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APPLICATION OF DR4 AND BM100 BIODEGRADABILITY TESTS TO TREATED AND UNTREATED ORGANIC WASTES

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SUMMARY: The aerobic DR4 and anaerobic BM100 biodegradability tests are currently applied in England and Wales for monitoring the reduction in biological municipal waste (BMW) achieved by mechanical biological treatment (MBT) plants (Environment Agency 2005). The protocol is applied only when outputs are landfilled and is based on estimating the reduction in potential biogas production between the MBT input, municipal solid waste (MSW), and all of the landfilled outputs, using the BM100 test. As this is a long term 100 day test the more rapid 4 day DR4 test may also be applied as this has been shown to correlate with the BM100 test. We have now applied the DR4 and BM100 tests to 132 organic waste samples including untreated and treated BMW and specific organic wastes. The results indicate that the correlation between the DR4 and BM100 tests has proved valid for mixed MSW derived BMW wastes. However when both tests are applied to specific organic wastes such as turkey feathers, cardboard packaging waste and pizza food wastes the correlation between the tests is less strong. It is concluded that the use of the DR4 and BM100 test correlation is valid for its designed application (monitoring MBT processes treating MSW derived mixed BMW), but that caution should be exercised when applying both tests to specific single component organic wastes.

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. In the U.K. most municipal solid waste (MSW) is landfilled and as this contains approximately 68% BMW this represents a significant challenge. 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. Annual, and in most cases, decreasing allowances for landfilling BMW have been set for Waste Disposal Authorities (WDAs) within the U.K. under national Landfill Allowance Schemes (Defra 2006). Strategies need to be developed and implemented by WDAs to meet these targets.

One option is to source segregate BMW and then biologically treat appropriate components to produce a recoverable compost. However, even where high levels of source segregation is applied, residual MSW containing BMW is still likely to be produced and collected. Treating MSW containing BMW in mechanical biological treatment (MBT) processes is an option becoming increasingly applied in the U.K. Such MBT processes will decrease the biodegradability of the BMW through the inclusion of either a biological composting and/or anaerobic digestion stage and may produce several possible output streams such as plastics, metals, glass, solid recovered fuel (SRF) and a compost like output (CLO). If any BMW containing outputs are landfilled then the question remains of how much BMW diversion from landfill has been achieved by the MBT process, especially when the biodegradability of the output BMW may have been reduced by the MBT treatment.

The Environment Agency for England and Wales has published guidance for monitoring MBT processes to determine the BMW diversion achieved by such processes (Environment Agency 2005). The basis of the protocol is to determine the change in potential biogas (CH_4 + CO_2) production between the input MSW and any landfilled MBT outputs. The approach is consistent with the recitals of the Landfill Directive *"Whereas measures should be taken to reduce the production of methane gas from landfills..........through the reduction of the landfill of biodegradable waste...."*. Where MBT outputs are to be landfilled, the Environment Agency's MBT monitoring protocol includes measuring the potential biogas production from MBT input and landfilled output waste samples using an anaerobic biodegradability test (BM100). This is a time-consuming method where the waste sample is incubated for up to 100 days until biogas production ceases. The MBT monitoring guidance however, allows for using a more rapid aerobic DR4 biodegradability test, and values for this have been shown to correlate with the BM100 test (Figure 3.1). Initially both tests are required to characterise a specific MBT plant performance, but once confirmation has been obtained that the correlation between the DR4 and BM100 results is valid for the specific site case, then it is envisaged that the more rapid DR4 test would be predominantly applied.

The DR4 and BM100 biodegradability tests were developed and evaluated using a limited number of waste samples (Godley *et al*. 2005a & 2005b, Malhotra *et al.* 2006). Since publication of the MBT monitoring guidance many more treated and untreated BMW samples from MBT facilities have been tested. Also the DEFRA sponsored Waste Characterisation project WRT220 has collected 40 further organic wastes from different treatment processes for analysis by several different test methods including the DR4 and BM100 tests. This gives a combined data set of over 130 organic wastes most of which are MSW derived mixed BMW (96) from MBT plants with the remainder being specific organic wastes that include fish, pizza, packaging (cardboard), newspaper, feathers, greenwaste, wood, and wastes treated thermally by autoclaving at a temperature of 160^{o}C for 30 minutes.

