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CHARACTERISATION OF UNTREATED AND TREATED BIODEGRADABLE WASTES

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SUMMARY: As part of a Defra sponsored project (WRT220), approximately 40 biodegradable wastes were characterised according to biodegradability (DR4 and BM100), total PTE content, C:N ratio and biochemical composition. Two leaching tests were employed; upflow percolation test and a one step LS10 test; eluates were analysed for TOC, pH, electrical conductivity, PTEs and a range of cations and anions. This paper contains a limited set of data for a selection of untreated and treated waste types representing four waste treatment processes (composting, MBT, MHT, anaerobic digestion). The DR4 and BM100 tests were found to be appropriate for a wide range of waste types but where possible they should be used in conjunction with other related tests. Longer-term MBT composting processes appeared to produce compost material with reduced ammonium concentrations and extractability of some PTEs. Carbon content (carbon analyzer - LECO) could be estimated as C = LOI/1.9 which is a routine operation. N LECO values were approximately 12% greater than the equivalent N Kjeldahl values.

1. INTRODUCTION

The Landfill Directive 1999/31/EC (European Council 1999) requires the progressive diversion of biodegradable municipal waste (BMW) from landfill in order to reduce fugitive emissions of CH_4 from landfills. The Environment Agency estimates that for England alone the amount of BMW landfilled in 2001/2 was 15 million tonnes and this will need to be reduced to 5.22 million tonnes in 2020. Waste Disposal Authorities (WDAs) within the U.K. have been set typically decreasing allowances for landfilling BMW under national Landfill Allowance Schemes (Defra 2006). It is clear that Waste Disposal Authorities need to develop and implement strategies to treat an increasing amount of biodegradable municipal waste and to utilise the residues in ways that minimise environmental impact.

In order to identify the most effective, sustainable and appropriate treatment routes for the new generation of biodegradable wastes, a complete understanding of their physico-chemical characteristics is required. Furthermore, the residues from waste treatment may themselves have significant environmental impact and an extensive characterisation programme is equally important for these to help ensure that residues are appropriately utilised. For example, it is anticipated that Mechanical and Biological Treatment (MBT) of MSW will increase substantially in the UK but more needs to be learned about the environmental impact of residues including the long term effects of these when landfilled (Robinson *et al*. 2005).

As part of a Defra sponsored Waste Characterisation project (WRT220), approximately 40 biodegradable wastes were fully characterised, including several examples of mixed municipal waste (MSW), as well as a range of individual waste types such as fish, feathers, pizza, packaging (cardboard), botanical waste and wood. Although many waste samples were untreated, others had been either partially or fully stabilised in either aerobic or anaerobic biological treatment systems, or had been treated by autoclave Mechanical Heat Treatments (MHT) i.e. treated thermally by autoclaving at a temperature of 160 ^{o}C for 30 minutes. All wastes were subjected to an extensive characterisation programme including determination of biodegradability using the DR4 and BM100 tests, total PTE content, C:N ratio and biochemical composition (fat, cell contents, hemicellulose, cellulose and lignin). In addition, two leaching tests were employed; upflow percolation test and a one step LS10 test; eluates were analysed for TOC, pH, electrical conductivity, PTEs and a range of cations and anions.

Arising from the Defra Waste Characterisation project, this paper will present a limited set of characterisation data for a selection of untreated and treated waste types representing four waste treatment processes (composting, MBT, MHT, anaerobic digestion). One aim of the paper is to explore and compare the use of waste characterisation tests to enhance our understanding of how the results from these may be fully integrated, interpreted and applied. The paper will also illustrate how data from these tests may be used to help understand the behaviour of untreated and treated biodegradable wastes in relation to different treatment processes.

2. MATERIALS AND METHODS

2.1 Laboratory analyses

The untreated and treated samples, except for the mixed MSW samples (A) and (B), were analysed on an as received basis. Input and output MSW samples from sources (A) and (B) were prepared by removing inert material leaving only the biodegradable fractions, BMW (A) and (B), which were analysed as described below.

Biodegradability under anaerobic conditions was measured by production of biogas according to BM100 test adapted from a sewage sludge digestion test method (SCA, 1977). Biodegradability in aerobic conditions was determined using a 4 - day dynamic respiration test for waste stability (DR4), adapted from ASTM D5975-96 (ASTM, 1996) with incubation temperature 35 ºC and moisture contents adjusted to 50 %. Outline test methods for BM100 and DR4 are contained in Environment Agency (2005).

