation potential of two mechanically biologically treated (MBT) waste samples in terms of biogas yield, solids composition (loss on ignition, total carbon, cellulose, hemicellulose and lignin contents), and assessment of leachate characteristics during the biodegradation process. Experimental results from a long term study of MBT wastes treated to different standards are analyzed and compared. The relationship between biogas potential and solids composition was investigated, and carbon and nitrogen mass balances are discussed. The biogas potential was shown to correlate well with the ratio of cellulose plus hemicellulose to lignin, loss on ignition and total carbon content of the waste indicating a clear link between these parameters. The results indicate that solids composition of MBT wastes may provide a useful indication of the biodegradation potential. The mass balance indicates that a large proportion of carbon and nitrogen remain locked up in the waste material and is not released.

Keywords: Biodegradability, BMP, landfill, leachate, MBT waste

1. INTRODUCTION

Legislation (e.g. the EU landfill directive) in some parts of the world now requires municipal solid waste (MSW) to be processed prior to landfilling to reduce its biodegradability. This pre-processing may be achieved through what is generically termed mechanical-biological treatment. The biochemical methane potential (BMP) test measures the methane or biogas that can potentially be produced under anaerobic conditions by a known quantity of waste. This test is well recognized to provide a reliable estimate of organic waste biodegradability (e.g. [1-3]). BMP tests are bioassays in which a waste sample is incubated in a temperature controlled system, with nutrients and bacteria added to optimize conditions for microbial methanogenesis. The organic matter found in solid waste includes cellulose, hemicellulose and lignin as described in [4]. Reference [5] have shown that cellulose and hemicellulose contributes

between 45 - 60% of MSW and are major biodegradable constituents responsible for up to 90% of methane production in landfills. As cellulose and hemicellulose degrades, most of the lignin remains and its percentage in the MSW increases. The relative concentrations of cellulose (C), hemicellulose (H) and lignin (L) have previously been used to assess the degree of decomposition of landfilled waste (e.g. [6, 7]). Over the past decade, field scale studies (e.g. [8, 9]) and laboratory scale studies (e.g. [10-15]) have operated MSW landfills as bioreactors to enhance the degradation process and accelerate waste stabilization, with the aim of bringing the landfill to a stable, non-polluting state in a relatively short time.

Data and experience on the performance of pre-treated MSW landfills i.e. those filled exclusively with MBT waste, is not currently available. Reference [16] investigated the impact of biological pre-treatment on leachate quality. Limited data are available on the long term leachate quality and gas generating potential of

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MBT waste, based on small scale studies (e.g. [17-22]). Most of these studies did not capture the complete stabilization process and it remains unclear how the solids composition change with the progression of decomposition of an MBT waste.

To address this, a series of BMP tests have been undertaken to characterize the anaerobic biodegradation potential of two MBT waste samples pre-treated to different standards. This characterization includes measurement of biogas yield, changes in solids composition, and assessment of leachate characteristics during the biodegradation process. The relationship between biogas potential and solids composition was investigated, and carbon and nitrogen mass balances are discussed.

2. MATERIALS AND METHOD

2.1. Waste samples

Two mechanically sorted and pre-treated waste samples were studied: UK MBT waste and German MBT waste. The waste UK MBT waste was obtained from a large scale waste pre-treatment facility New Earth Solutions plant in Southern England. This is a fully enclosed facility that takes non-source segregated household wastes. These are initially shredded and screened for ferrous metals and non-biodegradable material recovery. The remaining degradable fraction undergo a six week dynamic processing phase involving aeration and, close temperature and moisture control to stabilize the waste.

The waste German MBT waste was obtained from Hannover Waste Treatment Centre, a mechanical-biological treatment facility in Hannover, Northern Germany. During the mechanical stage of the process, waste was sorted, shredded and screened, and recyclable materials and metals were removed. The remaining degradable waste fraction was anaerobically digested in fermentation tanks for a period of three weeks. The digested material was extracted and transferred to an aerobic post treatment area where it was composted in enclosed windrows for approximately 6 weeks.