This paper will provide a brief description of the DR4 and BM100 tests, highlight key differences between the tests, and then compare the DR4 and BM100 test results carried out on the 96 BMW and 36 specific wastes. Finally some example estimations of BMW diversion from landfill will be presented based on the application of the DR4 and BM100 tests to MBT processes as described in the Environment Agency MBT monitoring guidance (Environment Agency 2005). These estimations will consider the impact of biological treatment time on the amount of BMW diverted from landfill in two scenarios. Firstly where all the MBT treated material is landfilled, and secondly where a substantial portion of the BMW is used as SRF.

2. COMPARISON OF AEROBIC DR4 AND ANAEROBIC BM100 TEST METHODS

The aerobic DR4 test (Environment Agency 2005) was adapted from the standard compost stability ASTM D 5975-96 test (ASTM 1996). Test organic waste material (100 g dry matter, DM, dried and shredded to <10 mm) is mixed with 100 g DM of mature greenwaste compost microbial seed. The moisture content is adjusted to 50% wet weight and additional nutrients (N and P) are added. The test mixture is then placed in an actively aerated reactor vessel and incubated at 35°C for 4 days. The O_2 consumed during the 4 days is estimated from the amount of CO_2 liberated and expressed in terms of the loss on ignition (LOI) content of the test material (mg O/kg LOI).

The anaerobic BM100 test is adapted from a sewage sludge digestion test method (SCA 1997). Twenty grammes LOI of the same prepared organic waste (dried and shredded to <10 mm) is placed in a reaction vessel with a nutrient medium and digested sewage sludge as microbial seed. The mixture is incubated anaerobically at 35°C and the biogas (CH_4 + CO_2) collected and measured. The test is carried out until no more biogas is produced (typically up to 100 days) and the results expressed as l/kg LOI.

Both tests have several features in common as follows

- The test organic waste is separated from non-biodegradable MSW components such as glass, metal and plastics minimising the potential incorporation of inhibitory materials in the test.
- The test organic waste material is shredded and ground to a particle size of <10 mm to minimise and normalise the impact of particle size in the biodegradation test.
- The tests include a microbial seed inoculum which means the tests may be applied to any organic waste, including those treated (sterilised) in thermal process such as autoclaves.
- The tests include a control substrate (e.g. cellulose) for quality assurance checking.
- Mixing with the microbial seed (and additional nutrient media in BM100 test) dilutes inhibitory materials present in the test material and makes a successful test more likely.
- The tests include nutrient additions ensuring there is no limitation on microbial activity from lack of essential nutrients.

The main difference between the DR4 and BM100 tests, apart from the DR4 being aerobic and the BM100 anaerobic, is that the DR4 test is run for a short timescale (4 days) which is insufficient time to completely decompose the test material. The DR4 therefore measures the average **rate** of aerobic degradation over the 4 days test period. The BM100 however is run until biogas production ceases, i.e. decomposition is complete, and therefore it measures the **extent** of anaerobic biodegradation rather than a rate.

The correlation (Fig. 3.1) between the DR4 and BM100 indicates that there is an approximately linear relationship for DR4 values up to 150000 mg O/kg LOI and BM100 values up to 405 litres/kg LOI. These values correspond to treated BMW. However, for untreated and some partially treated BMW types the DR4 value has been found to range between 150000 – 300000 mg O/kg LOI whilst the BM100 value has been relatively constant within this range (approximately 405 litres/kg LOI). This is believed to be due to the short timescale DR4 test being sensitive to small but variable amounts of readily biodegradable material. Such material would be preferentially decomposed at high rates during a short term test and contribute a significant proportion of the O_2 consumption during the four day test period. If it is assumed that 50% of the waste LOI is organic C then a DR4 value of 150000 mg O/kg LOI represents only 56 g C/kg LOI mineralised, i.e. only 11% of the total waste C present. The corresponding BM100 value of 405 litres/kg LOI represents 43% of the waste C being mineralised, i.e. four times the organic matter that would have been mineralised in the DR4 test. It is assumed that this comprises most of the medium and slowly biodegradable fractions as well as the readily biodegradable fraction and therefore may give a better representation of the overall waste biodegradability. Therefore a small change in the amount of readily biodegradable matter present might significantly change the DR4 value but may not impact on the long term BM100 value to as great an extent. This potential limitation of using short term biodegradation tests that measure the rate of degradation needs consideration when comparing results with long term tests that measures the full extent of degradation.

