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Guidance on monitoring of MBT and other treatment processes for the landfill allowances schemes (LATS and LAS) for England and Wales

Better Regulation Science Programme
Science report

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Steve Killeen

Head of Science

Executive summary

This document summarises the requirements for monitoring the treatment processes being used to bring about landfill diversion of biodegradable municipal waste (BMW). It provides the information needed for Waste Disposal Authorities (WDAs) to fulfil the data reporting requirements of the landfill allowance schemes of England and Wales.

The Landfill Directive (31/1999/EC) sets tough targets for reducing the amount of biodegradable municipal waste sent to landfill. In England and Wales, landfill diversion of BMW is monitored by the Environment Agency via the Landfill Allowance and Trading Scheme (LATS) for England and the Landfill Allowance Scheme (LAS) for Wales. Waste Disposal Authorities may employ mechanical biological treatment (MBT) and other processes to treat and divert BMW from landfill. Many treatment outputs are ultimately still landfilled and contain varying levels of biodegradable material depending on the processes undertaken. Under the landfill allowance schemes, WDAs should collect information on municipal waste arisings, quantify the reduction in the BMW content affected by treatment and calculate the final amount of BMW going for landfill disposal. The data is submitted to the Environment Agency electronically via WasteDataFlow.

This document presents guidance on monitoring MBT or similar processes in order to estimate the adjustment factor achieved by the treatment process. It is produced in two parts: summary guidance (part A) and detailed guidance (part B) so that those with different responsibilities can use the part with the appropriate level of detail.

The summary guidance in part A outlines what needs to be done by whom, the approach to monitoring an MBT or similar process with respect to LATS and LAS and explains why. Part B sets out when and how this needs to be implemented and includes technical details on monitoring plan design, sampling and sample testing, and the calculation of MBT performance. Annexes A to C set out the different test methods and an example sampling plan .

The guidance sets out how the WDA, or anyone acting on its behalf, should develop and put into practice monitoring plans to establish the performance of the treatment process. At all plants there will be an initial high intensity three-month (quarter) monitoring period following start-up of the plant. From data gathered during this period, the adjustment factor achieved by treatment will be calculated for all outputs landfilled in this initial quarter. The second phase allows for a potential reduction in monitoring in subsequent quarters, but this is dependent on the level of variability in the adjustment factor that was measured in the first monitoring quarter. At the end of the first year of monitoring the variability in the adjustment factor will dictate the monitoring frequency in the following year. It is therefore in the interests of plant operators to keep sampling and testing variability to a minimum to reduce monitoring effort and costs.

The adjustment factor may be based on either the reduction in the amount of organic matter (measured as loss on ignition (LOI)) or potential biogas production of the biodegradable waste between the input and landfilled outputs of the MBT.

Execution of the monitoring plans specified in this guidance will provide the necessary data to allow calculation of the BMW landfilled following treatment. This figure can then be used in WasteDataFlow for LATS or LAS purposes by Waste Disposal Authorities.

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Glossary of terms and concepts

Term	Description
A_f	adjustment factor. This is a measure of the change in biodegradable waste (material or content) between the input and landfilled outputs of a treatment process and is used to calculate the tonnes of BMW landfilled.
Bias	Bias is a quantification of trueness; that is, the difference between the average value of the series of measurements and the true value. A positive bias indicates an over-estimate and a negative bias indicates an under-estimate of the true value. Bias is thus equivalent to the total systematic error in the measurement.
Biodegradability	Biodegradability of a waste is a measure of the degree to which the plant- or animal- derived organic matter is decomposed by microbes during biological treatments such as aerobic composting, anaerobic digestion or following disposal in a landfill.
BMc	Biodegradability under methanogenic conditions at effective completion. Anaerobic test for methanogenic biodegradability monitored for biogas (CO_2 + CH_4) until biogas production effectively ceases (previously known as the BM100 test).This may take less or more than 100 days. Test results are expressed as l/kg LOI.
BMW	Biodegradable municipal waste. This is the biodegradable waste fraction in untreated municipal waste and comprises the components capable of undergoing anaerobic or aerobic decomposition. It includes materials such as paper, cardboard, wood, green waste, kitchen waste, textiles and fine/soil-like material. The biodegradable waste in each input is referred to as BMW_I and output from a treatment process as BMW_O. We distinguish BMW_O from BMW_I because treatment changes the characteristics of the input BMW, for example by removal of moisture, the separation of some components or by microbial decomposition.
Composite sample	A sample that is produced by mixing a specified number of smaller incremental samples taken from the same primary sample.
Confidence interval	The interval within which a particular population parameter may be stated to lie at a specified confidence level. The bounds of the confidence interval are termed the upper and lower confidence limits.
DM	Dry matter. The sample is initially dried to facilitate shredding and this moisture loss must be recorded. A portion of the sample is then dried to constant weight at 105°C. These two moisture losses must be combined to give an overall dry matter expressed as percentage wet weight. This is the value used in all calculations.
DR4	Dynamic respiration test. Aerobic biodegradability test carried out over four days. Measured as g O / kg LOI.

Term	Description
Grab sample	A large sample taken from nominated loads or at regular intervals during the day that are placed in a single pile and mixed to form a primary sample. The size of the grab sample means that this will be most effectively collected using mechanical scoop or bucket.
Increment	Individual portions of waste that are collected from a primary sample and are combined to form the (composite) sample to send to the laboratory. This would commonly be undertaken manually using a large spade or shovel.
Laboratory sample	Sample sent to the laboratory for testing, produced by taking increments from a mixed primary sample.
LAS	Landfill Allowance Scheme (Wales).
LATS	Landfill Allowance Trading Scheme (England).
LOI	Loss on ignition. A measure of the quantity of organic matter in the sample that can be combusted at 550°C. The loss in weight during combustion equates to the mass of organic matter in the sample. It is expressed as a percentage of dry matter content.
MSW	Municipal solid waste referred to here as municipal waste. Waste from households and other sources collected by or on behalf of Waste Collection Authorities (WCA). The components of municipal waste include biodegradable municipal waste (BMW), and essentially non-biodegradable materials such as plastics, glass, stones and metal objects.
Mass flow	Weight of the waste going into, or coming out from, an MBT process.
Plastics	Plastics are composed of organic matter but the timescales for degradation are many decades. For the purpose of biological treatment in the timescales of MBT and anaerobic digestion, they are considered to be non-biodegradable and are therefore categorised as a constituent of the non-BMW fraction of municipal waste.
Population	The population represents the total volume of waste about which information is required. In this case, this is the full year input to or output from the MBT plant.
Precision	The measure of precision is usually expressed in terms of imprecision and computed as a standard deviation of the test results. A lower precision is reflected by a larger standard deviation. The precision of a result is half the confidence interval.
Primary sample	Represents any large sample taken at the scale of sampling, that is, one day. The primary sample should consist of a number of large grab samples, which are combined and mixed and a representative sample taken for analysis – the laboratory sample.
RSD	Relative standard deviation – the positive square root of the variability of a dataset.
Sampling event	The sampling event describes the actions required to take a sample. For an MBT plant, each sampling event should take place on a separate day unless information on within-day sample

Term	Description
	variability is specifically required.
Sample weight	The sample weight defines the mass (in kilogrammes) of the sample taken to the laboratory for analysis.
Scale of sampling	The scale defines the total volume of waste from which the sample is to be taken. In this case, this is a day's input or output to the MBT.
Sub-sample	Any portion of material taken from the sample as part of laboratory tests.
SRF	Solid Recovered Fuel, also known as RDF or refuse derived fuel. A waste containing mainly the combustible fractions of municipal waste, such as paper, card and plastc.
Variability	Variability is a characteristic of the waste that cannot be changed without intensive manipulation of the waste. Its investigation is important because the more that is understood about the causes of variability affecting the material under investigation, the greater will be the opportunity for that knowledge to be exploited in designing the sampling programme.
WCA	Waste Collection Authority.
WDA	Waste Disposal Authority.
WDF	WasteDataFlow. A web-based tool for local authorities (both WCAs and WDAs) to input data on municipal waste. In this context it calculates the tonnes of BMW sent to the treatment plant.

Part A

Summary guidance on monitoring MBT and other treatment processes for the landfill allowances schemes in England and Wales (LATS and LAS)

1 Introduction

This guidance sets out the sampling and monitoring regime to generate acceptable evidence for the Environment Agency to estimate the diversion of biodegradable municipal waste from landfill achieved by mechanical biological treatment (MBT) and other waste treatment processes used to treat residual municipal waste prior to landfill.

The Landfill Allowance Schemes in both England and Wales set out the amount of biodegradable municipal waste that all local authorities are permitted to landfill. Biodegradable municipal waste (BMW) is the sum of the biodegradability of the different fractions in municipal waste. Both schemes are monitored by the Environment Agency, which calculates the net BMW content of any residual waste using a mass balance approach from the information reported on WasteDataFlow. Any biodegradable outputs that are landfilled will be subtracted from a local authority's landfill allowance, and therefore monitoring the amount of biodegradable waste that is diverted from landfill by any treatment process is key.

Part A summarises what needs to be done by whom and explains why. Part B sets out when and how this needs to be implemented and includes technical details on monitoring plan design, sampling and sample testing, and the calculation of MBT performance.

2 Monitoring a treatment process for LATS or LAS

2.1 Principles

Mechanical biological treatment changes the amounts and/or basic characteristics of biodegradable waste either through separation of some components (such as paper and plastic for solid recovered fuel (SRF)) or through biodegradation. The input and output BMW will therefore be different because:

- each stream landfilled may only be composed of some of the input BMW;
- it may have been dried and/or wetted; and
- it may have lost some of its organic matter content due to microbial decomposition during the biological stage of the treatment process (composting or anaerobic digestion).

To estimate the amount of BMW landfilled, the input to, and any outputs from, the MBT process need to be sampled and tested to determine their biodegradability. Figure 2.1 shows the calculation for a hypothetical MBT plant. These data can then be used with mass flow data to calculate the total amount of BMW that was landfilled.

There are currently two methods accepted by the Environment Agency for determining the reduction in BMW between the biodegradable waste in the input and outputs landfilled from the MBT process. These are:

- the change in loss on ignition (LOI); and
- the change in potential biogas production.

Detailed test methods for measuring these and associated parameters are provided in annex A. The Environment Agency may accept other tests subject to evidence that they are sufficiently correlated with either of the accepted methods. Further details are given in section 2.2.4 and annex B. The change in BMW achieved is referred to as the adjustment factor (A_f) and this is used with the tonnage sent to landfill to calculate the tonnage of BMW landfilled from the MBT outputs.

Tonnes BMW landfilled in MBT outputs (t BMW_L) = Σ tonnes $landfilled_{all\ outputs}$ x Mean A_F[1] x (%RB[2]/100).

The calculation of the A_f is based on dry weight, to ensure that any loss in moisture from the process is not counted as diversion of BMW.

[1] Mean A_F is the quarterly average of the A_F values derived for each linked batch of input(s) and output(s).

[2] RB% is the residual biodegradable percentage of municipal waste after recycling and composting calculated in WasteDataFlow.