2.2. Synthetic leachate

To enhance the decomposition of the waste by anaerobic bacteria, synthetic leachate containing mineral nutrients and trace elements dissolved in

deionised water as described in [23] was used in this study and the details are given in Table 1.

2.3. BMP reactors set up and operation

The BMP reactors were made from 1000 ml Nalgene bottles attached to a gas collection system that allowed the volume of gas produced during anaerobic degradation to be measured. The test set-up comprised 12 BMP reactors (B1 to B12) each filled with 140 g of dried MBT waste sample. To accelerate degradation of the waste by anaerobic bacteria, 500 ml of synthetic leachate containing anaerobically digested sewage sludge seed (10% by vol.) was added to each reactor placed in a water bath at 30°C to promote mesophilic methanogenic conditions. Individual reactors were sacrificed sequentially during the test to observe solids compositional changes and leachate characteristics at different stages of degradation to allow leachate and solid compositional changes to be tracked. Each waste sample was also analyzed for total carbon, total nitrogen, loss on ignition (LOI), cellulose, hemicellulose and lignin, and the leachate samples were analyzed for pH, volatile fatty acids (VFAs), total organic carbon (TOC), dissolved organic carbon (DOC), inorganic carbon (IC), total nitrogen (TN) and ammoniacal nitrogen (NH₄-N). Biogas samples taken from each BMP reactor were analyzed for methane (CH₄) and carbon dioxide (CO₂).

2.4. Analytical procedure

The biogas that accumulated in the head space of each BMP gas collection burettes was collected in a gas tight syringe and its composition (CH₄ and CO₂) determined by gas chromatography in Varian CP3800 GC fitted with a HaySep C column and a molecular sieve 13x (80-100 mesh) operated at a temperature of 50°C. Argon was used as a carrier gas at a flow of 50 ml/minute. Leachate samples were analyzed for pH using a Jenway Model 3010 digital pH meter. TOC, DOC, IC and TN analyses of leachate samples were carried out using a high temperature Dohrmann-Rosemount DC-190 TOC analyzer equipped with a Dohrmann ozonator for TN analysis. NH₄ -N was measured by steam distillation using a Foss Tecator Kjeltec System 1002 distilling unit. VFA composition was determined by gas chromatography using a Shimadzu-2010 GC.

Table 1. Recipe of synthetic leachate

Reagent	Conc. (mg L ⁻¹)	Reagent	Conc. (mg L ⁻¹)
K ₂ HPO ₄ .3H ₂ O	330.000	MnCl ₂ .4H ₂ O	0.500
NH ₄ Cl	280.000	CuCl ₂ .2H ₂ O	0.038
MgSO ₄ .7H ₂ O	100.000	(NH ₄) ₆ MoO ₂₄ .4H ₂ O	0.050
CaCl ₂ .2H ₂ O	10.000	AlCl ₃ .6H ₂ O	0.090
FeCl ₂ .4H ₂ O	2.000	NiCl ₂ .6H ₂ O	0.142
H ₃ BO ₃	0.050	Na ₂ SeO ₃ .5H ₂ O	0.164
ZnCl ₂	0.050	CoCl ₂ .6H ₂ O	2.000
EDTA	1.000		

Waste solids were analyzed for LOI, TC, TN, cellulose, hemicellulose and lignin contents. Prior to the analyses for LOI, TC and TN, all non grindables (metal, glass, ceramic and stone) were removed from the sample. The remaining waste was dried at 70°C and milled to a fine powder using a Foss Knifetec 1095 mill in conjunction with a Foss Cyclotec 1093 mill. LOI content was measured by ignition of dried sample at 550°C in a muffle furnace for two hours. TC and TN contents of the samples were measured using a CE Instruments Flash EA 1112 Elemental Analyser (Thermo Finnigan). Fibre analysis using the FibreCap test method was performed for the measurement of cellulose, hemicellulose and lignin content as described in [27] and [28].