3. RESULTS

3.1 Comparison of DR4 and BM100 test results for MSW derived BMW

The DR4 and BM100 tests, and the correlation between them, were originally developed from studies using a limited number of samples in order to monitor MBT processes treating MSW derived BMW (typically a mixture of kitchen waste, garden waste, textiles, paper, cardboard and wood). Since publication (Environment Agency 2005) however many more MBT treated and untreated BMW samples have been tested making a total data set to-date of 96 BMW samples to challange the original correlation. The results (Fig. 3.1) indicate that the original correlation has proved robust to the larger number of samples.

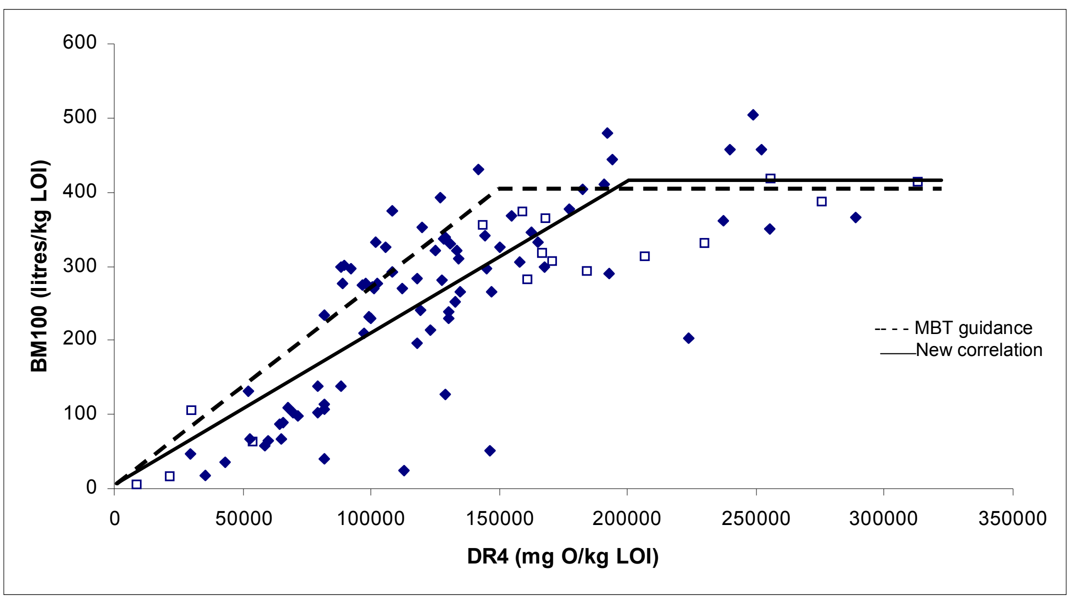

Fig.3.1 Comparison of DR4 and BM100 test result values for 96 treated and untreated MSW derived BMW samples (open squares are data from Defra project WRT220)

The larger data set now available allows re-examination of the correlation between the DR4 and BM100 tests in more detail. Figure 3.1 shows there are some outlying datapoints where the DR4 value is high relative to the BM100 test result suggesting that variability in the amount of readily biodegradable material present may be a source of poor correlation in some examples. The 66 data points with DR4 values below the inflexion point of 150000 mg O/kg LOI show a linear regression correlation coefficient (R^2 = 0.5422) which is highly significant, $P<0.001$. The regression line equation is BM100 = 0.0022 x DR4 and this gives a corresponding BM100 value of 330 litres/kg LOI at the inflexion point (lower than in the original correlation Fig.3.1). A better linear regression correlation with greater significance is shown if the 84 data points up to a DR4 value of 200000 mg O/kg LOI are considered (R^2 = 0.6344). In this case the line equation is BM100 = 0.0021 x DR4 and the BM100 value at the DR4 inflexion point of 200000 mg O/kg LOI is 420 litres/kg LOI. The correlation coefficient is lower (R^2 = 0.5427) if all the data are included in a linear regression implying that the inflexion point is a real observation and that data above a certain DR4 value should be excluded from the straight line correlation. This analysis implies there might be sufficient evidence to revise the original DR4-BM100 correlation slightly.

