Comparison of the SRI and DR4 biodegradation test methods for assessing the biodegradability of untreated and MBT treated municipal solid waste

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Abstract

The Environment Agency of England and Wales has sponsored research into evaluating organic waste biodegradability test methods for monitoring the diversion of biodegradable waste from landfill following treatment by MBT and other processes. The methods that were subsequently selected for this application were the aerobic DR4 and the anaerobic BM100 tests. A round robin laboratory evaluation of the DR4 and SRI methods carried out using organic wastes from an MBT plant indicated that the DR4 method may be more reliable than the SRI method for measuring the biodegradability of some partially composted wastes. It is thought that the use of a microbial seed (mature greenwaste compost) in the DR4 method might have contributed to the increased reliability. A modification of the SRI test with respect to also using a seed indicated that this would increase the reliability of the SRI for fresh or only partially degraded waste as well.

Keywords

Biodegradability, Biowaste, BM100, BMW, DR4, MSW, MBT, SRI

1 Introduction

The Environment Agency of England and Wales has sponsored research into methods for measuring the biodegradability of organic wastes that have been pre-treated in mechanical biological treatment (MBT) or other non-biological processes for the purpose of monitoring the diversion of biodegradable municipal waste (BMW) from landfill. The approach for monitoring MBT and other organic waste treatment processes has been the subject of consultation (ENVIRONMENT AGENCY, 2004 and 2005a) and will be based on the difference in biodegradability between the untreated and treated waste.

The research reviewed several organic waste characterization (including biodegradability) methods, evaluated experimentally some selected methods, and applied the tests to monitoring an MBT process (GODLEY ET AL., 2005). The biodegradability methods selected were an anaerobic methanogenic digestion test (BM100) and an aerobic dynamic respiration (DR4) method. The BM100 test involves incubating the test waste for up to 100 days under methanogenic conditions and monitoring the biogas (CO_2 + CH_4) production. As the Landfill Directive aims at reducing the risk of methane emissions from landfills the BM100 test is considered the most appropriate measure of waste biodegradability for landfill diversion purposes. However since the BM100 takes at least 100

days to complete it is not suitable for routine testing and a more rapid test was sought which correlated with the BM100 test. For such routine monitoring the four-day DR4 method, based on the ASTM D5975-96 test, has been developed and evaluated during this research project.

The DR4 and BM100 tests are the biodegradability tests described in the Environment Agency guidance for monitoring MBT processes in England and Wales (ENVIRONMENT AGENCY, 2005b). The DR4 test was evaluated in a round robin laboratory study to ensure the test would generate reliable results. Also in the UK there is interest in applying established MBT technologies developed elsewhere in Europe. Many of these processes are monitored and have process guarantees described by the SRI biodegradation test method (GERMAN FEDERAL GOVERNMENT, 2001). Therefore there is interest in correlating the SRI with the DR4 test method. Consequently the DR4 round robin laboratory waste samples were also tested by the SRI method in several German, Austrian and UK laboratories. This paper reports the main results of these round robin laboratory studies.

2 Comparison of DR4 and SRI test methods

Whilst the DR4 and SRI tests are both aerobic biodegradation methods they differ in several features (Table 1) that may affect their applicability in specific circumstances.

In the DR4 method the test waste is mixed with a microbial seed (mature greenwaste compost). This means that the test may be applicable to a wide variety of wastes, including those sterilised in thermal treatment processes such as autoclaves. The inclusion of a microbial seed in the DR4 method also allows the test to include a control test substrate (cellulose) enhancing quality control and quality assurance associated with the method. The DR4 test is carried out at a higher temperature (35^{o}C) than the SRI test (20^{o}C) and is actively aerated by passing air through the waste rather than relying on passive air diffusion as in the SRI method. This may increase the extent of waste decomposition occurring during the DR4 test, which might then provide a better representation of the biodegradability of the whole waste. Results from the DR4 test are the cumulative 4 day oxygen consumption as in the SRI test but are preferably reported in terms of the organic matter content of the waste (i.e. loss on ignition at 550^{o}C, LOI) rather than the dry matter content (DM). As the LOI content of wastes may differ it is thought that comparing the biodegradability of such diverse wastes would be better if reporting units are normalised in terms of LOI.