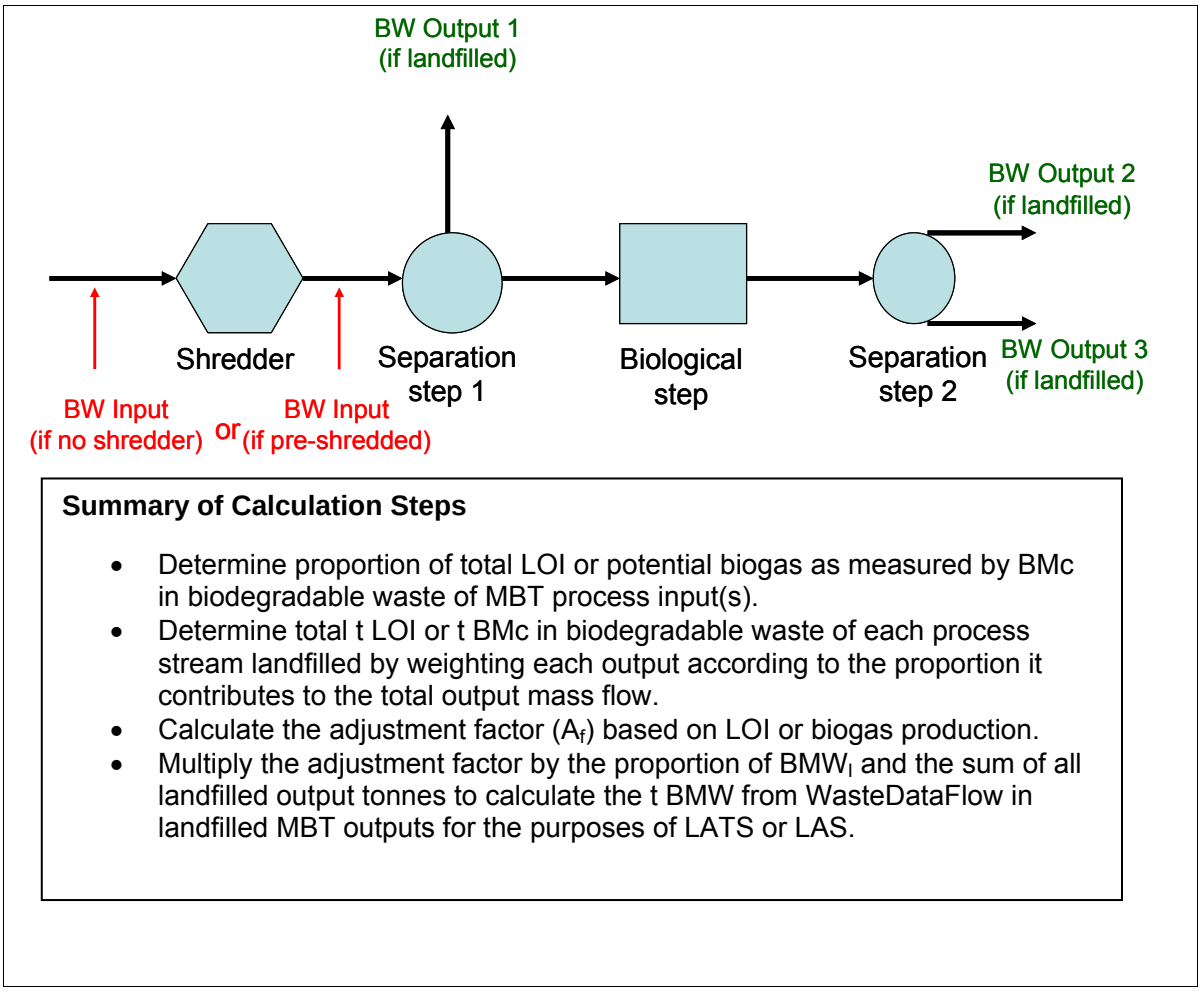


Figure 2.1 Schematic of typical MBT monitoring points for estimating BMW landfilled.

2.2 Calculating BMW diversion

2.2.1 Introduction

The LOI test does not differentiate between readily biodegradable organic matter and organic waste components that are resistant to microbial decomposition or non-biodegradable. The LOI test for landfilled outputs will report the loss of these resistant organics along with the loss of those that are readily degradable, therefore using the LOI method will typically give a smaller reduction than that measured by potential biogas reduction. A biological test only measures the biodegradability of the degradable fraction, so if all biodegradable matter is removed by processing, it is in theory possible to get a 100 per cent reduction.

2.2.2 Using the change in loss on ignition (LOI)

Loss on ignition (LOI) is the amount of organic carbonaceous matter lost from a dried waste when it is combusted in a furnace at 550°C. This removes all organic

carbonaceous materials (readily and slowly degradable and non-biodegradable,such as plastics). The combustion of untreated and treated biodegradable waste produces an ash from the non-combustible inorganic and mineral components in the biodegradable waste. The reduction in BMW landfilled is based on measuring the change in LOI between the inputs and landfilled outputs of the BMW fractions. The change in LOI is measured on a dry weight basis to ensure that the effects of any loss of moisture due to drying are excluded from the calculation. Full details of the test methods used are provided in annex A.

The adjustment factor for LOI based monitoring is calculated from:

$$A_f = \Sigma \text{ weighted LOI of all outputs} / \Sigma \text{ } LOI_I \text{ all inputs}$$

If there is only one input and output, the adjustment factor is calculated as: $A_f = LOI_O / LOI_I$

This is illustrated in figure 2.2 for a simple scenario where there is initial separation of a SRF containing biodegradable waste followed by biological treatment of the residual waste with all the output from the biological treatment landfilled.

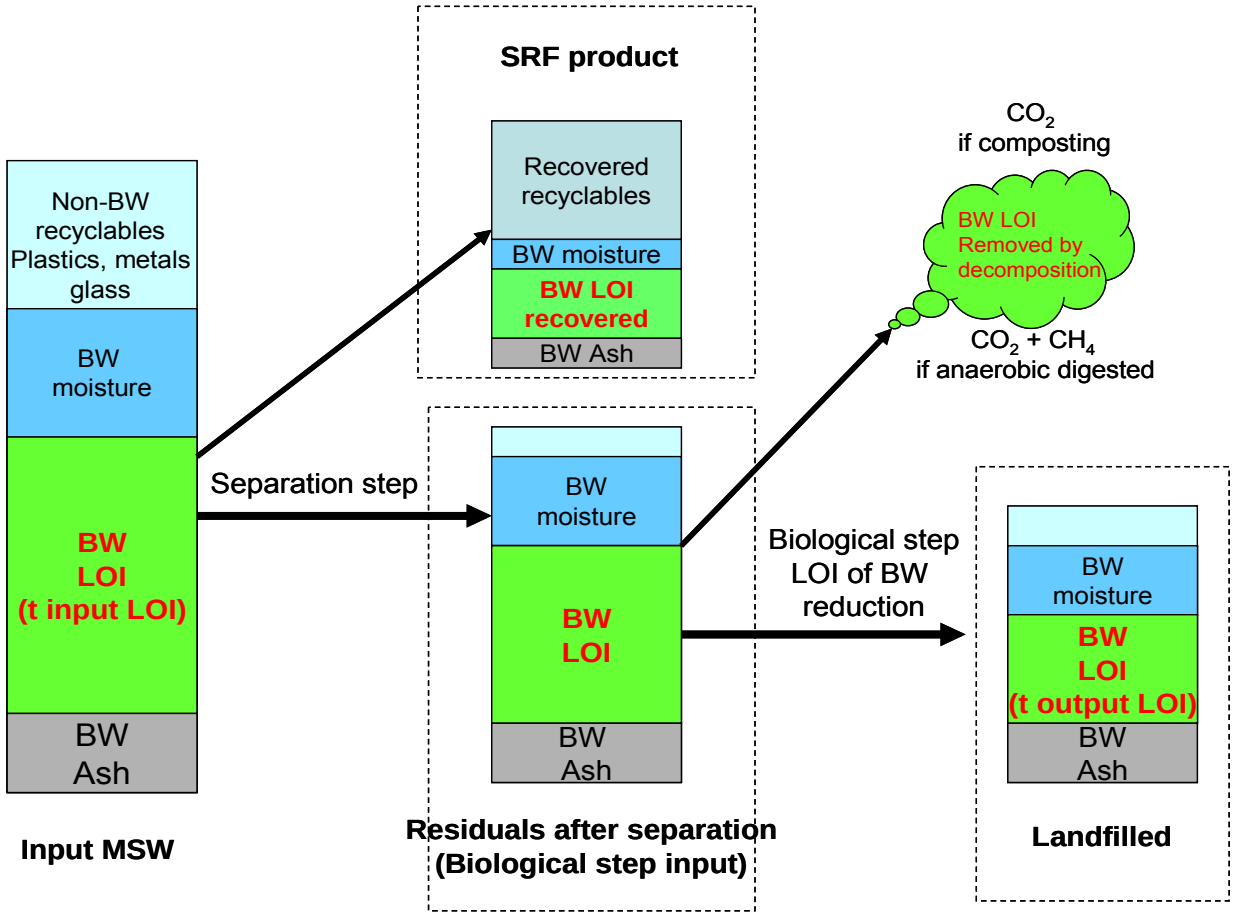


Figure 2.2 Monitoring MBT: adjustment factor based on LOI reduction.

2.2.3 Using the change in potential biogas production

The potential biogas production method for determining the adjustment factor differentiates between the readily biodegradable and recalcitrant or non-biodegradable organic matter. This method will therefore usually estimate a greater diversion of BMW than the LOI reduction alone. This is illustrated in figure 2.3.

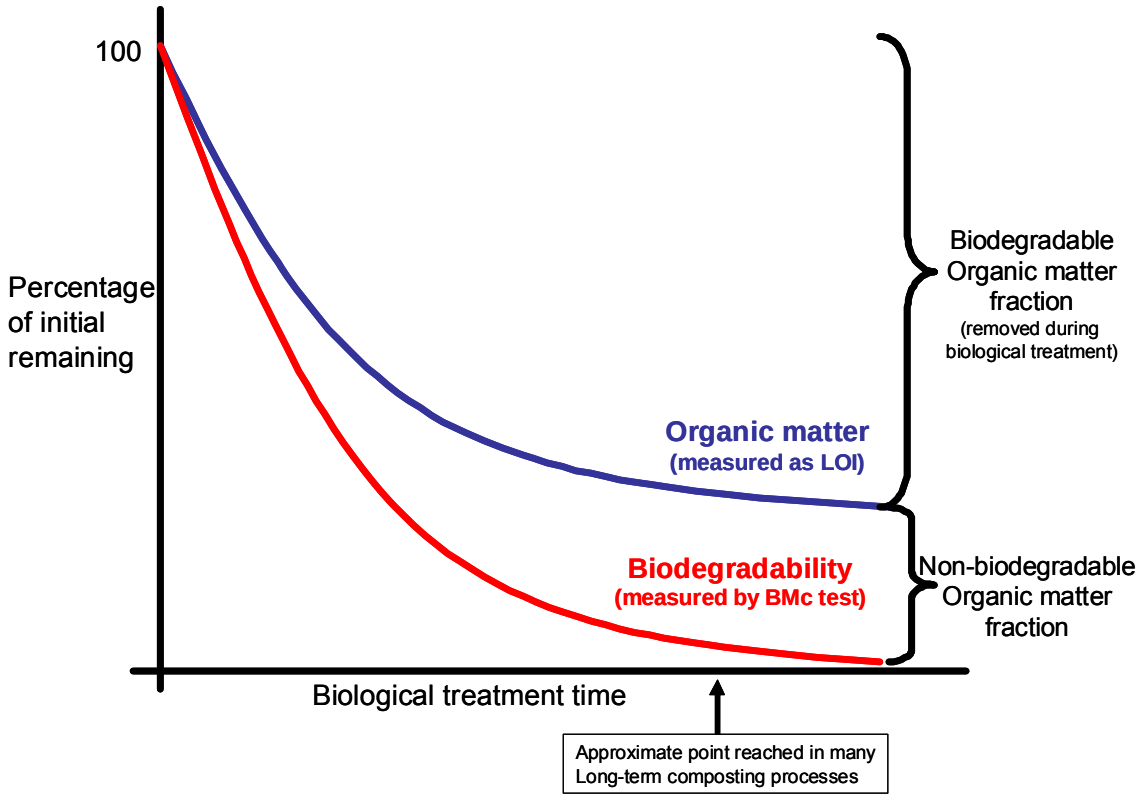


Figure 2.3 Use of LOI and BMc to calculate BMW diversion.

The assessment method is similar to monitoring by the LOI reduction approach except that the biodegradability of the biodegradable waste is also determined using the anaerobic biodegradation test BMc (formerly the BM100 test). The amount of BMW landfilled is measured in terms of the reduction in potential biogas production. The adjustment factor (A_f) is calculated by:

$$A_f = \Sigma \text{ (weighted BMc of all outputs landfilled)} / \Sigma \text{ BMc of all inputs}$$

The BMc test reports biodegradability as litres of biogas per kg LOI and may take 100 days or more to complete, that is, until biogas production ceases.