3.2 Comparison of DR4 and BM100 test results for specific organic wastes

In addition to mixed MSW derived BMW the DR4 and BM100 tests have been applied to 36 raw and treated specific wastes (Table 3.1) many of which might be common components of MSW derived BMW. Comparing the DR4 and BM100 results for these samples (Fig. 3.2) indicates that the linear correlation for the 30 data points up to the DR4 value of 150000 mg O/kg LOI (R^2 = 0.3378) is lower than for the BMW samples although it is still significant, $P<0.001$. The plot visually appears to show a wider scatter of data and the linear regression correlation for the whole 36 specific samples is even lower (R^2 = 0.211, $P<0.005$). This reduced correlation between the DR4 and BM100 tests may be due to a greater number of outlying data points associated with some of the specific single component wastes. Therefore we urge caution for the application of short term **rate** based biodegradation tests for estimating the potential **extent** of biodegradation for specific organic wastes.

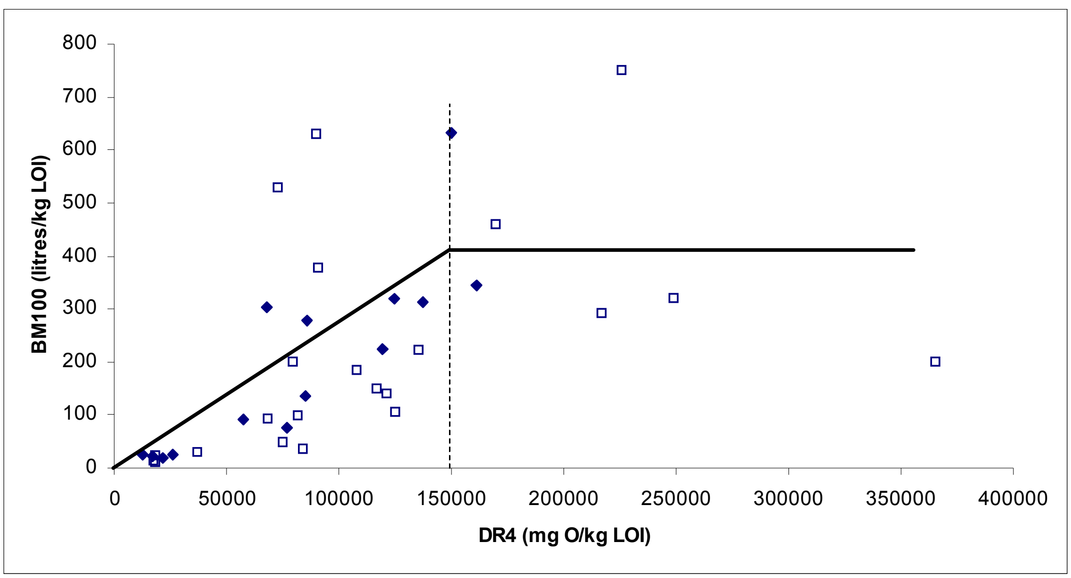

Fig. 3.2 Comparison of DR4 and BM100 test results for several treated and untreated specific organic wastes (open squares are data from Defra project WRT220)

Table 3.1 Results of DM, LOI and biodegradability tests for various specific organic wastes