Table 1 Comparison of the main features of the DR4 and SRI test methods

Test feature	DR4 test	SRI test
Temperature	35°C	20°C
Test time	Four days from setting up	Four days from end of lag phase
Microbial seed	Yes – mature greenwaste compost	None
Nutrients added	Yes – N and P added	None
Moisture adjustment	Yes – to 50% of wet weight	Yes – moisture content is sample dependent
Aeration	Active – flow through air	Passive – closed system
Sample size	100 g DM test material	20 g DM test material
Replication	Triplicate	Triplicate
Reporting units	DR4 value: mg O/kg LOI over 4 days	AT4 value: mg O/g DM over 4 days

3 DR4 and SRI round robin laboratory study methodology

Four samples of MSW were obtained from the Dunoon (Scotland) MBT plant (designed by Cambridge Recycling Services). These were collected on the same day from batches at different stages of the composting process (0, 10, 51 and 131 days composting times). It was anticipated that the samples would give a range of biodegradability levels from very biodegradable (untreated MSW - 0 days composting) to very stable (fully composted MSW -131 days composting).

The samples were prepared manually by separating the biodegradable fraction (BMW) from the MSW, shredding the BMW to a particle size of less than 10 mm diameter and then mixing to a homogenous sample. The percentage wet weight of BMW in the MSW samples were 81.5%, 80.2%, 68.7% and 66% for the 0, 10, 51 and 131 day old samples respectively. For SRI testing sub-samples of the prepared BMW were taken and stored frozen prior to despatch to participating laboratories as frozen samples. For DR4 testing the prepared biodegradable fractions were further dried at 70°C to about 80-90% dry matter content and then ground to a smaller particle size of less than 5 mm diameter. These samples were stored at 4°C.

Mature greenwaste compost from the High Heaven composting plant (Terra EcoSystems), High Wycombe, England, was collected as microbial seed (SEED) for the DR4 method and as an additional test material for SRI testing. The compost was sieved through a 9 mm sieve and stored at 4°C for DR4 tests and sub-samples were frozen for SRI testing. A control substrate of alpha-cellulose (CELL) was purchased from Sigma (stored at room temperature) for the DR4 test.

Samples were distributed to seven laboratories for DR4 testing and eleven laboratories for SRI testing (Table 2). The laboratories carrying out the SRI testing were also sent the control substrate alpha-cellulose as some of these also carried out a modification to the SRI test where substrate was mixed with an equal amount of microbial SEED. The dried and ground samples used for the DR4 testing were also tested for anaerobic biodegradability by the BM100 method by WRc. As biodegradability testing also required determination of DM and LOI contents of the waste samples the round robin study also provided data on the reproducibility of these determinations.

Table 2 Laboratories participating in DR4 and SRI round robin study

Laboratory/contact person	Country	Tests
WRc plc, Swindon/ Andrew Godley	UK	DR4 and BM100
Open University, Milton Keynes/ Jim Frederickson	UK	DR4
Cranfield University, Cranfield/ Richard Smith	UK	DR4
Leeds University, Leeds/ Ed. Stentiford	UK	DR4 and SRI
Glasgow Caledonian University/ Iain Macleod	UK	DR4
Reading University, Reading/ Jayantha Ratnayake	UK	DR4 and SRI
ABF BOKU/ DI.Binner	Austria	SRI
Technical University Braunschweig - Leichtweiss Institut/ Dr.	Germany	SRI
Technical University Hamburg-Harburg AB Abfallwirtschaft / Jörn Heerenklage	Germany	DR4 and SRI
SGS INSTITUT FRESENIUS GmbH/ Dr. Lebertz	Germany	SRI
Industrie- und Umweltlaboratorium / Vorpommern GmbH (IUL)/ Dr. Roßberg	Germany	SRI
Dr. Roth bioTEST/ Dr. Roth/Dr. Dietzmann	Germany	SRI
INFU mbH PlanCoTec/ Frau Marciniszyn	Germany	SRI
Fraunhofer-Institut für Umwelt-/Sicherheits- u. Energietechnik (umsicht)/ Dr. Merretig-Bruns	Germany	SRI
Technical University Darmstadt - Institut WAR/ Dr. Anke Bockreis	Germany	SRI