Organic matter was determined by loss on ignition at 450 ºC and converted to percentage C by dividing by 1.8 (BSI, 2000). A Kjeldahl digestion modified to include nitrates was used for total N (BSI 2001/2). In addition, total C, N and S were analysed by LECO CNS2000 elemental analyser (Nelson and Sommers, 1996, Bremner, 1996). Aqua regia digests for total elements (BSI 2001/1) were analysed for Cd, Cu, Cr, Ni, Pb, and Zn by ion-coupled plasma mass spectrometry (BSI, 1998) on an Agilent7500a ICP-MS.

Biochemical composition was determined (van Soest *et al*. 1991, Effland 1977, Richards 2005) using an adaptation of the Gerhardt Ltd. fibrebag system. Dried, ground samples, with fine material that would pass through the fibrebags removed, underwent sequential treatment with petroleum ether, neutral detergent solution, acid detergent solution, cold 72% sulphuric acid and ashing at 600 ºC. The fractions removed by these processes are nominally identified as fat, soluble material, hemicellulose, cellulose and lignin respectively. These designations may not be exclusively composed of the described biochemical classes but be mixtures of different materials with similar sequential extractive properties by the methodology.

Leaching tests were in accordance with the one-stage batch test for granular waste materials at solid:liquid ratio of 1:10 (LS10) (BSI, 2002). At least 3 replicate portions of each sample were leached. Eluate was separated from solid sample by centrifugation and sequential filtration to less than 0.45 µm. Eluates were analysed for pH, conductivity (EC), and dissolved organic carbon on a Shimadzu TOC-VCNS. Eluates were analysed by ion chromatograph for inorganic cations (Dionex DX100) and anions (Dionex ICS2500), and metal elements by atomic emission spectrometry (BSI, 1995) (Varian AA240FS). These are expressed on a dry weight basis (BSI, 2002).

All results quoted are the means of at least 3 replicates.

3. RESULTS AND DISCUSSION

3.1 Source segregated household wastes (composting)

For all composting processes it is useful to know the suitability of particular feedstocks for composting and the stability or degree of decomposition of the resulting composts. The aerobic DR4 and anaerobic BM100 tests were designed to determine the reduction in biodegradability achieved by MBT systems treating mixed MSW. However in order to determine their wider applicability they have been used in this project to help characterise other processes and waste types. The DR4 respiration test is run for a relatively short timescale (4 days) and hence only the more readily biodegradable fraction of the test material will mineralise during the test. The BM100 test however is run until biogas (CH_4 and CO_2) production ceases and decomposition is complete under anaerobic conditions. The decomposed material will therefore comprise most of the medium and slowly biodegradable fractions as well as the readily biodegradable fraction.

One example of how the DR4 and BM100 tests perform in relation to other parameters can be seen from the composting process data presented in Tables 1, 2 and 3. The TC content (LECO) of the mixed kitchen and green waste feedstock (40.3%) was similar to that for the green waste only feedstock (39.4%), whereas both the DR4 and BM100 values were much greater for the mixed kitchen and green waste. The DOC was also over ten times greater for the mixed kitchen and green waste feedstock compared with the green waste. In this case, the increased levels of DR4, BM100 and DOC may reflect the biochemical composition of the two feedstocks with the mixed kitchen and green waste material having a greater proportion of readily biodegradable material (sum of fat, soluble and hemicellulose fractions; 51.5%) compared with the green waste alone (43.4%), and a reduced level of recalcitrant lignin.

The compost derived from the mixed kitchen and green waste showed greatly reduced values of DR4 and BM100 compared with the feedstock and this high level of stabilisation is typical for extended and well managed composting processes. However, the green waste compost which was only partially composted and then screened to remove the larger oversize twigs and branches, showed slightly higher levels of DR4, BM100, DOC and electrical conductivity (nutrient status) compared with the input material. This suggests that the apparent large reduction in the LOI fraction between input (74.4%) and the screened output (59.0%) was probably due to removing recalcitrant material with an LOI content greater than the input green waste during screening and it is likely the screened green waste compost was only poorly stabilised due to the short composting duration.