Specific waste description	DM % wet wt	LOI %DM	DR4 mg O/kg LOI	BM100 l/kg LOI
Pizza food waste	51.1	90.3	226000	748
Tinned meat (beef mince)	22.7	93.8	150000	633
Autoclaved packaging waste (wet cardboard)	39.2	93.1	90000	630
Packaging waste (wet cardboard)	44.5	94.2	73000	527
Fish waste	46.7	72.1	170000	457
Turkey feathers	56.6	97.9	91000	375
Organic fibre from autoclaved MSW (1)	52.3	74.9	161000	345
Cardboard packaging	92.3	90	125000	320
Organic fibre from autoclaved MSW (2)	50.3	78.3	249000	319
Raw vegetable mixture	13.4	94.5	137000	312
Commercial cellulose (batch 2)	94.2	99.7	68200	304
Kitchen and greenwaste (untreated)	33.3	75.1	217000	292
Disposable nappies (un-soiled)	96.8	85.6	86100	278
Grass (lawnmower cuttings)	18.9	86.4	119000	225
Partially composted greenwaste	45.9	61.2	136000	221
Commercial cellulose (batch 3)	94.4	99.1	80000	200
Autoclaved turkey feathers	33.1	96.1	366000	199
Greenwaste (untreated)	40.9	73.7	108000	182
Fish, peat, wood, greenwaste mix	48.6	59	117000	150
Anaerobically digested sewage sludge cake	18.6	60.9	122000	140
Commercial cellulose (batch 1)	95.8	99.4	84900	136
Partially composted kitchen and greenwaste	38	73.1	125000	103
Composted kitchen and greenwaste	50.8	59.6	82000	99
Tree twigs and branches (apple)	63.5	96.6	57100	93
AD treated Fibre from autoclaved MSW	27.6	73.4	69000	92
Newspaper	90.8	92.8	76600	76
Partially composted fish and greenwaste	53.1	52.8	75000	47
Autoclaved construction wood waste	65.2	87.3	84700	35
Construction wood waste	77.3	88.7	37600	27
Bedding sheets (75% cotton)	97.2	99.3	12900	26
Stabilised greenwaste compost (1)	62.5	31.8	26300	24
Knitting wool (57% wool)	93.9	94.9	17000	21
Stabilised greenwaste compost <25 mm	68.8	29.4	19000	21
Stabilised greenwaste compost (2)	58.6	38.3	21100	19
Stabilised greenwaste compost <10 mm	70.4	30.2	18000	12
Composted fish and greenwaste	65.8	35.2	19000	8

4. APPLICATION OF TESTS TO MBT AND OTHER PROCESSES

The Environment Agency MBT monitoring guidance (Environment Agency 2005) estimates the BMW diversion achieved by measuring the reduction in potential biogas production of the landfilled waste. Samples of the input MSW and any BMW containing outputs sent to landfill are taken and the following parameters determined.

- Mass wet weight flow of the input or output.
- Percentage wet weight of BMW in the samples.
- Dry matter (DM) content of the BMW fraction.
- Loss on ignition (LOI) content of the BMW fraction.
- Potential biogas production of the BMW by BM100 test (or by the DR4 test and conversion to biogas production using the DR4-BM100 correlation).

The potential biogas production from the input and landfilled outputs are estimated using:

Biogas production (m^3) = mass flow x (%BMW/100) x (%DM/100) x (%LOI/100) x BM100. Where %BMW is the percentage wet weight of BMW in the MSW, %DM and % LOI are the dry matter and loss on ignition contents of the BMW fraction, and BM100 is the potential biogas production value (litres/kg LOI) of the BMW fraction from the BM100 test.

The percentage BMW diverted from landfill is then calculated from:

100 – ((Landfilled Output biogas/Input MSW biogas) x 100)

In this section two hypothetical MBT cases are considered based on limited monitoring data of real MBT plants. The first example is pre-treatment for landfill where all the MSW is composted for an extended period (12 weeks) prior to landfilling. The second case is where the MBT has a short bio-drying two week composting phase and where a significant percentage of the BMW output is diverted from landfill in solid recovered fuel (SRF). To date only a few MBT facilities have been fully commissioned in the U.K. and full monitoring data according the Environment Agency monitoring guidance is not yet available. These examples serve to demonstrate the principles of the monitoring guidance and estimation of BMW diversion.