2.2.4 Alternative biodegradability tests

The BMc test provides important baseline data during initial characterisation of the process, however it may not be preferable for routine, onward monitoring of an MBT plant if more rapid reporting of performance is required. Alternative tests which are sufficiently correlated with the BMc test can be used. Where another test for biodegradability is proposed, both the alternative test and the BMc test should be used during the initial monitoring until sufficient data are obtained for a site-specific correlation between the two tests. The correlation coefficient (R) between the two test

methods should be demonstrated to the satisfaction of the Environment Agency, and should be in excess of 0.9 over the period of dual monitoring which will require parallel testing of 12 or more samples. Further information on correlation is provided in annex B.

2.3 Monitoring requirements for MBT for LATS and LAS

2.3.1 Introduction

The approach in this guidance is based on the principles described in the European Standard BS EN14899:2005 (British Standards, 2005). A monitoring plan (and sampling plan) should be developed prior to or during commissioning and should be submitted to the Environment Agency prior to commencing sampling and testing. Following commissioning, when the plant is operating at full capacity, the process should be monitored according to this guidance to establish the total amount of BMW landfilled each quarter for LATS or LAS. Monitoring MBT processes for LATS or LAS should be consistent with the three principal levels of testing laid out in the Landfill Directive (for more detail see part B, section 5.3.2):

- Level 1 (Basic characterisation): an initial phase of comprehensive monitoring to provide a baseline of plant performance to calculate the adjustment factor for the first quarter and (if an alternative biogas production assessment option is proposed) sufficient samples to determine an acceptable correlation with the BMc test. The Level 1 monitoring plan should demonstrate that consideration has been given to points in section 5.3.

- Level 2/3 monitoring ('Level 3' is used to refer to data that can be collected at a plant without recourse to analytical testing): Level 1 monitoring data produced during the first three months of routine operation should be used to calculate the variability in the A_f and estimate the ongoing sampling frequency required for Level 2/3 monitoring for the remainder of the 12-month period. The more variable the outputs, the more frequently the plant will need to be sampled. Following the guidance on sample collection in part B, sections 6 and 7.2.2 will help to reduce the variability. The procedure for calculating the number and frequency of samples is summarised in section 3.3.1. The frequency of sampling in subsequent years will be based on the variability in data observed over the previous year's monitoring.

The various activities undertaken as part of monitoring should be defined in the monitoring plan. The contents of a monitoring plan are defined in section 3.2, along with the recommended procedure for defining sampling frequencies in the first year and subsequent years, sample size and sample collection procedures (section 3.3). This information is discussed in more detail in sections 6 and 7 in part B.

3 The monitoring regime

3.1 Principles

This guidance is based on the European Standard BS EN 14899:2005. Additional guidance has been published for plant operators by the Environment Agency (2005) and the Environmental Services Association Research Trust (ESART) (2004).

Any monitoring activity should be planned thoroughly and the monitoring plan for determining the BMW landfilled from an MBT plant should cover:

- Start-up monitoring for the first quarter of full-scale operation after the commissioning period. The period over which commissioning is required will depend on the timescale required to optimise the process and the period of monitoring needed to capture and characterise seasonal changes and variability in the input wastes and process outputs. This could commonly be a year or more.

- Onward monitoring applying a rolling assessment approach which looks at changes in the quarterly A_f and annual reassessment of the monitoring frequency.

The Environment Agency will review any monitoring plans submitted to determine whether they meet the requirements of this guidance.

A key element of a monitoring plan will be the development of a sampling plan for each waste stream (inputs and outputs) to be sampled. Obtaining suitably representative samples is an implicit requirement of the sampling plans.

All monitoring data should be submitted to the Environment Agency, together with a calculation of the tonnes of BMW landfilled in MBT outputs, and notification of any change in plant operation and the action being taken.

Detailed guidance on the development of monitoring plans is given in part B, section 5.

3.2 The monitoring plan

The key elements required for the monitoring plan are:

- A description of process including MBT outputs landfilled.

- The objectives of monitoring.

- The test on which the adjustment factor will be calculated (by change in LOI or biogas production) and the process parameters and waste characteristics to be monitored.

- Details of any proposed alternative test to the BMc. All samples taken under Level 1 comprehensive monitoring should be analysed both by the BMc and the alternative tests to provide a site-specific correlation. If the

DR4 test is the proposed alternative test then the default DR4-BMc correlation (annex B) can be applied until results from the Level 1 monitoring are available. Monitoring data obtained during commissioning may also be submitted to the Environment Agency as evidence in support of the correlation.

- The calculation proposed for determining the adjustment factor, based on the principles shown in the examples in section 8.

- The ongoing process monitoring proposed, for example, monitoring the weights of all inputs and outputs on a monthly basis.

The sampling plan will identify the specific details of the intended sampling activities and should include details of:

- Process streams proposed to be sampled (as a minimum, the inputs and any outputs landfilled). This is to establish the adjustment factor for the plant for outputs that are landfilled. This is further described in section 6.2. The output samples should correspond to the same waste streams as the input samples; that is, output sampling will need to take account of the residence time in the process. If the output that may be landfilled is not known, all outputs should be sampled and analysed.

- How representative samples will be collected, in accordance with the sampling plan (further guidance is provided in part B, section 7.2), and how they will be stored and transported.

- Who will carry out independent sampling of the plant. How many samples would be collected by the independent sampler(s) and how many by the plant operators (see section 7.4).

- How many samples will be taken and when (for Level 1 and Level 2/3 monitoring). Initially the process should be monitored for one quarter with a minimum of 10 linked BMW input and BMW output samples to be landfilled.

- The sample size (weight or volume) to be taken and what studies have been carried out to determine the precision provided by the sample size. Default sample sizes for typical MBT waste streams are provided in section 3.3.2 and part B, section 7.3.

- What the samples will be analysed for.

- The quality assurance/quality control (QA/QC) procedures for the monitoring activity, including record keeping.

- How the monitoring data will be reported to the Environment Agency, including how the adjustment factor will be calculated using the approach described in more detail in sections 7.4 and 6.3 respectively.

- Provision for annual review, using a full 12 months of data to re-calculate the variability of the data using the approach detailed in section 6.3.

3.3 Guidance on sample collection

3.3.1 Sampling frequencies

At start-up there is limited (from plant commissioning data) or no information about the variability in the A_f over time and a default sampling frequency is therefore used to provide an initial characterisation of the plant in the first quarter (Level 1 monitoring).

Level 1 monitoring, quarter 1: During the first three months, samples should be collected and the A_f calculated for every working day over two consecutive weeks at a randomly chosen start time during the first three months, when the plant is running under 'standard' conditions. This will produce either 10 or 12 estimates of the A_f that together should reflect some of the day-to-day and week-to-week variation in the A_f.

For each day's sampling, the operator should analyse the input to determine its biodegradable content and subsequently take linked[3] samples for each output stream. All wastes sampled should be analysed for DM and LOI. If biodegradability is being measured using biogas production, the BMc test and any alternative test proposed for onward monitoring should be carried out. In addition, the total weights of each waste stream should be recorded at least monthly. This first three months of monitoring represents an initial intensive Level 1 characterisation exercise which will be followed by three quarters of Level 2 compliance monitoring.

Level 2/3 monitoring, quarters 2 to 4: The frequency of Level 2 monitoring will be based on the variability of the dataset produced in the first quarter monitoring. In subsequent years the level of monitoring will be set following a review of the previous year's monitoring data and will be the same for each quarter.

The initial variability in BMW content for each output will be determined from the results of the first quarter of Level 1 comprehensive monitoring. This variability[4] can be pooled to calculate the ongoing sampling frequency required to complete Level 2 monitoring in the remainder of the first year of compliance monitoring. The guidelines on sample collection (see section 6) will help to ensure that the variability is as low as possible. A ceiling on the number of samples has been set at 12 per quarter. The more variable the A_f, the more frequently the plant will need to be sampled during Level 2 monitoring for the remainder of the year. Having established the sampling frequency, samples should be collected on randomly selected working days throughout each quarter.

3.3.2 Sample size

Municipal waste is both heterogeneous and variable. Large samples are required to ensure the results are representative and to reduce sampling error to an acceptable level. Sample weights of more than 500 kg are not unusual. Table 3.1 gives guideline values to calculate recommended *minimum* sample weights (in kilogrammes) for typical MBT inputs and outputs. These weights are based partly on empirical studies and partly on practical experience with the type of materials associated with MBT processes.

[3] In the linked samples the outputs are sampled from the same batch as the inputs but after treatment.

[4] The variability between the samples is measured by a statistical function, the relative standard deviation, (RSD).

To determine the guideline minimum sample size, the reference value for a given type of waste needs to be multiplied by the appropriate factors, depending on particle size, BMW and moisture content. The reference values in table 3.1 are the sample weights for materials with a BMW content of <30% or >70% with a moisture content of less than 50 per cent. Sample weights for materials with other characteristics can be calculated using the multipliers. For example, a batch of large screening reject material with a BMW content of 60 per cent, a moisture content >50 per cent and a particle size >100 mm would require a sample weight of 50kg x 2 x 2 x 2 = 400 kg.

The guideline *minimum* sample weights given in table 3.1 relate to the recommended sampling frequency outlined above. This table and the explanation are repeated in section 7.3.1 and more detail on sampling generally and the statistics of sampling are given in section 7 and section 6 respectively.

Table 3.1 Default minimum sample weights (kg) for materials of varying characteristics.

Material	Reference Value (kg)	BMW (%)			Moisture (%)		Particle size (mm)		
		<30	30-70	>70	<50	>50	<20	20-100	>100
Black bag input municipal waste	**100**	x1	x2	x1	x1	x2	NA	NA	NA
Shredded input municipal waste	**50**	x1	x2	x1	x1	x2	NA	NA	NA
Large Screening Reject	**50**	x1	x2	x1	x1	x2	NA	x1	x2
Small screening reject/fines	**5.0**	x1	x2	x1	x1	x2	x1	x2	NA
Solid Recovered Fuels (SRF)	**2.5**	x1	x2	x1	x1	x2	x1	x2	x4
Compost like output (CLO)	**2.5**	x1	x2	x1	x1	x2	x1	x2	NA

NA = not applicable

3.4 Reporting monitoring data to the Environment Agency

Table 3.2 provides a summary of the results of the comprehensive Level 1 and onward Level 2/3 monitoring, together with calculated adjustment factors and subsequent calculated tonnages of equivalent BMW landfilled. All the results for samples in that quarter and the mean values should be reported to the Environment Agency.

The results for the waste inputs and their associated outputs will be used to determine the adjustment factor which we will enter in WasteDataFlow to calculate the tonnes of BMW landfilled from that input.

A discussion of other information reporting requirements for the site monitoring plan are discussed in section 3.2 and in further detail in section 7.4.

Table 3.2 Data required for monitoring MBT and other similar processes.

Data required	Units	Process input	Outputs landfilled
Data required for LOI reduction option			
Tonnes wet weight of municipal waste	t municipal waste	tM_I	tM_O
Percentage wet weight of biodegradable waste (BMW) fraction of the municipal waste	%BMW	$\%BMW_I$	$\%BMW_O$
% BMW input (from WasteDataFlow)	%BMW	RB%	
Percentage dry matter (DM) content of BMW fraction	%DM	$\%DM_I$	$\%DM_O$
Percentage organic matter (LOI) of the dry matter content of the BMW fraction	%LOI	$\%LOI_I$	$\%LOI_O$
Additional data required for biogas reduction option by direct BMc testing			
Anaerobic biodegradability (BMc) of the BMW fraction	Litres biogas /kg LOI	$BMc_{(I)}$	$BMc_{(O)}$
Additional data required for biogas reduction option by alternative biodegradability test correlating with BMc (BMc data required as well to develop site specific correlation)			
Alternative biodegradability test (e.g. DR4) of the BMW fraction	various	Bio_I	Bio_O
Correlation between alternative and BMc test (optional)			

Notes: BMW for input municipal waste is the %BMW content measured as a percentage of the whole wet weight. There may be more than one MBT output stream landfilled. The data above is required for each output landfilled.