Table 2. Elemental and fibre analysis data

Chemical analysis	Concentration (% dry mass)	
	UK MBT waste	German MBT waste
Cellulose, %	10.24	7.96
Hemicellulose, %	4.54	3.91
Lignin, %	12.63	13.01
(C+H)/L ratio	1.17	0.91
Total carbon, %	22.68	19.85
Total nitrogen, %	1.81	1.52
Loss on ignition, %	42.91	34.84

3. RESULTS AND DISCUSSION

3.1. Biogas volume and composition

The net biogas yield attributable to 140 g dried waste sample in each reactor was determined by subtracting the measured biogas yield of the control bottles from the total biogas produced by each reactor. The volume of biogas collected was standardized to dry gas at STP as explained in [29]. Gas production started virtually immediately the reactors were assembled; methanogenic conditions were rapidly established. The acidogenic phase was virtually absent, probably due to the partial degradation of some organic compounds during the pre-treatment phase. This is in agreement with the findings of [18-20] and [21]. Biogas production for the MBT wastes increased in a similar trend but at different rates and most of the gas had been produced by day 100. Thereafter, gas production continued at a much lower rate until day ~200 when it had effectively ceased for both wastes. A similar observation for the gassing rate was made by [24] regarding the continuation of low level emissions in landfills over the long term. The UK MBT waste produced considerably more biogas, reaching approximately 45.54 L kg⁻¹ dry matter (DM) after 347 days. In contrast, biogas production from the German MBT waste was 16.39 L kg⁻¹ DM after 279 days. The biogas yield of UK MBT waste is greater than in some other studies (e.g. [17, 19]), but within the range reported by [20] and [22].

The higher gas production potential in the UK MBT waste is due to the more limited biological pre-

treatment process used and correlates with the higher values of the organic content i.e. the LOI, cellulose and TC contents in Table 2. The gas composition in both waste samples was similar with the methane content in the range of 58% - 62% and the carbon dioxide content 35 - 40%. The cumulative gas volume for raw MSW (collected from White's Pit waste processing plant in Southern England) degraded anaerobically for 919 days as reported in [28] was significantly higher (243.55 L kg⁻¹ DM) which is attributable to the higher organic waste composition in the raw MSW. This reduced gassing potential of the MBT wastes demonstrates diversion of the degradable fraction from disposal to landfill as a result of the biological pre-treatment process, but also that landfill gas control measures will still be required to prevent fugitive gas emissions from landfill.

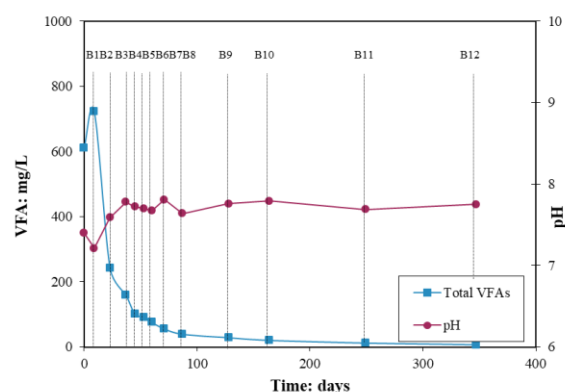


Fig 1. Leachate VFA and pH in BMP reactors for the UK MBT waste

The higher gas production potential in the UK MBT waste is due to the more limited biological pre-treatment process used and correlates with the higher values of the organic content i.e. the LOI, cellulose and TC contents in Table 2. The gas composition in both waste samples was similar with the methane content in the range of 58% - 62% and the carbon dioxide content 35 - 40%. The cumulative gas volume for raw MSW (collected from White's Pit waste processing plant in Southern England) degraded anaerobically for 919 days as reported in [28] was significantly higher (243.55 L kg⁻¹ DM) which is attributable to the higher organic waste composition in the raw MSW. This reduced gassing potential of the MBT wastes demonstrates diversion of the degradable fraction from disposal to landfill as a result of the biological pre-treatment process, but also that landfill gas control measures will still be required to prevent fugitive gas emissions from landfill.