4.1 MBT process with extended (12 week) composting as pre-treatment for landfill

The biological process of the Linde designed MBT plant at Linz (Austria) consists of a 4-week in-vessel tunnel aerobic composting system followed by 8 weeks windrow composting. Duplicate samples of the input MSW, in-vessel tunnel output and final windrow composted material, were analysed according to the MBT guidance. For simplicity we have assumed all the input MSW is composted and then landfilled. In practice the plant mechanically separates some SRF prior to composting process. We have also estimated the mass flow data on the assumption that the input MSW is 10000 t wet weight and that the non-BMW fractions of the MSW (metals, plastics, glass, stones) and the ash content of the BMW are conserved during the composting process. The analysis of the input MSW and landfilled output samples are shown in Table 4.1 and the estimated BMW diversion after 4 and 12 weeks composting in Table 4.2.

These results suggest that BMW reduction when measured by LOI loss alone is less than when both the LOI and biodegradability reductions of the BMW are taken into account. The justification for this approach is that reduction in potential biogas production is an appropriate measure of the reduced risk of fugitive CH_4 emissions if the output material were landfilled. The results also indicate the impact of composting time as the additional 8 weeks aerated windrow composting increased the BMW reduction from 72% (after in-vessel tunnel treatment) to 93%. This allows assessment of the cost/benefit of increasing the composting footprint to the aerated windrow stage in addition to the initial tunnel in-vessel stage.

Table 4.1 Analysis input and outputs Linde MBT plant at Linz (from Malhotra & Godley 2006)

Sample	BMW % wet wt MSW	DM of BMW % wet wt BMW	LOI of BMW % DM of BMW	DR4 test mg O/kg LOI
Input MSW (0 weeks)	70	45.7	68	182000
Output tunnel (4 weeks)	66.4	54.6	45.7	106000
Output windrow (12 weeks)	71.7	75.4	34.7	40800

Table 4.2 Estimation of BMW diverted from landfill by Linde MBT plant at Linz

Parameter	Units	Input MSW (0 weeks)	Output Tunnel (4 weeks)	Output windrow (12 weeks)
MSW	t wet wt	10000	6454	5080
Non-BMW*	t wet wt	3000	3000	3000
BMW	t wet wt	7000	3454	2080
BMW-DM	t	3199	1886	1568
BMW-LOI	t	2175	862	544
BMW-Ash*	t	1024	1024	1024
BMW-LOI reduction	%		60.4	75.0
BM100**	litres/kg LOI	405	286	110
Potential biogas	m^3	881005	246480	59856
BMW reduction	%		72	93

* Assumed are conserved in this example to estimate MSW mass data of outputs.
** BM100 values determined from DR4 test results using correlation of DR4 and BM100

4.2 MBT process with bio-drying and Solid Recovered Fuel production

The Ecodeco MBT at Villfalletto, Italy, is a short term two week bio-drying composting process producing three main outputs. The major ouput is SRF which when used as a fuel is fully diverted from landfill. Two other outputs, heavy rejects and organic fines are likely to be landfilled and therefore would be monitored according to the Environment Agency MBT monitoring guidance. In this study input MSW, and output SRF, heavy reject and organic fines were all sampled in triplicate and analysed according to the MBT monitoring guidance. The mass flow data in this case was as supplied by the plant operators. The mean results of the analysis of the samples are shown in Table 4.3 and the estimated BMW diversion shown in Table 4.4 where in this case the calculation is based on the BM100 results directly.

The results indicate there is a modest reduction in biodegradability during the short two week composting phase and that the there would only be a modest reduction in BMW landfilled if all the output streams were landfilled. However assuming the SRF would be fully diverted from landfilling the BMW diversion for landfilling only the heavy rejects and organic fines is estimated to be about 72%.