For England, enquiries, proposed monitoring plans and quarterly monitoring data should be sent to: LATS@Environment-Agency.gov.uk. For Wales the relevant contact details are
Or telephone the National Customer Contact Centre (NCCC) 08708 506 506 and ask for a member of the LATS or LAS team as appropriate..

4 References

British Standards (2005), Characterisation of wastes. Sampling of waste materials: Framework for the preparation and application of a sampling plan, BS EN 14889:2005.

Environment Agency (2005). Guidance on the sampling and testing of wastes.

Environmental Services Association Research Trust (ESART) (2004). A Practitioner's guide to testing waste for onward use, treatment or disposal acceptance.

Part B

Detailed guidance on monitoring MBT and other treatment processes for the landfill allowances schemes (LATS and LAS) for England and Wales

5 General guidance on the development of a waste testing programme

5.1 The testing programme

The European Standardisation Committee (CEN), Technical Committee 292 (TC 292) – Characterisation of waste, has produced a range of standards to help ensure the objectives of any waste testing programme are consistently met. CEN TC 292 has developed and agreed a process flow chart that defines the essential elements of a testing programme and how those elements are linked. This flow chart is presented in figure 5.1.

5.2 Monitoring plan design

The process flow chart in figure 5.1 shows the key elements of a testing programme, the first step of which is the development of a project monitoring plan. This should define all the steps required to successfully complete the overall testing programme. Appropriate definition of the monitoring plan will ensure the data produced from monitoring meets the overall objectives of the testing programme, which in this instance is directed at LATS or LAS. Apart from this primary objective, data on waste characteristics are also relevant to, and a legal requirement for, waste hazard assessment, Duty of Care, best practicable environmental option (BPEO) assessment, landfill acceptability, environmental and health and safety risk assessments. This guidance only provides advice on monitoring MBT processes for LATS and LAS, but keeping in mind these other requirements for data can help maximise the value from a given set of samples.

The monitoring plan should include the calculation proposed for determining the adjustment factor, based on the principles shown in the examples in Section 0.

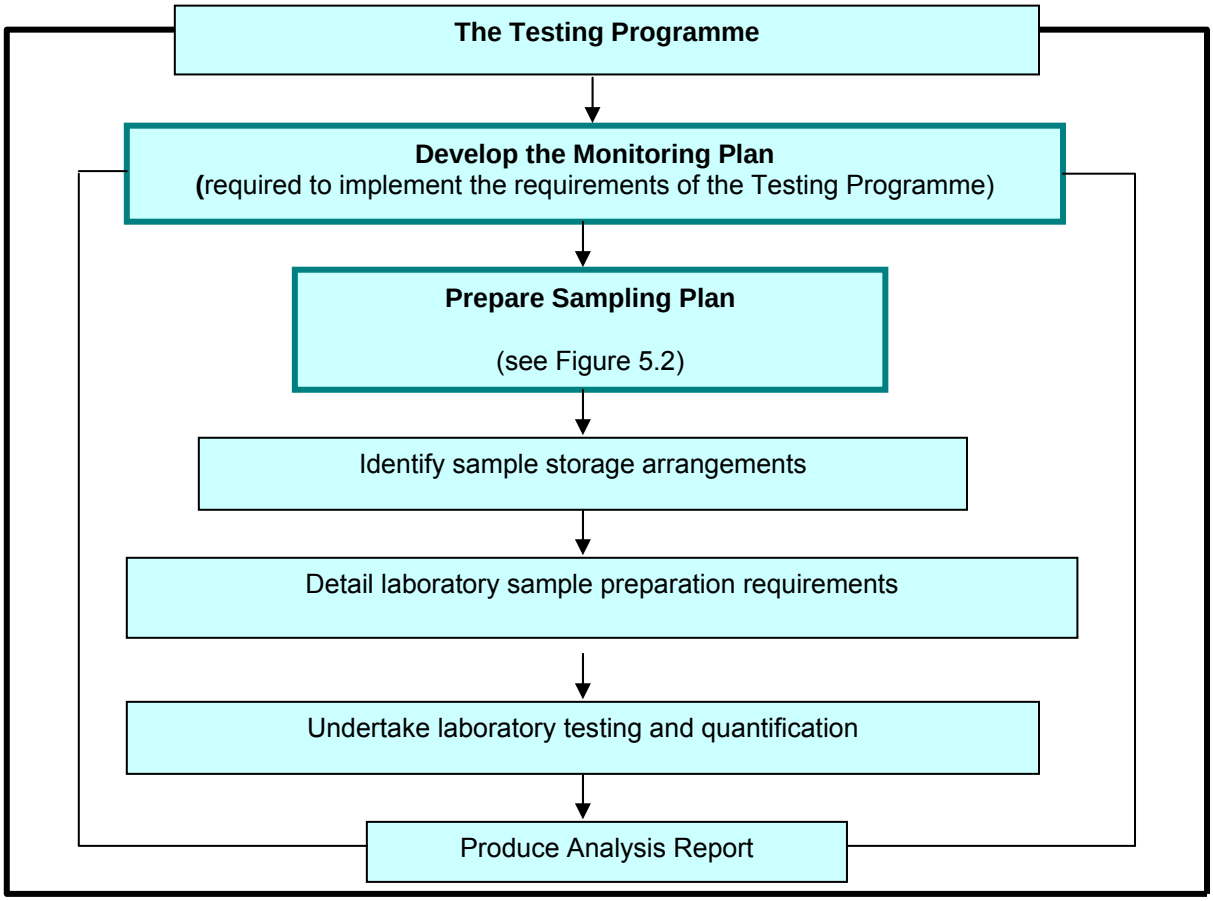
5.3 Sampling plan design

One of the most important activities in defining the monitoring plan for any given testing programme is the development of a sampling plan as advocated in Framework Standard EN 14899[5]. The sampling plan should describe the appropriate practical activities required to achieve the set objectives of the testing programme.

The monitoring (and sampling) plan should be submitted to the Environment Agency and should demonstrate that due consideration has been given to the frequency of, and approach to, sampling.

[5] The European Standardisation Committee (CEN), have produced a Framework Standard (EN 14899) and detailed supporting technical reports to cover all aspects of waste sampling and testing.

Figure 5.1 The main elements of a testing programme including the relationship between monitoring and sampling plans.



5.3.1 The sampling plan approach

Where wastes are to be landfilled, the Landfill Directive and UK Landfill Regulations require that a sampling plan should be prepared in accordance with the CEN Framework Standard. However, the approach is valid for testing programmes with other objectives and using it will help to ensure that adequate thought is given to developing a programme of monitoring that delivers the data required and that it is of adequate quality. Importantly, the plan should provide an audit trail of the sampling exercise and sampling should only be carried out in accordance with an agreed plan.

5.3.2 Key steps in sampling plan development

The development of a sampling plan is guided by the overall objectives of the testing programme. Seven key steps should be considered in the development of a sampling plan (as summarised in figure 5.2). Further guidance on each of these steps is given in EN 14899, but the key issues of relevance to MBT process monitoring are elaborated in the following section.

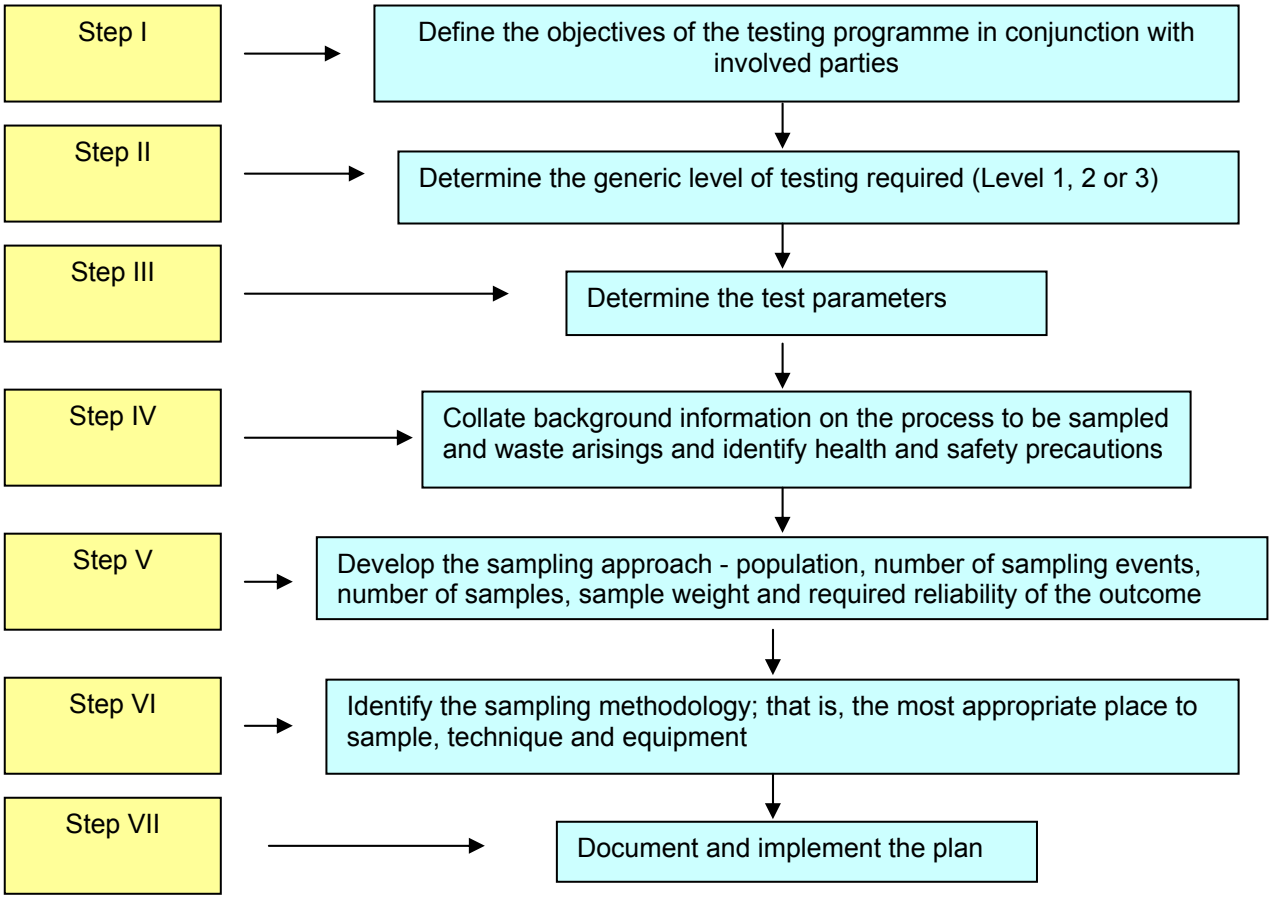


Figure 5.2 Key steps in developing a sampling plan.

Step I: Define the overall objectives of the testing programme

The overall objectives of the testing programme define the type and quality of information required from sampling. This objective can then be translated into specific objectives in the sampling plan that are sufficiently detailed to determine all aspects of sampling - the type, size, scale and number of samples to be taken, the way they are selected from the material under investigation, and so on.

For LATS and LAS, the objective of the testing programme is to provide data to estimate the quarterly tonnage of BMW landfilled from the MBT process to a given level of precision and confidence.

The organisation responsible for undertaking treatment of the waste should identify a project manager to oversee development of the sampling plan. This role may be delegated to a technical consultant. The plan should have agreed objectives and take into account plant-specific issues. The monitoring plan, including the sampling plan, should be submitted to the Environment Agency prior to start-up of the monitoring programme. The project manager should ensure that the final plan is implemented.

The objectives of a monitoring and sampling plan affect the location, number and volume or weight of samples taken, and the minimum testing requirements. When preparing the detailed sampling instructions, the sampling personnel need to know the reasons for the sampling that affect the way the samples are taken, how many are taken, what they are to be tested for and precautions needed to preserve their integrity

during transport to the laboratory. The objectives should therefore be clearly defined to ensure that the sampling and testing meet these objectives.