3.2. Leachate Characteristics

The pH of the leachate decreased slightly at the start of the degradation process due to the built up of VFAs during the first week due to the accumulation of hydrolytic products, and started to decrease thereafter as the methanogens utilized these as a substrate for conversion to biogas. Final stable values of pH were between 7.5 and 7.7, similar to those found in previous studies (e.g. [10, 14-15]). The decrease in VFA composition is consistent with an increase in pH and biogas production as shown in Fig

1. The low VFA concentration is an indication that most of the available organic matter has been converted into biogas and that biological stabilization has been achieved. The TOC concentration increased at the start due to the rapid release and hydrolysis of organics from the waste into the leachate. It was then decreased slowly in accordance with the progression of microbially mediated stabilization processes to about 465 and 198 mg L⁻¹ by the end of the test for the UK and German MBT wastes respectively (Fig 2). The lower organic content of the leachate associated with the MBT wastes are in agreement with the findings of [16] and [20], but the values are in excess of those observed by [17] and [22].

The organic strength i.e. TOC of the leachate from the German MBT waste was low compared with that from the UK MBT waste, consistent with the reduced organic content of the German waste owing to the different biological processing steps used during pre-treatment. Most of the TN was found to be in the form of ammoniacal nitrogen. After the initial increase, TN and NH₄-N remained stable until the end of the tests. This is in agreement with the findings of [25] and [26]. These results indicate that the leaching potential of nitrogen from the German MBT waste was less than that from the UK MBT waste and is due to the lower initial TN content of the German MBT waste.

3.3. Solids Composition

The cellulose and hemicellulose values show a decreasing trend while lignin increased (becoming a greater proportion of the remaining waste) being a recalcitrant material (Fig 3). This is consistent with the depletion of cellulose and hemicellulose as about 50 to 60% of cellulose and 40 to 45% of the hemicellulose degraded over the whole period of test for the MBT wastes. The cellulose content decreased from 10.2% to ~ 3.8% and from 7.9% to ~3.9% for the UK and German MBT wastes respectively. The hemicellulose content decreased from 4.5% to about 2.5% and from 3.9% to 2.4% for the two wastes respectively. The presence of cellulose and hemicellulose that is not degraded can be explained by the fact that lignin forms a physical barrier around some cellulose and hemicellulose which eliminates microbial access. The lignin content increases due to a relative decrease in cellulose and hemicellulose contents and the lignin enrichment of the remaining solids. A strong linear correlation was found between the biogas potential and the (C+H)/L ratio for the wastes. Decreasing (C+H)/L ratios correlate well with decreasing biogas potential. For both the wastes, a good correlation was found when comparing the biogas potential to LOI and TC content of the wastes. The LOI content of the solid waste samples showed a decreasing trend over the test period, which is consistent with the depletion of TC. Therefore, the changes in solids composition e.g. (C+H)/L ratio, LOI and TC are interrelated and there is a clear link between these parameters and biogas potential (Fig 4).