Table 1 BM100 and DR4 results, and biochemical composition for untreated and treated wastes

Waste & Process Type	BM100	DR4	Biochemical composition % dm					
	Litres biogas $kgLOI^{-1}$	mgO_2 $kgLOI^{-1}$ $96hr^{-1}$	Fat	Readily soluble material	Hemi-cellulose	Cellulose	Lignin	Residue after ashing
Source segregated household wastes (composting)								
Kitchen/green waste (input)	292	217000	3.1	33.9	14.5	19.1	15.5	14.0
Kitchen/green waste output (fully composted)	99	82000	1.0	33.4	7.9	16.1	16.1	25.4
Green waste (input)	182	108000	1.5	25.9	16.0	19.8	19.7	17.1
Green waste output (partially composted & screened)	221	136000	1.8	27.7	11.7	14.8	17.3	26.7
Mixed municipal household wastes (MBT)								
BMW (A) input	418	256000	3.2	31.0	11.1	21.7	10.9	22.1
BMW (A) output (fully composted)	105	30000	0.5	24.2	8.7	5.2	6.2	55.2
BMW (B) input	386	276000	8.3	41.1	10.1	14.5	9.1	16.8
BMW (B) output (14 days composted)	293	184000	1.6	39.4	10.1	19.1	15.6	14.1
BMW (B) composted output (screened < 8mm)	314	167000	0.8	40.7	9.6	11.1	11.5	26.3
Industrial and commercial wastes (autoclaving)								
Packaging waste (cardboard) input	527	73000	2.7	7.1	11.3	42.6	34.0	2.3
Autoclaved packaging waste output	630	90000	2.4	8.1	8.0	46.2	31.9	2.8
Turkey feathers input	375	91000	3.9	11.6	66.9	4.2	12.5	0.9
Autoclaved turkey feathers output	199	366000	2.9	62.5	24.6	4.4	3.9	1.7
Mixed municipal household wastes (anaerobic digestion)								
Fibre from autoclaved MSW input	319	249000	3.0	34.9	8.1	26.2	18.9	8.9
Digested autoclaved MSW fibre output	92	69000	0.6	26.8	10.5	11.9	40.2	10.0
MSW (C) input	413	313000	2.9	31.6	9.0	25.9	9.6	20.9
Digested MSW (C) output	62	54000	0.4	29.4	10.8	17.4	20.9	21.0

Total PTE concentrations for both source segregated feedstocks were generally low. During composting organic matter was lost but despite PTE concentrations generally increasing due to this concentration effect, both composted products were found to have total PTE concentrations which were within the PAS100 upper limits expressed as mg $kgdm^{-1}$, which are Cd (1.5), Cr (100), Cu (200), Ni (50), Pb (200) and Zn (400). PAS100: 2005 is the British Standards Institute specification for composted materials (BSI, 2005).

Often fully or partially composted materials, derived from source segregated waste, are applied to agricultural land making it important to understand the leaching behaviour of specific PTEs. The LS10 leaching test was applied to all wastes included in the project. Table 3 presents the concentrations of a limited set of PTEs in the eluate for the selected wastes. As an example of leaching behaviour, it was found that for the fully composted kitchen/green waste compost, the ratios of water soluble to total Ni and Zn were 1.4% and 1.6% respectively. These ratios were much lower than for the input, untreated waste, which were 8.3 % and 5.7% respectively, suggesting that effective composting can reduce mobilization of metals. Bhattacharyya *et al.* (2004) studied this effect and reported that for waste and compost the availabilities for Ni were 1.7% and 1.03% and for Zn 4.95% and 3.92% respectively. In this study, no reduction in availability as a result of composting was found for the short duration green waste composting process, indicating that degree of decomposition may be a factor in determining the availability of PTEs in the composted products.

The dry matter mass reduction factor (1.75) was estimated from the LOI contents of the treated and untreated kitchen/greenwaste by assuming that there was no leachate produced during composting and that the ash content was then conserved. This value matched closely the mean concentration factor increase of 1.74 estimated for the total metal determinations. This implies that no metals were lost and that genuine metal stabilisation occurred. However whether this a permanent or only temporary stabilisation is not certain and long term studies on metal leaching from deposited treated wastes are required.