For LATS and LAS the objective is to provide data to estimate the quarterly tonnage of BMW landfilled from the MBT process. The tonnage of BMW landfilled is estimated by multiplying the quarterly tonnage of municipal waste landfilled from the MBT plant (the figure from WasteDataFlow (WDF)) by the BMW content of the residual municipal waste (from WDF) and the adjustment factor for the MBT plant for the same quarter. The quarterly adjustment factor is calculated from the results of testing, which need to allow the amount of BMW landfilled to be estimated with the required precision. To achieve this, the frequency and method for sampling these streams must be defined in a site-specific sampling plan.

Step II: Determine the generic level of testing required (Level 1, 2 or 3)

The Landfill Directive sets out three principal levels of testing:

- ***Level 1: Comprehensive ('basic') characterisation***. *A thorough determination, according to standardised analysis and behaviour-testing methods, of the short and long term leaching behaviour and/or characteristic properties of the waste.*

  When monitoring MBT, the first step is to define the basic plant performance in line with the monitoring requirements laid out in sections 6 and 7 of this guidance. This should normally be carried out when the plant is operating at full capacity. If an alternative test to the BMc is proposed for onward monitoring, this alternative test should be included in the Level 1 characterisation programme. Some data collected during commissioning may possibly be included, for example, if correlation data between an alternative and BMc biodegradability tests has already been calculated and proven under conditions which mirror full-scale operations.

  Questions to be answered during Level 1 characterisation to ensure that performance data has been based on a valid monitoring schedule include:

  - Is the waste consistent or variable in quality?
  - What are the ranges of concentration of the parameters of interest as well as their average concentrations?
  - Which operational or time-related factors have the greatest effect on the quality of the landfilled outputs?

- ***Level 2: Compliance testing***. *Periodic testing by similar standardised analysis and behaviour testing to determine whether a waste complies with permit conditions and/or other specific reference criteria*. *The tests focus on key variables identified by Level 1.*

  For MBT processes the same waste streams should be sampled and tested but for a more restricted list of key parameters identified in Level 1. Where the process is stable, this may be at a lower frequency to provide data to calculate the quarterly characteristics of the MBT plant input and output waste streams based on a rolling estimate assessment. Level 2 monitoring can be based on an alternative test to BMc where sufficient correlation between this test and the BMc has been established.

- ***Level 3: On-site verification.*** *Rapid check methods to confirm that a waste is similar to that which has been subjected to compliance testing and as described in the accompanying documentation.*

  This should use simple and rapid monitoring checks of the MBT process plant parameters to provide sufficient, routine evidence that the plant is operating in a stable manner. This does not necessarily require any waste sampling, rather it should focus on parameters such as material flows, temperature and aeration profiles of composting stages, as well as biogas production from any anaerobic stages. In Level 3 monitoring the total weights of each input and output (not just those landfilled) should be recorded for reporting purposes.

Level 2 and 3 monitoring is defined in this guidance as onward compliance monitoring and is linked to the characterisation data produced under Level 1. However, should the composition of any waste stream change, for example, through a change in operations, or a change in the collection system, the Level 1 testing (that is, the intensive sampling, BMc testing and correlation with any alternative tests) should be repeated (figure 2.4). Resources allocated to understanding the key issues which affect the waste quality and consistency and links between inputs and outputs during characterisation will allow a significant reduction in onward compliance monitoring over time. The monitoring frequency in quarters 2 to 4 in the first year of monitoring will be dependent on the RSD of the 10 or 12 measurements of A_f made during the first quarter Level 1 testing. The monitoring frequency in subsequent years will be set by the RSD of the mean and SD of the A_f calculated for each quarter. (See Section 6.3).

In practice the mean waste characteristics determined during the initial Level 1 assessment would be used together with the Level 3 mass flow data to determine the adjustment factor for the initial quarter. Subsequent quarterly adjustment factors would be calculated on the basis of the samples collected in each quarter and Level 3 mass flow data for that quarter. Further specific details on the requirements for Levels 1, 2 and 3 monitoring for MBT are provided in sections 6 and 7.

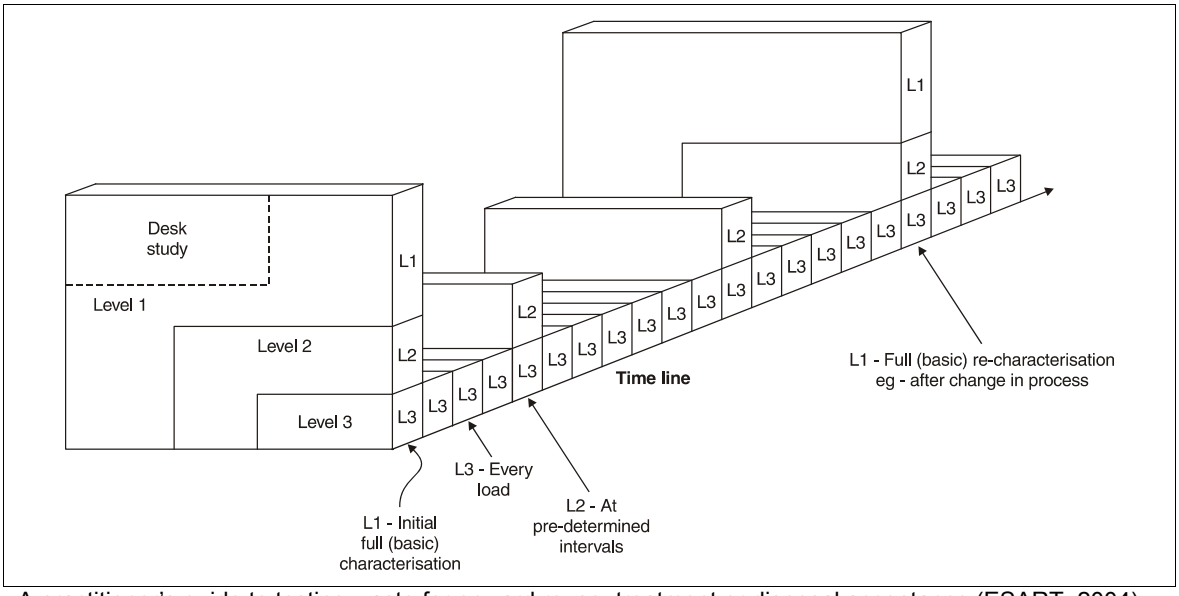
Step III: Determine the test parameters

The sampling plan should identify the parameters to be measured in any waste sample. These parameters should be linked directly with the objectives and goals identified in the monitoring plan.

Where the biogas production option is to be used, the biodegradability of the organic matter will also need to measured by the anaerobic BMc test or an alternative test that provides a high level of correlation (see annex B).

Step IV: Collate background information on the process to be sampled and waste arisings and identify health and safety precautions

The sampling plan should identify all necessary health and safety precautions that should be followed. A risk assessment should be carried out before any sampling and measures identified to protect, and minimise any risks to, those involved. Any organisation involved in sampling should have a health and safety policy that sets out the requirements of safe working. This guidance does not cover the necessary health and safety issues and separate, additional guidance on the requirements should be sought.



A practitioner's guide to testing waste for onward reuse, treatment or disposal acceptance (ESART, 2004).

Figure 5.3 The timeline for different levels of sampling and testing.

Step V: Develop the sampling approach

Consideration of the sampling approach is a key part in developing a sampling plan and includes giving due thought to a number of statistical criteria to ensure in particular that the size, type and number of samples taken will generate data with the required precision and that the resulting data are fit for purpose.

As a minimum, the steps in figure 5.4 should be followed in the development of any sampling approach. These requirements are expanded in sections 6 and 7.

Develop the sampling approach

Define the population to be sampled

Assess variability

Identify the scale

Choose the required statistical approach

Choose the desired reliability

↓

Determine the practical instructions

Choose the sampling pattern

Determine the increment/sample size

Determine the use of composite or individual samples

Determine required number of samples

Figure 5.4 Essential steps in the development of the sampling approach.

Step VI: Identify the sampling technique

The sampling technique is the physical procedure employed by the sampler to collect a representative sample of the waste for subsequent investigations. The sampling technique adopted depends on a combination of different characteristics of the material and circumstances encountered at the sampling location. These determining factors are:

- the situation at the sampling location/the way in which the material occurs (for example, in a lorry, a stockpile, on a conveyer belt);
- the (expected) degree of heterogeneity (for example, mixtures of solid materials); and
- the level of testing, which may influence the approach to the selection of composite or individual samples.

The issues guiding sample collection are elaborated in sections 6 and 7.

Step VII: Document and implement the plan

The sampling plan that evolves from the decisions outlined above should now be clearly documented and submitted to the Environment Agency as part of the overall monitoring plan submission. As a minimum the plan should record the information that will allow any results to be interpreted in an appropriate context and to allow a comparable programme to be repeated. A worked example of relevance to MBT process monitoring is provided in annex C.

6 Statistics for sampling MBT inputs and outputs

6.1 Statistical terms, their relevance to this guidance and their consideration

6.1.1 Population and scale

Population: Municipal waste is extremely heterogeneous and variable. The sampling plan should ensure any samples are representative of the waste about which information is needed (the population). For MBT monitoring, this is a 12-month measure of the inputs and outputs to the process. There also need to be sufficient samples to identify changes in municipal waste quality, particularly with time.

It is not feasible to sample all the waste going into the plant during the year to obtain this information. Using a statistical approach to sampling, we can ensure that any part of the population has an equal chance of being selected or sampled. Adopting this approach for MBT monitoring means that we can say that the data produced from a sample taken on only selected days (at the chosen scale of sampling) in the period of interest provides information on the entire population of waste (that is,, annual performance of the MBT).

Scale: The scale is the quantity (mass or volume) of material below which variations are judged to be unimportant. For MBT monitoring the scale is ‘a day’s input of waste’, and therefore variations in any characteristic of the waste within the volume/mass of waste received within the day are effectively of no concern. It follows that test data should be representative of average concentrations within the day. This issue is illustrated in figure 6.1. The variability of samples collected at a smaller scale,, for example, from single lorry loads, would be expected to be greater than a sample that is representative of all the lorries which arrived in any given day. For MBT monitoring, samples collected from individual loads across the selected day of sampling should be composited and thoroughly mixed together before taking a sample from this that is representative of the agreed scale of a day’s input and output of waste

6.1.2 Variability

Variability is a characteristic of the waste that cannot be changed without intensive manipulation of the waste. Its investigation is important because the more that is understood about the causes of variability affecting the material under investigation, the greater will be the opportunity for that knowledge to be exploited in designing the sampling programme; this is illustrated in figure 6.2.

The types and causes of any variability in the waste to be sampled should be understood and used to ensure sampling is appropriately targeted. The different types of variability that may need to be addressed include:

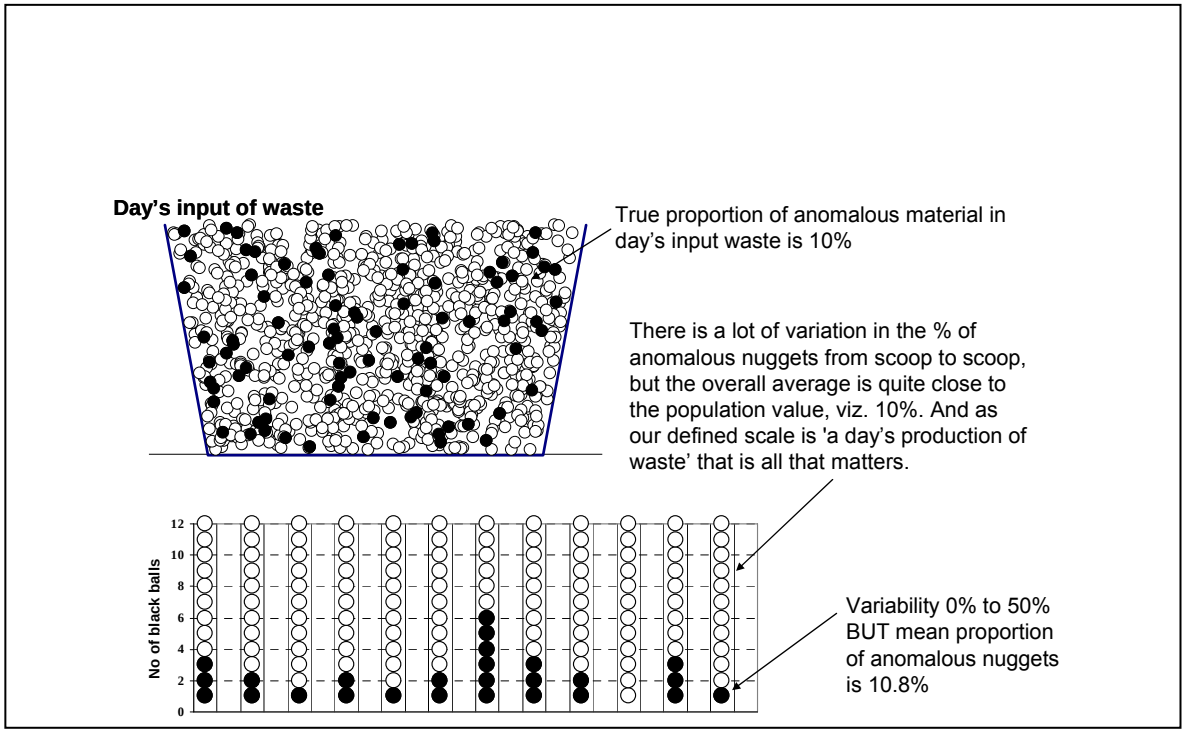


Figure 6.1 Illustration of importance of sampling at the prescribed scale.