4 Round robin laboratory study results

4.1 DM and LOI determinations

The results of the waste DM and LOI determinations (Tables 3 and 4) indicated that there was less variation between laboratories for determination of DM contents compared with the LOI. Laboratory reporting of replicate results was incomplete and only average laboratory values are reported here. There was the occasional outlying result, which were not included in calculation of the overall mean and percentage relative standard deviation (%RSD).

Table 3 Results of waste sample DM (% wet weight) determinations. Outliers in bold italics.

Waste	SEED	CELL	0 day BMW		10 day BMW		51 day BMW		131 day BMW	
Test			DR4*	SRI	DR4*	SRI	DR4*	SRI	DR4*	SRI
Average lab DM results	58.6	96.4	75.7	***62.5***	75.4	37.4	88.1	54.1	82.4	52.8
	58.4	94.4	75.2	37.8	73.0	39.0	88.0	57.1	82.2	63.3
	57.3	94.1	77.0	47.2	71.5	43.3	89.2	59.0	81.9	63.4
	59.1	93.0	74.3	***83.7***	73.1	36.9	86.9	58.7	83.9	60.1
	58.4	92.8	75.5	41.2	74.7	40.6	88.6	58.2	82.8	67.5
	59.8	97.1	76.7	41.1	74.7	42.4	89.0	57.0	82.9	62.8
	58.8	92.2		36.3		41.2		55.1		62.5
	58.3	94.6		51.2		45.5		55.5		62.9
	58.1	93.1		37.1		38.9		56.2		63.2
	59.0	93.0		44.7		***71.9***		58.7		61.4
	59.0	94.8		37.3		43.9		58.7		58.3
	58.0	95.0		41.9		48.8		59.9		64.5
	58.4	93.3						***40.1***		
	59.4									
Mean	**58.6**	**94.2**	**75.7**	**41.6**	**73.7**	**41.6**	**88.3**	**57.4**	**82.7**	**61.9**
%RSD	**1.08**	**1.46**	**1.31**	**11.8**	**2.00**	**8.69**	**0.96**	**2.84**	**0.85**	**5.87**

*BMW was dried and ground for DR4 test.

Table 4 Results of waste sample LOI determinations (%DM). Outliers in bold italics

Waste	SEED	CELL	0 day BMW		10 day BMW		51 day BMW		131 day BMW	
Test			DR4*	SRI	DR4*	SRI	DR4*	SRI	DR4*	SRI
Average lab LOI results	36.0	98.4	61.0	66.9	57.6	66.5	41.2	43.5	41.7	43.1
	39.0	99.9	65.7	70.2	64.0	65.8	39.3	45.6	46.0	51.8
	40.9	99.8	67.6	***40.0***	64.1	48.8	47.4	37.7	47.3	41.0
	39.1	99.7	64.6	57.3	66.5	***84.3***	47.6	50.3	41.9	***63.7***
	33.3	99.8	67.5	70.1	57.3	53.7	30.3	49.9	44.0	45.9
	36.9	99.7	57.8	54.9	59.0	55.5	32.7	41.9	40.1	47.7
	65.5	99.7		62.8		49.0		36.6		***61.7***
	38.8	99.7				73.5				50.2
	39.2	99.7				61.0				46.5
	40.9	99.9				56.1				43.1
	38.5	99.9								
	38.6	99.8								
Mean	**38.3**	**99.7**	**64**	**63.7**	**61.4**	**58.8**	**39.8**	**43.6**	**43.5**	**46.2**
%RSD	**5.73**	**0.40**	**6.09**	**10.2**	**6.42**	**14.3**	**18.2**	**12.3**	**6.34**	**8.0**

*BMW was dried and ground for DR4 test.