3.2 Mixed municipal household wastes (MBT and Anaerobic Digestion)

From Tables 1, 2 and 3, it can be seen that the characteristics of the three untreated mixed MSW derived BMW feedstocks selected for this study were relatively similar in many respects such as carbon content and all had relatively low proportions of lignin (approximately 10%). The C:N ratios for the untreated mixed BMW inputs were very variable (19:1, 24:1 and 32:1) with a wide range of nitrogen contents (from 1.1% to 1.9%). The lowest C:N ratio waste (BMW B) also had the largest highly soluble fraction (approximately 50%) and the lowest cellulose content as shown by the biochemical composition. The BM100 values corresponding to the C:N ratios 19:1, 24:1 and 32:1 were 386, 418 and 413 litres biogas $kgLOI^{-1}$. By comparison, the autoclaved MSW fibre had the highest C:N ratio (38:1), carbon content (41.8%), DOC (25200 mg $kgdm^{-1}$) and lignin content (18.9%) and the BM100 value for this treated waste was lower than the MSW inputs at 319 litres biogas $kgLOI^{-1}$. The MSW fibre product from autoclaving represent an organic fraction of the BMW that has been enriched in cellulose and lignin compared with the BMW. As this fibre has a lower biodegradability than the BMW it suggests that autoclaving this particular mixed MSW did not appear to enhance the biodegradability of the resulting fibre and that probably the lower biodegradability was because some of the more readily biodegradable components had been removed by autoclaving by hydrolysis and extraction into the process liquid condensates.

Total PTE concentrations (Table 2) for the four mixed MSW derived BMW feedstocks were in general considerably higher than those of the source segregated feedstocks. The compost like outputs (CLOs) from the mixed MSW inputs are not eligble for PAS100, since the feedstocks are not source segregated, however they may be utilised in some types of land reclamation projects. While the concentrations of some PTEs (Cd and Cu) were below PAS100 limits for three of the CLOs, other PTE concentrations were consistently greater than the PAS100 limits (Ni, Pb and Zn). Understanding leaching characteristics for PTEs are equally important for the treated material if landfilled or applied to land. For the fully composted MSW (A) the ratios of water soluble to total concentration were Ni (0.3%) and Zn (0.2%). Again, as for the composted source segregated materials these ratios were much lower than for the untreated input MSW which were 1.9% and 1.8% respectively, suggesting that extended composting can reduce mobilization of specific metals.

Table 2 Selected elemental composition for untreated and treated wastes

Waste & Process Type	LOI % dm	C (LOI) % dm	TKN % dm	C:N ratio (LECO)	LECO % dm			Selected PTE concentrations (total) mg $kgdm^{-1}$					
					C	S	N	Cd	Cr	Cu	Ni	Pb	Zn
Source segregated household wastes (composting)													
Kitchen/green waste (input)	76.1	42.3	1.58	24	40.3	0.3	1.7	0.28	32	26	15	34	99
Kitchen/green waste output (fully composted)	58.4	32.5	1.57	16	31.0	0.3	1.9	0.52	41	50	21	78	170
Green waste (input)	74.4	41.3	1.09	36	39.4	0.2	1.1	0.35	35	18	20	40	101
Green waste output (partially composted & screened)	59.0	32.8	1.20	25	30.5	0.2	1.2	0.40	52	30	26	61	120
Mixed municipal household wastes (MBT)													
BMW (A) input	68.7	38.2	1.28	24	33.0	0.2	1.4	1.33	39	211	23	120	148
BMW (A) output (fully composted)	26.5	14.7	0.63	20	13.7	0.2	0.7	1.08	109	164	70	222	511
BMW (B) input	66.6	37.0	1.64	19	36.8	1.0	1.9	0.60	50	48	65	3550	230
BMW (B) output (14 days composted)	67.3	37.4	1.43	23	38.5	1.1	1.7	1.00	257	199	146	501	403
BMW (B) composted output (screened < 8mm)	55.1	30.6	1.48	21	29.6	0.7	1.6	0.79	264	420	157	670	519
Industrial and commercial wastes (autoclaving)													
Packaging waste (cardboard) input	94.7	52.6	0.15	235	46.9	0.2	0.2	0.21	n.d.	16	3	n.d.	43.
Autoclaved packaging waste output	93.1	51.7	0.30	159	47.6	0.2	0.3	0.43	12	19	6	n.d	157
Turkey feathers input	96.4	53.6	12.7	4	50.1	4.5	14.3	n.d.	14	11	8	n.d.	109
Autoclaved turkey feathers output	94.8	52.7	11.2	4	51.6	3.5	12.9	0.14	10	89	8	n.d	143
Mixed municipal household wastes (anaerobic digestion)													
Fibre from autoclaved MSW input	79.8	44.3	0.96	38	41.8	0.3	1.1	1.42	158	142	55	104	271
Digested autoclaved MSW fibre output	74.3	41.3	1.19	30	45.6	0.5	1.5	1.71	185	166	74	117	445
MSW (C) input	67.1	37.3	1.05	32	35.0	0.5	1.1	0.52	33	115	25	244	242
Digested MSW (C) output	60.6	33.7	1.43	23	33.9	0.6	1.5	1.30	52	159	36	675	491