- **Spatial variability:** this is commonly due to inadequate mixing. For example municipal waste collected from different collection rounds on the same day may differ in composition. This can be reduced by mixing, or through sampling of individual streams before mixing.

- **Temporal variability.** Most processes vary with time, for example, changes occur in the municipal waste, collection systems, the process, the operational efficiency of the plant, or some combination of these. The sampling programme should account for temporal variation. For example, where the day-to-day variation from a production process is greater than the variation within any given day, more information would be gained by sampling on as many different days as possible, rather than sampling on a single day.

Preliminary studies to determine how the waste varies with time are advisable so that the sampling plan accounts for any temporal variation, for example by sampling on different days rather than the same days each week/month.

6.1.3 Choose the required level of reliability

The reliability of a testing programme is a general term embracing three statistical concepts: bias, precision, and confidence.

Bias: a quantification of trueness –that is, the difference between the average value of the large series of measurements and the true value. A positive bias indicates an over-estimate and a negative bias indicates an under-estimate of the true value. Bias is thus equivalent to the total systematic error in the measurement.

Precision: a measure usually expressed in terms of imprecision and computed as a standard deviation of the test results. A lower precision is reflected by a larger standard deviation. The precision of a result is half the confidence interval (see below).

Confidence: the interval within which a particular population parameter may be stated to lie at a specified confidence level. The bounds of the confidence interval are termed the upper and lower confidence limits

The required level of reliability will depend on the objective of the programme, but the greater the reliability required, the greater the cost.

The average results from a sampling programme will rarely be equal to the true average of the population, because sampling introduces uncertainty (known as 'sampling error'). This uncertainty is quantified by the 'confidence interval' around the result. A confidence interval is specified at a level of confidence, such as 90 per cent.

This means that we can be 90 per cent certain that the true value for the population lies within the interval – or, if the sampling exercise were repeated an infinite number of times, the true figure would be within the confidence interval nine times out of 10. The precision of a result is half the confidence interval. A higher level of confidence, such as 95 per cent or 99 per cent improves the chances of the true value lying within the interval but, if no additional samples are collected, the confidence interval will be wider than it was for 90 per cent.

For a given level of confidence, two main factors influence the width of the confidence interval. The first is the number of samples or sampling events undertaken - the more samples that can be afforded, the better the precision will be. The second is the variability of the population - the more variable this is, the more samples will be required to achieve the required precision.

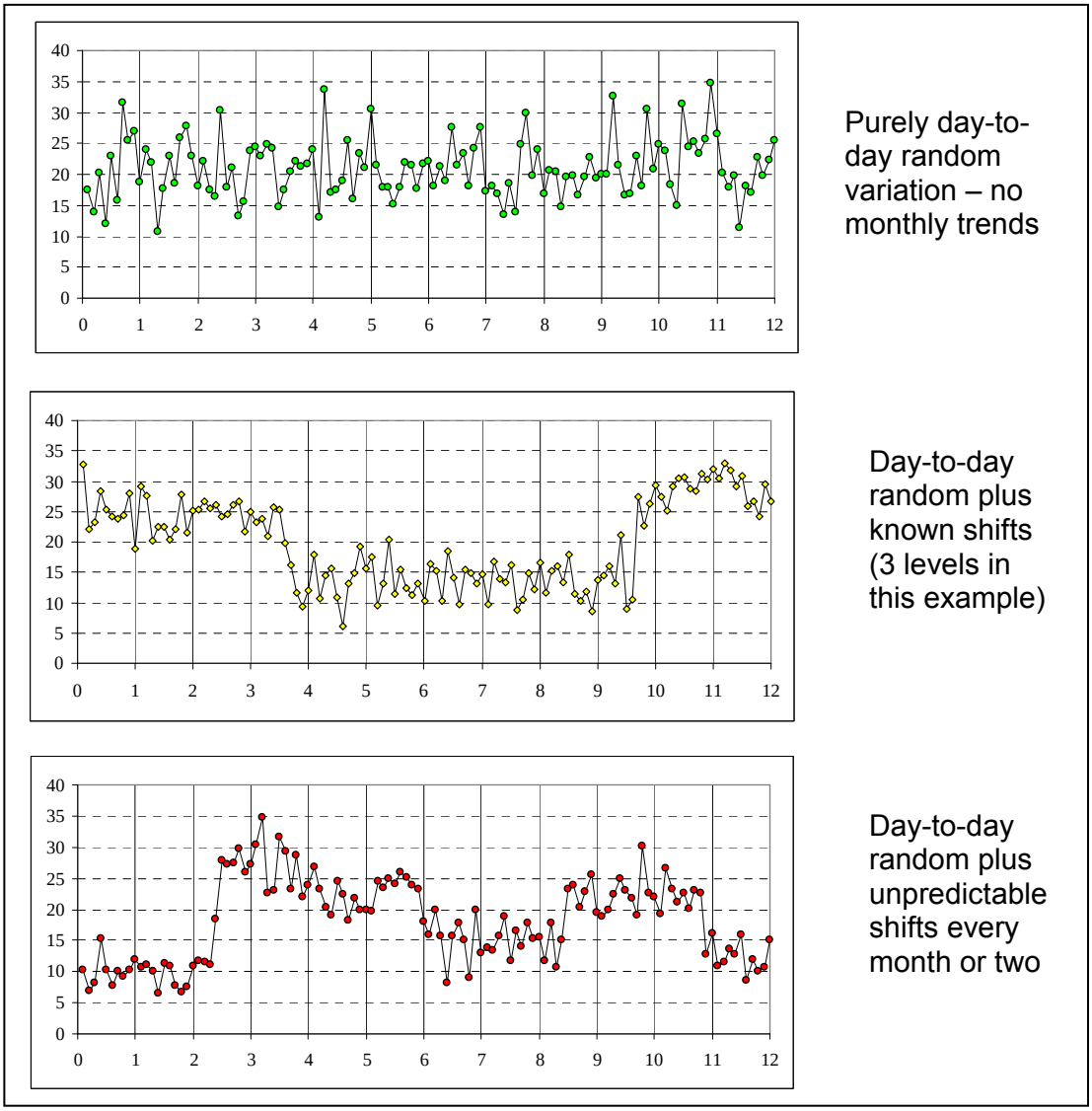
6.2 Sampling frequency

This section specifies the minimum number of samples and other monitoring required for Level 1 (comprehensive) and Level 2/3 (onward compliance) of an MBT process or plant.

6.2.1 Initial sampling frequency (Level 1)

At start-up there are limited data from plant commissioning or regarding the variability in the A_f with time, so a default sampling frequency is used initially to characterise the plant.

During the first three months of the plant is running under 'standard conditions', (normally stable, full-scale operation), the A_f should be estimated on five consecutive working days if the plant operates Monday to Friday, or six days if the plant operates Monday to Saturday, for two consecutive weeks at a randomly chosen start time. This will produce 10 or 12 estimates of the A_f that together capture the day-to-day and week-to-week variation in the A_f and can be used to estimate the mean A_f in the first quarter.



Note: Y axis represents data for a key analytical parameter and X axis months in an annual period.

Figure 6.2 Variability of the underlying population should be considered when scheduling sample collection.

The input should be sampled to determine the input BMW for the day and the output derived for each stream to be landfilled from that sampled input following processing to estimate the A_f of each output stream. All waste sampled should be analysed for LOI and, if calculating the A_f using the reduction in biogas potential, for biodegradability by both the BMc and any alternative test if one is proposed for onward monitoring.

In addition, the total monthly weight of each input and output should be recorded.

6.3 Ongoing sampling frequency (Level 2/3)

The data from the Level 1 initial characterisation are used to calculate the ongoing sampling frequency for Level 2 monitoring required both to estimate the quarterly mean A_f with adequate precision and confidence and to detect changes in the A_f with adequate power.

The required sampling frequency is determined by the temporal variability in the A_f over time; the greater the variability in the A_f, the greater will be the potential uncertainty in the estimated quarterly mean A_f, and the more samples will be required to reduce the uncertainty.

The temporal variability in the A_f over time is quantified by the relative standard deviation (RSD) of the 10 or 12 measurements of the A_f made during the Level 1 initial characterisation:

$$RSD(A_F) = SD(A_f) / mean(A_f)$$

where $SD(A_f)$ = the standard deviation of the A_f measurements.

The higher the RSD, the more variable the A_f, and the more frequently the plant will need to be sampled during Level 2. Following the guidelines on sample collection (section 7) will help to ensure that the RSD, and therefore the required sampling frequency, are as low as possible.

Table 6.1 gives the minimum sampling frequencies required to estimate the quarterly mean A_f with a precision of at least ±10 per cent at 90 per cent confidence. This means that one can be 90 per cent confident that the true (unknown) mean A_f is within ±10 per cent of the mean A_f estimated from the data. The required sampling frequencies also ensure that there is at least a 66 per cent chance of successfully detecting a change of 20 per cent in the A_f between quarters.

The number of samples for Level 1 and Level 2/3 onward compliance monitoring may need to be increased if subsequent statistical evaluation indicates that the monitoring does not provide an acceptable level of confidence in the results.

Table 6.1 Required sampling frequencies for Level 2 monitoring according to RSD A_f.

RSD of A_f	Sampling frequency (events per quarter)[1]
0.000 – 0.022	2
0.022 – 0.059	3
0.059 – 0.085	4
0.085 – 0.105	5
0.105 – 0.122	6
0.122 – 0.136	7
0.136 – 0.149	8
0.149 – 0.161	9
0.161 – 0.173	10
0.173 – 0.183	11
0.183 – 0.193	12[2]

[1] These requirements will be reviewed periodically by the Environment Agency as more monitoring data becomes available.

[2] It should be noted that the achievable precision will be worse than ±10 per cent if the RSD of the A_f is greater than 0.193. If the calculated RSD is equal to or greater than 0.193, a larger primary sample consisting of more than five grab samples or collection of a larger composite sample weight, should be taken to try and reduce sample variability.

Table 6.1 sets the sampling frequency for the remaining three quarters in the year. Having established the sampling frequency, samples should be collected on randomly selected working days throughout each three-month period.

The sampling frequency should be reviewed annually (that is, after 12, 14, 36 months and so on). On each occasion, the preceding 12 months of data should be used to update the RSD. To do this, first calculate the SD of the A_f in each quarter and the mean A_f in each quarter. The new RSD is then given by:

$$\text{RSD}(A_f) = \frac{\sqrt{\left(\sum SD(A_f)^2\right)/4}}{\sum Mean(A_f)/4}$$

The new sampling frequency to be used in the following year is then determined from table 6.1 as before.

Biogas production in Level 2 can be assessed using an alternative short form test to the BMc, providing that an acceptable correlation has been demonstrated in Level 1 (a correlation coefficient of at least 0.9 over the monitoring of 12 paired samples). This is conditional on the alternative test having a similar or lower RSD than the BMc test. If diversion is being assessed on the basis of a reduction in LOI there is no need to undertake the BMc test.