4.2 DR4 and SRI method results

Five laboratories reported results for the DR4 method biodegradation test shown in units of mg O/kg LOI (Table 5) and mg O/kg DM (Table 6). The SRI test results from ten laboratories are shown in Table 7 in units of mg O/kg DM for comparison with the DR4 results. The within-laboratory repeatability S_r and the between-laboratory reproducibility S_R were estimated according to ISO 5725-2:1994 for both the DR4 and SRI results (Table 8). The within-laboratory repeatability S_r was for replicate tests of a sample carried

out at the same time. Investigation of within-laboratory repeatability of tests carried out on the same sample at different times in independent experiments was beyond the scope of this study.

Table 5 Mean and standard deviation (in brackets) for DR4 test results in mg O/kg LOI

Waste	SEED	Cellulose	0 Day BMW	10 Day BMW	51 Day BMW	131 Day BMW
Results from 5 labs	22000 (4670)	63800 (5720)	237000 (3210)	160000 (6200)	91800 (7800)	47000 (4330)
	12800 (1800)	47300 (3540)	205000 (13800)	157000 (14640)	68100 (12200)	27600 (6000)
	19300 (6940)	92500 (2527)	224000 (19500)	234000 (13060)	165000 (8450)	53000 (5860)
	31400 (15100)	72600 (20000)	302000 (55200)	195000 (4580)	96300 (5950)	45500 (4180)
	20200 (4200)	64400 (10260)	292000 (251)	236000 (9880)	168000 (15600)	50800 (943)
Average	**21100**	**68200**	**252000**	**197000**	**118000**	**44800**
%RSD	**31.7**	**24.1**	**17.0**	**19.5**	**38.8**	**22.5**

Table 6 Mean and standard deviation (in brackets) for DR4 test results in mg O/kg DM

Waste	SEED	Cellulose	0 Day BMW	10 Day BMW	51 Day BMW	131 Day BMW
Results from 5 labs	8010 (1740)	62800 (5720)	144000 (2080)	92000 (3520)	37800 (3210)	19800 (1820)
	4990 (701)	47300 (3540)	135000 (9050)	101000 (10500)	27700 (5310)	13700 (1440)
	6600 (2160)	92000 (2520)	151000 (3100)	134000 (7430)	50000 (2570)	23300 (2580)
	12200 (5860)	72500 (17300)	195000 (35700)	130000 (3040)	46000 (2830)	19100 (1750)
	7470 (1550)	64300 (10300)	169000 (145)	138000 (5760)	55100 (5100)	20400 (378)
Average	**7864**	**67800**	**159000**	**119000**	**43300**	**19230**
%RSD	**34.4**	**24.1**	**14.9**	**17.5**	**24.9**	**28.3**

Table 7 Mean and standard deviations (in brackets) for results of SRI tests (mg O/kg DM)

Waste	SEED	0 Day BMW	10 Day BMW	51 Day BMW	131 Day BMW
Results from 10 labs	3050 (212)	48400 (7590)	10300 (566)	9170 (1080)	4800 (100)
	5200 (400)	57000 (961)	2330 (252)	9250 (495)	5100 (458)
	4470 (58)	66300 (141)	2170 (58)	11000 (346)	6570 (451)
	4630 (115)	57200 (1590)	6930 (551)	11600 (854)	6630 (404)
	4140 (134)	74500 (3840)	3310 (1380)	12700 (541)	10600 (437)
	4900 (608)	58800 (2020)	2070 (379)	11500 (351)	7300 (1060)
	3880 (40)	71600 (1420)	2970 (486)	10900 (571)	9520 (266)
	3860 (29)	71000 (3590)	2720 (646)	9430 (386)	4630 (521)
	4570 (115)	79900 (987)	4130 (1460)	12100 (818)	8970 (723)
	3620 (151)	34300 (242)	2660 (672)	6580 (1060)	4950 (395)
Average	**4230**	**61900**	**3960**	**10400**	**6910**
%RSD	**15.3**	**22**	**66.9**	**17.4**	**31.2**