Detection limits: Cd, 0.06 mg $kgdm^{-1}$, Cr, 8.6 mg $kgdm^{-1}$, Pb, 30 mg $kgdm^{-1}$

In terms of other output characteristics derived from processing the mixed MSW, the composted output from the extended MBT composting process for MSW (A) was characterised by much reduced levels of LOI, hemicellulose, cellulose and lignin. In addition, stabilisation was effectively achieved as shown by the low values for the DR4 (30000 mgO_2 $kgLOI^{-1}$ 96 h^{-1}) and BM100 tests (105 litres biogas $kgLOI^{-1}$). In contrast, the output from the short duration composting for MSW (B) was characterised by a high LOI content, DR4 (184000 mgO_2 $kgLOI^{-1}$ $96hr^{-1}$) and BM100 (293 litres biogas $kgLOI^{-1}$) and was found to have a biochemical composition which was typical of input BMWs for that plant. It would also appear that extended composting can greatly reduce ammonium concentrations (Table 3) in the output material (e.g.

MSW A) whereas short duration composting appears to have little effect (e.g. MSW B). This is an important consideration if the output material is landfilled (Robinson *et al*. 2005).

When MSW (C) was anaerobically digested for 16 days only, the de-watered digestate was found to have a low level of biodegradability as shown by the DR4 test (54000 mgO_2 $kgLOI^{-1}$ $96hr^{-1}$) and a particularly low value for the BM100 test (62 litres biogas $kgLOI^{-1}$). Another feature to note is the high lignin content of the digestate (20.9%), which was double that for typical input MSW. This feature was also found for the autoclaved MSW fibre (40.2%) which was subjected to anaerobic digestion and both these results highlight the recalcitrant nature of lignin under anaerobic conditions. While these results suggest that the AD process has been very effective in stabilising the MSW there may be other reasons for the low BM100 and DR4 results. It is possible that since the AD process would decompose those compounds susceptible to decomposition under anaerobic conditions, it would also be expected that the anaerobic BM100 test would produce a low result. Anaerobic digestates may still therefore show significant aerobic biodegradability especially from the as yet un-degraded lignin present. It is also possible that the de-watering of the digestate removed a proportion of the soluble and readily degradable carbon; for example the digestate DOC level was relatively low (4215 mg $kgdm^{-1}$) compared with 14-day composted MSW (16070 mg $kgdm^{-1}$) and this may have contributed to the low biodegradability.