6.4 Changes to the adjustment factor

6.4.1 Why the adjustment factor may change

Step changes in the MBT reduction factor may occur due to:

- modification of the MBT plant, for example, by installation of new processing modules or changing the process operating conditions of the biological treatment stage;
- diversion of an MBT output from landfill; or
- changes in the input due to upstream changes in municipal waste collection systems.

Other changes may occur gradually because of:

- small or incremental changes in municipal waste composition;
- changes in the residual waste composition;
- “wear and tear’ of the MBT equipment, and
- minor adjustments to the MBT facility.

Some of the changes in process or input wastes may be sufficient to cause a substantial change in the calculated quarterly A_f. Any resultant change in the A_f needs to be calculated and action taken.

6.4.2 Calculating the quarterly A_f

The mean A_f in each quarter is estimated by averaging the A_f estimated on each of *n* sampling events (days) in that quarter:

$$\text{Mean } (A_f) = \frac{\sum A_f}{n}$$

6.4.3 Testing for a change in A_f over time

As part of the ongoing monitoring programme, the mean A_f should be checked to ensure that it has not changed.

To do this, the A_f in the first quarter is compared to the mean A_f in each subsequent quarter. (Note that this may detect seasonal changes which is correct where these have a substantial effect on the A_f).

The change in the mean A_f between two quarters is quantified by calculating a statistical function known as a t-value, which measures the difference in the mean A_f between the two quarters relative to the amount of temporal variability in the A_f during that time:

$$t = \frac{A_{f1} - A_{fx}}{SD_p}$$

where A_{f1} = the mean A_f in the first quarter, A_{fx} = the mean A_f in a subsequent quarter (x), and SD_p is the pooled standard deviation of the A_f, calculated as:

$$SD_p = \sqrt{\frac{(n_1 - 1)SD_1^2 + (nX - 1)SD_X^2}{n_1 + nX - 2} \times \left(\frac{1}{n_1} + \frac{1}{n_X}\right)}$$

where n_1 = the number of sampling events in the first quarter, n_X = the number of sampling events in the subsequent quarter, SD_1 = the SD of A_f measurements in the first quarter and SD_X = the SD of A_f measurements in the subsequent quarter.

To judge whether the magnitude of the change is statistically significant, compare the calculated t-value to the relevant critical t-value given in table 6.2. Ignore the sign (+ or -) of the calculated t-value (for example, -2.33 should be treated as +2.33).

If the calculated t-value is less than the critical t-value, then the change in the mean A_f is not statistically significant. In this situation, the mean A_f during the first quarter remains the baseline against which the mean A_f of subsequent quarters is compared. For example, if there is no change in the mean A_f between the first and second quarters, then the mean A_f in the third quarter is compared to that in the first quarter. If there is still no change then the mean A_f in the fourth quarter is compared to that in the first quarter, and so on. The baseline mean A_f remains in force until such time as a change is detected.

On the other hand, if the calculated t-value is greater than or equal to than the critical t-value, then the change in the mean A_f is regarded as statistically significant. When a significant change in the mean A_f is detected, the most recent quarter is taken as the new baseline, and subsequent quarters are compared to it. For example, if the mean A_f for the third quarter is significantly different from the mean A_f for the first quarter, then

the mean A_f for the third quarter becomes the new baseline and each subsequent quarter is tested against this. Note that a significant change in the mean A_f has no influence on the sampling frequency, which is set annually as described in section 6.3.

Table 6.2 Critical t-values to judge whether a change in mean A_f between two quarters is statistically significant[1].

		Number of samples in first quarter										
		2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Number of samples in subsequent quarter	**2**	4.30	3.18	2.78	2.57	2.45	2.36	2.31	2.26	2.23	2.20	2.18
	3	3.18	2.78	2.57	2.45	2.36	2.31	2.26	2.23	2.20	2.18	2.16
	4	2.78	2.57	2.45	2.36	2.31	2.26	2.23	2.20	2.18	2.16	2.14
	5	2.57	2.45	2.36	2.31	2.26	2.23	2.20	2.18	2.16	2.14	2.13
	6	2.45	2.36	2.31	2.26	2.23	2.20	2.18	2.16	2.14	2.13	2.12
	7	2.36	2.31	2.26	2.23	2.20	2.18	2.16	2.14	2.13	2.12	2.11
	8	2.31	2.26	2.23	2.20	2.18	2.16	2.14	2.13	2.12	2.11	2.10
	9	2.26	2.23	2.20	2.18	2.16	2.14	2.13	2.12	2.11	2.10	2.09
	10	2.23	2.20	2.18	2.16	2.14	2.13	2.12	2.11	2.10	2.09	2.09
	11	2.20	2.18	2.16	2.14	2.13	2.12	2.11	2.10	2.09	2.09	2.08
	12	2.18	2.16	2.14	2.13	2.12	2.11	2.10	2.09	2.09	2.08	2.07

[1] That is, there is only a 5 per cent chance that a change of that magnitude or larger could have arisen by chance.

The approach outlined above ensures that the A_f is reviewed on a quarterly basis and adjusted whenever there is a statistically significant change in the mean A_f.

Figure 6.3 shows a hypothetical application of the guidance to determine the required sampling frequency (top panel) and to assess the performance of the plant (bottom panel). (Note that setting the sampling frequency and assessing plant performance are two separate tasks, albeit based on common data).

In the upper panel, the sampling frequency is set a default of 12 in Q1, then reviewed after Q1, and revised to 6 per quarter for the remainder of the first year. It is then reviewed again at the end of Q4, when the sampling frequency for the following year will be set (section 6.3).

In the lower panel, the monitoring results in each quarter are used to compute a mean A_f (light diamonds). At the end of each quarter the mean A_f is compared with the current baseline A_f (dark diamonds) to assess whether there has been a change in plant performance (section 6.4.3). In this example, performance is not significantly different between Q2 and Q1, but the A_f jumps in Q3, making that the new baseline. Performance then remains steady in Q4 and Q5, but the mean A_f in Q6 is significantly lower than that in Q3, so the Q6 result becomes the new baseline.

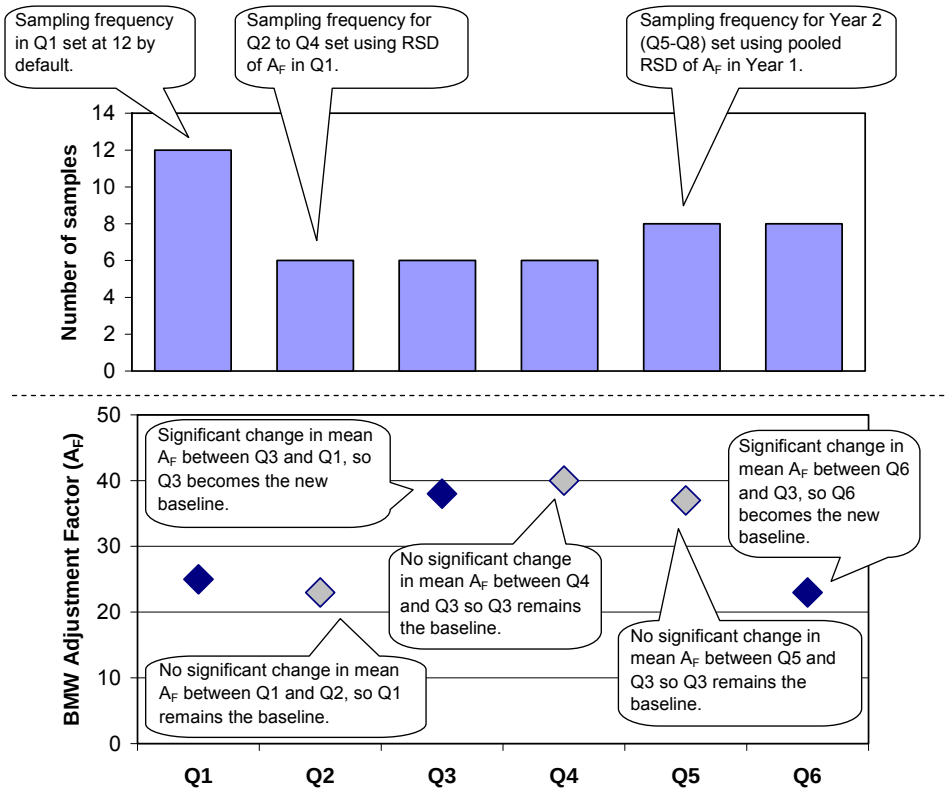


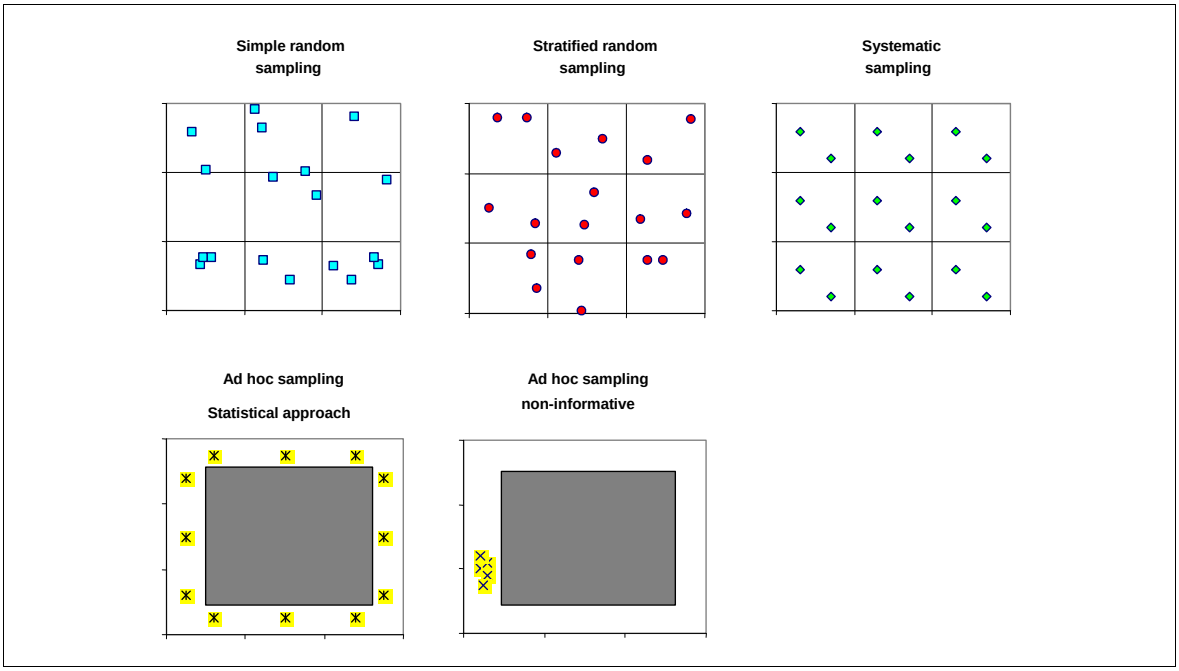
Figure 6.3 Example showing how to determine the required sampling frequency and assess the performance of the plant using change in A_f.

7 Practical considerations for sampling

Several additional, practical issues need to be considered before undertaking any sampling.

7.1 The sampling pattern

The sampling pattern defines where, when and how the required samples will be selected from the population. Figure 7.1 illustrates three potential approaches that could be used in probabilistic sampling, which is designed to avoid bias, and also shows two types of 'ad hoc' sampling, which will not produce unbiased information. Use of statistical sampling patterns to identify the loads to be sampled at random through the day avoids the need to sample every load. Each of the samples taken from an individual lorry should be of at least the minimum sample size required for the final composite sample as specified in section 7.3.1. These should then be mixed and the final sample collected for analysis. This approach ensures that each grab sample is representative of the load from which it is sampled.



After: ESART (2004).

NOTE: The figure illustrates possible sampling patterns for a two-dimensional spatial area. However, the concepts apply equally to sampling over time.

Figure 7.1 Some possible sampling patterns.