Table 4.3. Analysis Ecodeco Villfalletto MBT input MSW and output SRF, Heavy Reject and Organic Fines data (mean of three samples)

Sample	Mass flow t	BMW % wet wt MSW	DM of BMW % wet wt BMW	LOI of BMW % DM of BMW	BM100 Litres/kg LOI
Input MSW	10000	62.6	48.8	78.2	343
SRF	4750	62.4	82.8	79.6	300
Heavy Reject	650	45.6	81.2	74.1	305
Organic Fines	1850	85.3	82	56.2	240

Table 4.4 Estimation BMW diversion for Ecodeco Villfalletto MBT producing an SRF output

Parameter	Units	Input MSW	Output SRF	Output Heavy Rejects	Output Organic Fines
MSW	t wet wt	10000	4750	650	1850
BMW	t wet wt	6260	2964	296	1578
BMW-DM	t	3055	2454	241	1294
BMW-LOI	t	2389	1954	178	727
BM100	l/kg LOI	343	300	305	240
Potential biogas	m^3	819398	586061	54394	174535
BMW reduction	%		28	93	79

4.3 Performance of other processes sampled as part of project WRT220

As part of project WRT220, input and output material from several waste treatment plants were collected and subjected to waste characterisation including the MBT monitoring guidance parameters. The following examples although based on single waste samples provide some insight into how the process may have affected the waste biodegradability.

5.3.1 Anaerobic digestion of MSW derived BMW

Shredded and macerated MSW was separated by particle size and the smallest particle fraction anaerobically digested for about 16 days. Samples of the input and output were taken and the BMW fraction analysed. The results (Table 4.5) indicate that the output BMW was much wetter from the moisture addition to the anaerobic digestion process, but that the LOI content and biodegradability of the BMW had been reduced during digestion. We have estimated the percentage reduction in LOI as 26.3% by assuming that the ash content of the BMW is conserved during anaerobic digestion. The DR4 and BM100 biodegradability test result are typical for untreated BMW, however, the BM100 result (62 litres/kg LOI) for the anaerobically digested material is lower than might be expected (114 litres/kg LOI) from the DR4 test value of 54400 mg O/kg LOI. Whilst this study is based on limited sample numbers we suspect that this might be a reflection of the anaerobic digestion.

Under anaerobic digestion only those components of the waste degradable under anaerobic conditions may be expected to decompose and consequently a low test result would be expected using an anaerobic biodegradability test. Components like lignin will be largely recalcitrant under the anaerobic conditions of the process but may still show some biodegradability if tested under aerobic conditions in the DR4 test. The estimated reduction in biogas production of the BMW if landfilled would be high (estimated as 89%) reflecting the stabilisation achieved under anaerobic landfill conditions. The anaerobically digested BMW may still have significant biodegradability under aerobic conditions but this would not pose the risk of fugitive methane emissions from landfilling. The DR4 and BM100 test methods were designed to assess potential biogas production of landfilled BMW and should only be used outside this context with caution.

Table 4.5 Biodegradability and estimated BMW reduction for anaerobic digestion of BMW (based on 1 tonne input BMW)

	Units	Input BMW	Output BMW
DM of BMW	% wet weight	56.1	33.2
LOI of BMW	% DM	67.1	60.6
Ash of BMW	% DM	32.9	39.4
t BMW	t wet weight	1	1.38
t DM	t	0.56	0.46
t Ash	t	0.18	0.18
t LOI	t	0.38	0.28
% LOI reduction	%		26.3
DR4	mg O/kg LOI	313000	54400
BM100	Litres/kg LOI	413	62
Biogas (BM100 based)	m^3	155	17
BMW reduction	%		89

Autoclave processing of turkey feathers

Waste turkey feathers were collected and autoclaved (160°C for 30 minutes) in a pilot scale waste treatment (Estech Europe Limited Fibrecycle) autoclave system. The untreated and treated feathers were then analysed for their DM, LOI and biodegradability by the DR4 and BM100 tests (Table 4.6). Turkey feathers are largely composed of the protein keratin which is a crystalline structural protein and therefore would be expected to be biodegradable under both aerobic and anaerobic conditions but the rate of degradation might be slow. Autoclaving might be expected to denature and partially hydrolyse the keratin and make it more amenable to biodegradation. The autoclaving reduced the well defined feather structure to a black sludge indicating significant denaturation had occurred. Also during the autoclave process some of the soluble organic compounds formed may be removed from the waste into the steam condensate generated thereby reducing the waste organic matter content.