3.3 Industrial and commercial wastes (autoclaving)

High carbohydrate and lignin cardboard packaging waste (C:N 235:1) and high protein turkey feathers (C:N 4:1) were selected to illustrate the effect of autoclaving. The biochemical composition of the packaging waste showed as expected a high percentage of cellulose and lignin (76.6%), whilst the biochemical compositional analysis of the turkey feathers indicated this was composed mainly of hemicellulose (66.9%). As turkey feathers are likely to be composed mainly of keratin protein it seems likely that most keratin was extracted in the same fraction normally associated with hemicellulose. Therefore caution is required when interpreting biochemical compositional analysis for some materials and it should be reiterated that the designated fractions of fats, solubles, hemicellulose, cellulose and lignin may not be composed exclusively of these chemical groups. Autoclaving the packaging waste did not change the biochemical compositional analysis significantly and the biodegradability (DR4 and BM100 tests) of the packaging waste was only slightly increased by autoclaving. The DR4 values were however relatively low (73000 – 90000 mgO_2 $kgLOI^{-1}$ $96hr^{-1}$) compared with the mixed BMW derived from MSW (249000 - 276000 mgO_2 $kgLOI^{-1}$ $96hr^{-1}$) whilst the BM100 values (527 – 630 l $kgLOI^{-1}$) were higher than that of the mixed BMW (386 – 418 l kg LOI^{-1}). This is believed to be due to a low content of readily biodegradable material in the packaging waste with the majority of biodegradable material being slowly degradable cellulose. The low DOC content of these materials support this conclusion (Table 3). The physico-chemical effects of autoclaving turkey feathers were profound in that the feathers were transformed to a black sludge material with no distinct feather structures present. The biochemical analysis indicated the treated feathers were composed mainly of readily soluble material (62.5%) and there was a four fold increase in the DOC of the autoclaved feathers. This suggests that autoclaving caused significant denaturing and possibly hydrolysis of much of the feather structure. It can be seen from Table 1 that the untreated feathers were relatively unreactive as characterised by the DR4 test and moderately biodegradable in the longer term as shown by the BM100 test. This may reflect the biochemical composition which showed that the feathers contained a relatively large insoluble fraction, which in this case was operationally labelled as “hemicellulose”.

Table 3 LS10 one step leaching test data for untreated and treated wastes

Waste & Process Type	pH eluate	EC eluate mS.cm	DOC eluate mg kg dm^{-1}	Selected eluate PTE concentrations mg kg dm^{-1}						Selected eluate ion concentrations mg kg dm^{-1}		
				Cd	Cr	Cu	Ni	Pb	Zn	Cl	SO_4	NH_4
Source segregated household wastes (composting)												
Kitchen/green waste (input)	5.8	5.4	33900	0.13	0.39	1.36	1.28	2.04	5.64	2700	1570	983
Kitchen/green waste output (fully composted)	7.2	3.2	7430	n.d.	0.19	1.80	0.30	0.56	2.73	3440	54	n.d.
Green waste (input)	7.1	1.6	2570	n.d.	0.16	0.68	0.13	0.65	3.59	1660	546	n.d.
Green waste output (partially composted & screened)	7.0	2.0	3520	n.d.	n.d.	0.61	0.15	n.d.	4.52	1990	671	84
Mixed municipal household wastes (MBT)												
BMW (A) input	6.4	4.4	14800	n.d.	0.16	2.14	0.42	1.32	2.63	5110	2610	1810
BMW (A) output (fully composted)	7.3	3.6	1660	n.d.	n.d.	1.79	0.21	n.d.	0.94	6570	2740	127
BMW (B) input	6.6	5.2	9160	n.d.	0.35	0.28	1.43	1.08	1.66	6310	7910	873
BMW (B) output (14 days composted)	7.0	4.5	16100	n.d.	1.14	15.0	8.16	6.04	15.3	3130	13200	690
BMW (B) composted output (screened < 8mm)	7.1	4.9	17100	n.d.	0.65	22.1	8.14	4.70	13.8	3200	11700	617
Industrial and commercial wastes (autoclaving)												
Packaging waste (cardboard) input	7.8	0.6	3340	n.d.	n.d.	0.15	0.12	n.d.	2.48	208	283	n.d.
Autoclaved packaging waste output	7.1	1.0	4160	n.d.	0.11	0.54	0.06	n.d.	1.27	336	1010	227
Turkey feathers input	6.2	1.6	12600	n.d.	n.d.	0.92	0.19	n.d.	16.0	1430	1450	2110
Autoclaved turkey feathers output	6.9	4.1	53800	n.d.	0.38	0.94	0.43	n.d.	4.48	1820	3310	5730
Mixed municipal household wastes (anaerobic digestion)												
Fibre from autoclaved MSW input	6.1	4.8	25200	0.17	3.55	6.82	6.34	4.04	18.2	2360	3604	965
Digested autoclaved MSW fibre output	7.0	3.1	7760	n.d.	2.46	0.39	1.85	0.84	1.34	2746	2379	189
BMW (C) input	5.9	7.0	45800	0.26	1.45	52.0	8.18	16.9	16.2	3280	6089	722
Digested BMW (C) output	7.0	2.9	4210	n.d.	0.13	0.62	2.19	0.75	1.05	1612	5154	983