Table 8 Repeatability (S_r) and reproducibility (S_R) evaluation of DR4 and SRI test results. Expressed as percentage of the mean.

Waste	DR4 (mg O/kg LOI)		DR4 (mg O/kg DM)		SRI (mg O/kg DM)	
	$\%S_r$	**$\%S_R$**	**$\%S_r$**	**$\%S_R$**	**$\%S_r$**	**$\%S_R$**
SEED	35.9	43.8	36.4	45.8	6.1	15.3
Cellulose	15.2	23.9	15.3	23.9		
0 Day BMW	10.3	19.2	10.6	17.4	5.2	21.4
10 Day BMW	5.5	20.2	6	18.1	19.9	63.0
51 Day BMW	9.1	40.1	9.5	27.2	6.6	17.1
131 Day BMW	10.7	25.7	8.9	20.8	7.9	31.9
Mean	**14.5**	**28.8**	**14.5**	**25.5**	**9.1**	**29.7**

These results (Table 8) suggest that there was a wide range of repeatability and reproducibility levels associated with specific waste samples and with the different methods tested. The overall mean values however suggest that DR4 and SRI methods are quite comparable with respect to S_r and S_R indicating that the variability within and between

laboratories for the DR4 and SRI methods was similar. This is quite encouraging as only two of the labs undertaking the DR4 test had previous experience with the newly developed test whilst the SRI test is more established and most of the laboratories had many years' experience of the SRI method. The DR4 test result values are greater than the SRI values confirming that more waste decomposition occurs in the DR4 test during the 4 day monitoring period than in the SRI method. For example the DR4 was 2.57 times greater than the SRI value for the untreated (0 day composted) BMW sample. The SRI test results did not correlate well with DR4 results particularly for the partially composted 10 day old sample, which gave particularly low values by the SRI method compared with the DR4 results. The SRI results were however reproducible between labs indicating that this was a feature of the SRI test rather than an abnormal result from any particular laboratory.

We suspect that in this example partial composting may have produced some waste decomposition products or acidity that may have inhibited microbial activity in the SRI test. The 10 day old BMW sample in particular gave the lowest SRI result of 3960 mg O/kg and was taken from a holding tank of prepared BMW that would have been composting as an uncontrolled static pile for this 10 day period. This might have caused anoxic conditions within the waste affecting the subsequent response in the SRI test causing failure of the microbial population to develop. When one of the testing laboratories mixed this sample 1:1 with SEED on a dry weight basis the SRI method result was much higher (119000 mg O/kg DM) indicating the inhibition had been overcome. It is also possible that freezing the samples as the storage method for the SRI test has produced some inhibitory condition, e.g. from low temperature shock or perhaps lysis of newly grown microbes in the partially composted materials.

In the DR4 test we suspect that the risk of such inhibition is reduced as the test material is always diluted 1:1 with the mature greenwaste compost seed, which also adds a new source of microbes. Furthermore mature compost has got a high buffer capacity to buffer organic acids produced at the early stages of the decomposition. We are confident that the DR4 results for the partially composted wastes are valid as the biodegradability of the 10 day composted material was found to be marginally reduced compared with the untreated BMW. Moreover the DR4 results for all the BMW samples matched well with the anaerobic (BM100) test results (Figure 1).