The results in Table 4.6 indicate that autoclaving the feathers increased the ash content of the residual solid waste suggesting there was solubilisation of organic matter. If it is assumed that the ash was conserved then an estimated 46% of the feathers' LOI were lost by autoclaving, presumably as soluble components in the condensate. The untreated feathers gave a low aerobic DR4 biodegradability test value but a high biodegradability in the long term BM100 test. The autoclaved feathers, however had a high DR4 biodegradability and a lower BM100 biodegradability. These results do not conform well with the correlation between DR4 and BM100 results. We believe these results reflect a limitation of the short-term aerobic test in that it is sensitive to the amount of readily biodegradable material present. For the untreated feathers the DR4 test indicates a low rate of degradation, but with sufficient time a high degree of biodegradation is demonstrated in the BM100 test. The treated feathers may be postulated to contain a much higher content of soluble readily biodegradable material which gives a high value in the short term DR4 test. This example illustrates the dangers of comparing aerobic and anaerobic tests out of context for which they are designed.

Table 4.6 Effect of autoclaving turkey feathers on biodegradability

	Units	Input Feathers	Output Feathers
DM of BMW	% wet weight	56.6	33.1
LOI of BMW	% DM	97.9	96.1
Ash of BMW	% DM	2.1	3.9
t BMW	t wet weight	1	0.93
t DM	t	0.566	0.308
t Ash	t	0.012	0.012
t LOI	t	0.554	0.296
% LOI reduction	%		46.6
DR4	mg O/kg LOI	91000	366000
BM100	Litres/kg LOI	375	199
Biogas (BM100 based)	m^3	208	59
BMW reduction	%		72

6. CONCLUSIONS

From the results presented here we make the following conclusions

- The 4 day aerobic DR4 test measures a biodegradation **rate** and results may reflect the amount of readily biodegradable organic matter present in the waste rather than the overall biodegradability.

- The 100 day anaerobic BM100 test measures the **extent** of biodegradation under anaerobic conditions and may not account for the biodegradation of materials such as lignin which are more biodegradable under aerobic conditions.

- The Environment Agency of England and Wales MBT monitoring guidance is based on applying the BM100 test to determine the reduction in potential biogas production of landfilled MBT outputs compared with the input untreated MSW.

- The DR4 and BM100 biodegradability do not correlate well for many specific organic wastes. Consequently the DR4-BM100 correlation should be used with extreme caution when applied to wastes other than MSW derived mixed BMW.

- The 4 day aerobic DR4 biodegradability test correlates well with the 100 day anaerobic BM100 test for most treated and untreated MSW derived mixed BMW samples.

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REFERENCES

ASTM (1996). ASTM D 5975-96. Standard test method for determining the stability of compost by measuring oxygen consumption. http://www.astm.org.

Defra (2006). Guidance on the Landfill Allowance Schemes: Municipal waste. www.defra.gov.uk/environment/waste/localauth/lats/pdf/lats-municipalwasteguidance.pdf.

Environment Agency (2005). Guidance on monitoring MBT and other pre-treatment processes for the landfill allowance schemes (England and Wales). August 2005. www.environment-agency.gov.uk/commondata/acrobat/mbt_1154981.pdf.

European Council (1999). Directive 1999/31/EC on the landfilling of waste. *O J L 182, 16.7.1999.*

Godley A. R., Graham A. Frederickson J. & Barker H. (2005a). Update on Environment Agency evaluation of organic waste biodegradability measurement methods. Proceedings CIWEM 3rd National Conference 6th-8th September 2005, Wakefield. U.K. Paper 50, Vol 2, p37-48. ISBN 1-903958-14-8.

Godley A., Muller W., Frederickson J. & Barker H. (2005b). Comparison of the SRI and DR4 biodgradation test methods for assessing the biodegradability of untreated and MBT treated municipal solid waste. Int. Sym. Mechanical-biological treatment of municipal solid waste

23-25 Nov 2005, Hanover, Germany.

Malhotra S. & Godley A. (2006). Application of the Environment Agency MBT monitoring guidance. Proceedings Waste 2006 Conference: Sustainable waste and resource management 19 – 21 Sept 2006. Stratford-upon-Avon. UK., p 267-276.

SCA (1977). Standing Committee of Analysts. Amenability of sewage sludge to anaerobic digestion (1977 version). Blue book method 5. ISBN 0117512508. HMSO, London.