Detection limits: Cd 0.12 mg $kgdm^{-1}$, Cr, 0.07 mg $kgdm^{-1}$, Pb, 0.8 mg $kgdm^{-1}$, NH_4, 7.5 mg $kgdm^{-1}$

The DR4 value for the autoclaved feathers was substantially increased indicating the treated material contained a much higher content of readily biodegradable material. However, the BM100 value for the treated feathers was reduced from 375 to 199 l $kgLOI^{-1}$ as a result of the autoclaving suggesting the overall biodegradable content (sum of the readily, medium and slowly biodegradable fractions) was lower. It is possible that a significant proportion of the soluble and very reactive material produced by autoclaving may have been lost as part of the process condensate thereby reducing the biogas production. It is also possible that some inhibition of the anaerobic BM100 test may have occurred due to the high initial ammonium concentration in the treated feathers (5572 mg $kgdm^{-1}$ for LS10 eluate) and this may have increased during the 100 day digestion period as the high N containing proteinaceous waste decomposed during the test. High ammonium and ammonia levels are known to inhibit anaerobic digestion (Lay, 1997). These two examples show that the correlation between the DR4 and BM100 tests as used for MSW derived mixed BMW wastes in the Environment Agency MBT monitoring guidance may not apply when specific organic wastes are being considered (Godley *et al.* 2007).

3.4 Comparison of C and N test methods

All materials (input and output waste materials) included in the waste characterisation project were analysed for LOI, C and N as described below. Carbon was determined by the LECO combustion method which is not carried out routinely and also estimated using the robust and commonly used expression LOI/1.8 (i.e. assumed organic carbon content 55.5%). Zhang, Li and Stoffella (2005) found a good relationship between the two methods assuming a C content of 58%). The aim of this was to investigate the relationship between LOI estimated carbon and LECO determined carbon to ascertain if the equation C = LOI/1.8 was applicable over a range of waste types and to determine any modification which was required. For example over the range of materials tested it was clear that while results for both methods were in general agreement, results for the LOI method were typically higher than for the LECO method.

A strong relationship between LECO and LOI based carbon contents for all samples was found (R^2 = 0.9610): C (LECO) = 0.5331 x LOI. This suggests that modifying the normal equation C = LOI/1.8 to C = LOI/1.9 would give a stronger relationship with carbon content as determined by the LECO combustion method (assumed organic carbon content 53%).

Total nitrogen was determined by LECO and also by the Kjeldahl method and while it is known that differences between N Kjeldahl and N LECO exist for green waste (Frederickson 1999) the relationship between the two methods has not been established over a range of waste types. In this study the LECO method tended to produce consistently higher values compared with the Kjeldahl method and this may be due to nitrogen losses during the Kjeldahl procedures. For 41 samples between 0 and 5% N, there was a strong relationship between N LECO and N Kjeldahl (R^2 = 0.9855) of the form N LECO = 1.1193 N Kjeldahl. This indicates that the LECO values were approximately 12% greater than the Kjeldahl values for the wide range of waste types included in this project.

4. CONCLUSIONS

- DR4 and BM100 tests were found to be appropriate for determining the biodegradability of a wide range of waste types and the interpretation of these results could be greatly assisted by refererence to other parameters such as biochemical composition and leaching characteristics.
- While data from the DR4 and BM100 tests were useful, it is important to be aware of the limitations of such tests and where possible they should be used in conjunction with other related tests.
- There was some evidence to suggest that longer-term composting processes can produce compost material with reduced extractability of some PTEs while this does not seem to be the case for short duration processes.
- Extended composting can reduce ammonium concentrations in the output material whereas short duration composting appears to have little effect. Autoclaving seems to have the potential to increase ammonium levels in the treated output.
- For a wide range of waste types, it was found that LECO carbon content could be estimated as 0.5331 x LOI (R^2 = 0.9610) and this equates to C = LOI/1.9.
- N LECO values were approximately 12% greater than the equivalent Kjeldahl values.

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