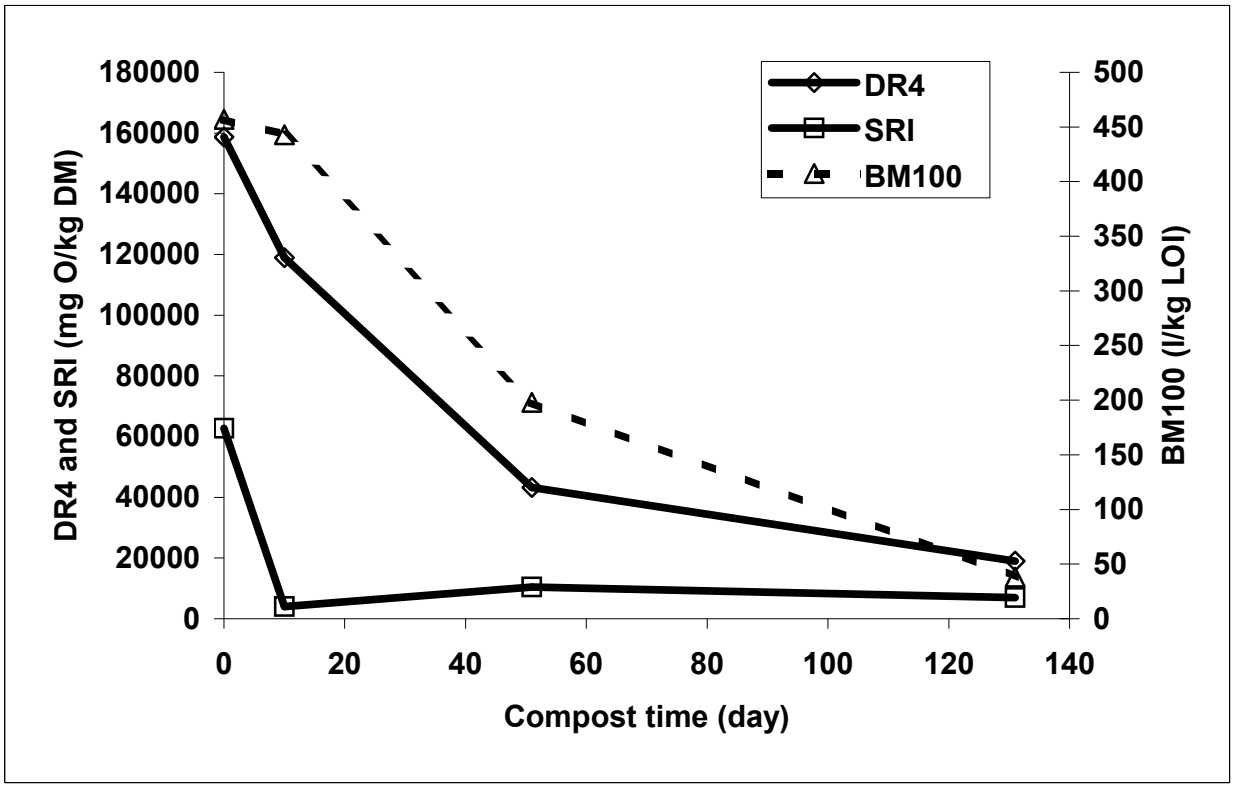

Figure 1 Comparison of DR4, SRI, and BM100 results for BMW samples of different composting age

5 Summary

The aerobic DR4 and anaerobic BM100 tests have been developed for monitoring the performance of MBT and other organic waste treatment processes in England and Wales.

A round robin laboratory study of the DR4 test has indicated that it is reproducible for untreated, partially treated and fully stabilised BMW.

The main differences between DR4 and SRI tests are that the DR4 test is carried out at a higher temperature, is actively aerated, includes a microbial seed and a control substrate for quality assurance purposes.

A comparison between the DR4 and SRI methods indicates that the DR4 approach promotes greater waste decomposition during the test period and that it may be more reliable for measuring the biodegradability of some partially composted wastes.

Inclusion of a microbial seed in the SRI may overcome the limitation of the SRI test for measuring the biodegradability of partially composted wastes.

6 Literature

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