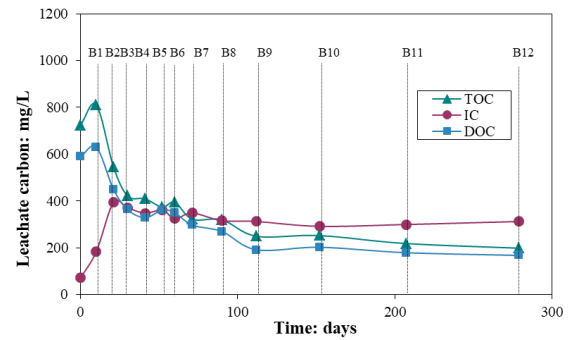


Fig 2. Leachate carbon in BMP reactors for the German MBT waste

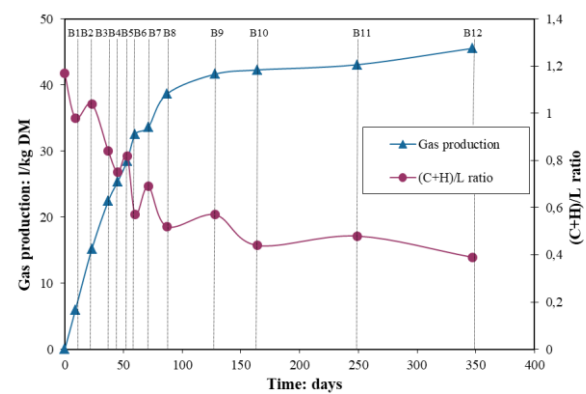


Fig 3. (C+H)/L ratio and gas production in BMP reactors for the UK MBT waste

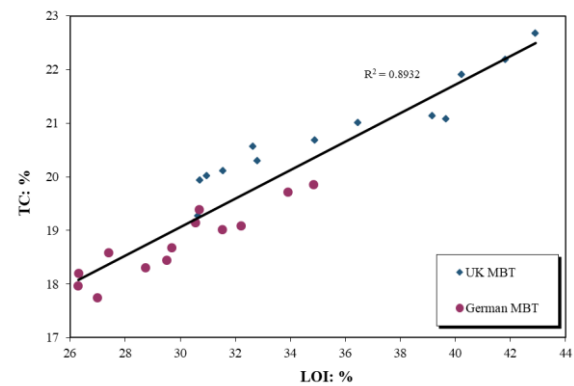


Fig 4. Correlation between LOI and TC contents of the UK and German MBT wastes

3.4. Carbon and nitrogen mass balance analysis

Carbon and nitrogen mass balance calculations for the UK and German MBT wastes are summarized in Tables 3 and 4 respectively. The mass balance shows that 85 - 90 % of the carbon initially in waste remained there, 10% was removed in the biogas, and less than 1% was transferred into the leachate. About 90 % of the nitrogen remained in the waste at the end of degradation and 5% transferred into the leachate, with 5% unaccounted for.

Table 3. Summary of carbon mass balance in the UK and German MBT wastes

Parameter	UK MBT waste	German MBT waste
C _{initial waste} , g kg ⁻¹ DM	226.8	198.5
C _{synthetic leachate} , g kg ⁻¹ DM	1.78	1.49
C _{CH₄} , g kg ⁻¹ DM	15.13	5.18
C _{CO₂} , g kg ⁻¹ DM	9.03	3.42
C _{leachate} , g kg ⁻¹ DM	2.71	1.82
C _{degraded waste} , g kg ⁻¹ DM	192.7	179.7
C _{CaCO₃} , g kg ⁻¹ DM	0.32	0.28
C _{MgCO₃} , g kg ⁻¹ DM	0.03	0.09
Mass balance error, g kg ⁻¹ DM	8.66	9.5
Mass balance error, %	3.8	4.7

Table 4. Summary of nitrogen mass balance in the UK and German MBT wastes

Parameter	UK MBT waste	German MBT waste
N _{initial waste} , g kg ⁻¹ DM	18.1	15.2
N _{synthetic leachate} , g kg ⁻¹ DM	0.34	0.24
N _{degraded waste} , g kg ⁻¹ DM	16.1	13.9
N _{leachate} , g kg ⁻¹ DM	1.49	0.65
Mass balance error, g kg ⁻¹ DM	0.85	0.89
Mass balance error, %	4.6	5.8

4. CONCLUSIONS

The biogas yield and leachate characteristics have demonstrated that pre-treatment of raw MSW substantially reduces the gas generating potential and leachate strength.

Degradability of MBT waste was evaluated using LOI, TC, biogas potential, cellulose, hemicellulose and lignin contents of decomposing waste in small scale BMP reactors. A strong correlation was found between the biogas potential and the (C+H)/L ratio. The initial cellulose and hemicellulose contents of the pre-treated wastes were reduced, but in the degraded state were very similar to degraded MSW indicating that the same state of final decomposition is achieved. LOI content of the waste samples decreased with the progression of degradation which is consistent with the depletion of the TC content. The biogas potential was shown to correlate well with LOI and TC content of the waste. The BMP test results indicate that changes in LOI, TC and (C+H)/L ratio and biogas potential are inter-related and solids composition of MBT waste may provide a useful indication of the biodegradation potential.

The carbon and nitrogen mass balances indicate only a small proportion of the carbon and nitrogen in the system is unaccounted for. A large proportion of carbon and nitrogen remain locked up in the waste material and is not released.

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