Figure 7.1 above illustrates different methods of sampling:

- Simple random sampling – although every part of the population has an equal chance of being sampled, the resulting samples will probably not be evenly spread across the population.

- Stratified random sampling – strata (sub-populations whose members are more similar) are identified within the population and specified numbers of samples are spread randomly within each stratum. The benefits of this approach are that all the strata are sampled adequately but the advantages of random sampling are retained.

- Systematic sampling – this is similar to stratified random sampling, except that the samples are taken at the same time or location from each of the identified strata. This can lead to bias if there is a systematic component of variation within the process that runs in step with the chosen sampling interval.

- Judgemental sampling – this approach is unacceptable, because it may result in bias and the size of the statistical sampling error of the sample cannot be determined. It only works where the waste is both homogeneous and consistent.

7.2 Determining the sample weight or volume

7.2.1 Types of sample and their meaning in this guidance

The following types of sample and sampling activity are used to describe the procedures used to collect a sample for onward testing:

- *a grab sample* is an initial large, snapshot sample collected from a specified load of waste or from a conveyor at specified intervals during operation;
- a *composite sample* is a combination of a number of grab samples, which should be thoroughly mixed;

- a *primary sample* is a composite made up from all the grab samples of the particular waste *stream* collected during the specified time period (scale of sampling); and

- an *increment* is used here to describe the smaller sub-samples which are taken from the primary *sample* to produce the *laboratory sample* for onward testing. This procedure is elaborated further in the next section.

7.2.2 Sample collection

The objective of each sampling event should be to obtain a sample that is representative of the input or output waste stream(s) on that particular day (the specified scale of sampling). The procedure employed to collect a representative

sample of the waste will depend on the characteristics of the waste and the circumstances at the sampling location. These are:

- the layout of the sampling location/the way in which the material is presented (for example, in a lorry, a stockpile, on a conveyer belt);

- the (expected) degree of heterogeneity (such as the variability in different component materials); and

- whether or not there is a need to establish within-day variability of the waste (this might be relevant if a plant accepts waste from more than one source and calculation of LATS diversion is required for each). This is more frequently required under Level 1 when sub-samples may be analysed separately. In Level 2, it is usually sufficient to produce a composite sample to compare with previous data.

When the output samples that correspond to the input samples need to be collected will depend on the process residence time..

Production of the primary sample:

- A representative primary sample will consist of several grab samples, either randomly selected or at predefined time periods throughout the operational day. The equipment used to take the grab sample should always have a larger capacity than the largest sized item within the material to be sampled. In the case of unshredded municipal waste this means using a loading shovel, mechanical excavator or similar heavy plant.

- It is generally better to sample a waste while it is being moved and is accessible, for example, on a conveyor, in a falling stream or during transfer of material from a stockpile to a conveyor. This allows access to the whole day's input or production of waste thus ensuring unbiased sampling.

- If the waste to be sampled is discharged into a bin, skip or trailer then it is also important to sample all the material from different depths and not just the most accessible. The best approach is to take grab samples at set intervals as the containers are being filled. If this is not practical, the waste should be well mixed and a larger grab sample taken which should again be thoroughly mixed prior to sub-sampling.

- Grab samples should not be taken from a conical pile where the waste has been discharged above the pile without mixing. This is because as the material is discharged and cascades down the pile, it can become segregated by differences in the size, shape and density of the particles. If it is necessary to sample from a 'static' stockpile then the pile should be thoroughly mixed and spread out over as large an area as practicable to allow full access to the waste.

- If the waste is in discrete loads, each load to be sampled should be discharged onto a clear area and then mixed and turned with a front-end loader or similar equipment, prior to collection of a large grab sample from this mixed waste. This should be repeated for every load to be sampled across the day's operation and the grab samples combined to form a single, primary sample. If the waste stream is not in discrete loads, take at least ten grab samples at pre-determined intervals (either regular or

random) throughout the day. Grab samples from a conveyor should cover the full width of the conveyor.

Each grab sample should be of sufficient size to include the largest item and should also meet the minimum weight requirements for each stream detailed in table 7.1. The grab samples should be combined to form a single primary sample.

Production of the laboratory sample: Sub-sampling of a primary sample is best carried out by systematic sampling. Mix the primary sample thoroughly using a front-end loader and spread the material out into an approximate square. Divide the square into notional quarters and take similar-sized increments from each quarter until the combined weight is at least the sample weight specified in table 7.1. This is the sample for onward testing and is referred to as the laboratory sample. Where the composite sample fills more than one receptacle it should still be treated as being a single sample.

7.2.3 Collection, delivery and storage of samples

The collection of samples and their delivery to the laboratory are described below and are listed in table C2 (annex C) in a form that can be used as an on-site checklist.

Sample containment: The purpose of the sample container is to protect the sample during transport and storage until it is preserved or analysed. The container should not be made from materials which may react with, or otherwise contaminate, a sample. Scientific advice should be sought, usually from the receiving laboratory, regarding the type and size of sample(s) and container(s), preservation method(s), maximum storage time prior to analysis, and the appropriate labelling system. In general, the storage period should be as short as possible.

For MBT monitoring, the use of large sealable high-density polyethylene (HDPE) dustbins or containers is generally appropriate. Once the details have been agreed with the laboratory, they should be included in the sampling plan.

Sample labelling: Each container should be labelled with all the information necessary for unequivocal identification of the sample. Give each sample container a legible, unique, unambiguous code, either by writing directly on to the container using a permanent marker pen, or by writing on an adhesive label and sticking it to the sample container. Attach a label to the main body of the container in addition to any attached to the lid, top or cap of the container. Where a label might become detached, for example, as a result of condensation, place the labelled container in a sealed plastic bag.

Any third party should be notified of any hazardous substances in the sample.

Sample preservation and storage: Ideally, samples should be analysed immediately after collection. When this is not possible, the sample should be preserved. The preservation method will depend on the nature of the waste, the components to be determined and the length of time between collection and analysis. If the sample is biologically active, storage should minimise loss or change (chemical or biological) of any constituents. In particular it should inhibit photochemical reactions, changes in the chemical nature of certain substances due to changes of temperature or pressure, loss of the vapour phase, modification of the pH, conductivity, solubility and carbon dioxide absorption from the air and reaction with carbon dioxide or water.

Where biological degradation is likely to occur, the time between sampling and preparation for analysis should be kept to a minimum and should never exceed seven

days. Appropriate methods of storage of relevance to MBT inputs and outputs include dark, cool storage (4 ± 2°C). If there is to be any significant period between collection and drying, the sample should be frozen. Following compositional sorting, the sample should be dried at 70°C to minimise further changes in the sample. Note samples which require compositional analysis for volatile metals such as mercury or other organic parameters should be air dried at 30°C or less to minimise loss of volatiles.

Information on sample preparation prior to testing is given in annex A with each analytical method.

7.3 Size of the laboratory sample

Each laboratory sample should be sufficiently large to allow the percentage BMW of the input or output waste stream on that day to be determined with the required level of precision. The minimum sample weight required depends on several factors:

Variability of different wastes – waste that has been processed has probably been separated, mixed and shredded. This will tend to even out within-day variations. A smaller sample of processed waste should give the same precision as a larger sample of unprocessed waste.

% BMW content – The within-day variation in the waste stream peaks when the %BMW content reaches 50 per cent, and approaches zero as the %BMW content nears zero per cent or 100 per cent. Waste streams with a moderate %BMW content therefore require larger sample weights than waste streams with very low or very high %BMW content.

Moisture content –The higher the moisture content, the lower the proportion of dry matter in the waste. As it is the dry matter content of the BMW that is analysed (for example, for its LOI content), wastes with a higher moisture content will require a larger sample.

Particle size – The smaller the particle size, the greater the number of particles per unit weight. Precision generally improves as the number of particles in the sample increases. Therefore fine materials generally require smaller sample weights than coarse materials to achieve similar precision.

7.3.1 Recommended minimum sample weights

Table 7.1 recommends minimum sample weights (in kg) for waste MBT inputs and outputs. These weights draw on the best available information - partly from empirical studies and partly from practical experience with the type of materials associated with MBT processes.

The reference values are the sample weights (in kg) for waste with a BMW content of <30 per cent or >70 per cent and low (<50 per cent) moisture content. Sample weights for waste with other characteristics can be calculated using the multiplication factors. For example, a batch of large screening reject material with a BMW content of 60 per cent, a moisture content >50 per cent and a particle size >100 mm would require a sample weight of 50 kg x 2 x 2 x 2 = 400 kg.

The recommended minimum sample weights given in Table 7.1 should be used in

conjunction with the recommended sampling frequency detailed in sections 6.2 and 6.3.

Table 7.1 Default minimum sample weights (kg) for materials of varying characteristics.

Material	Reference Value (kg)	BMW (%)			Moisture (%)		Particle size (mm)		
		<30	30-70	>70	<50	>50	<20	20-100	>100
Black bag input municipal waste	**100**	x1	x2	x1	x1	x2	N/A	N/A	N/A
Shredded input municipal waste	**50**	x1	x2	x1	x1	x2	N/A	N/A	N/A
Large screening reject	**50**	x1	x2	x1	x1	x2	N/A	x1	x2
Small screening reject/fines	**5.0**	x1	x2	x1	x1	x2	x1	x2	N/A
Solid recovered fuels (SRF)	**2.5**	x1	x2	x1	x1	x2	x1	x2	X4
Compost like output (CLO)	**2.5**	x1	x2	x1	x1	x2	x1	x2	N/A

N/A = not applicable

7.4 Independent sampling and reporting

7.4.1 Independent sampling

Sampling the MBT plant for both Level 1 and Level 2/3 monitoring should include some samples taken by an independent body. The identification of samples taken by the independent body should be noted on the sample analysis data submitted to the Environment Agency.

The minimum number of samples that should be taken by an independent body are:

Level 1 monitoring: four samples of input and four samples of every output landfilled during the Level 1 monitoring quarter.

Level 2/3 monitoring: one sample of input and one sample of every output landfilled per quarter.

7.4.2 Laboratory accreditation

Laboratories carrying out analysis of MBT-derived samples for the determination of the amount of BMW landfilled in MBT outputs should provide evidence of acceptable quality control and quality assurance for the results. Laboratories should aim to gain UKAS (United Kingdom Accreditation Service) accreditation for the BMc test on waste matrices.

7.4.3 Reporting monitoring data to the Environment Agency

Contacting the Environment Agency

For England, enquiries, proposed monitoring plans and quarterly monitoring data should be sent to: LATS@environment-agency.gov.uk. For Wales the relevant contact details are: LAS@environment-agency.gov.uk.

Or telephone the National Customer Contact Centre (NCCC) 08708 506 506 and ask for a member of the LATS or LAS team as appropriate..

Reporting Level 1 comprehensive monitoring

The following monitoring data should be reported in Level 1:

- Monthly weight of each municipal waste input.
- Monthly weight of each output (whether or not it is landfilled).
- The mean percentage BMW, DM and LOI of all linked input and landfilled output samples and the calculated standard deviation.
- The mean BMc and any alternative test chosen for all input and landfilled output and the calculated standard deviation.
- If an alternative test has been chosen for onward compliance monitoring, the correlation between it and the BMc test.
- The calculation steps and calculated mean adjustment factor (A_f) for the Level 1 monitoring quarter.
- The calculation steps for and calculated tonnes BMW_O landfilled for the first quarter.

Reporting Level 2/3 compliance monitoring

The minimum requirements for quarterly reporting of the Level 2/3 compliance monitoring data and subsequent calculations are as follows:

- Monthly total weight of each municipal waste input.
- Monthly total weight of each output (whether or not it is landfilled)..
- The mean percentage BMW, DM and LOI of all input and landfilled output samples, and the calculated standard deviation.
- The mean BMc results (minimum one per quarter) and the results of any alternative test for all input and landfilled output samples and the calculated standard deviation if more than one sample is taken.
- The calculation steps and calculated mean adjustment factor (A_f) for the MBT for the current Level 2/3 monitoring quarter.
- The calculation steps and outcome of the test for change in the A_f baseline (section 6.4).

- The calculation steps for and calculated tonnes BMW_O landfilled for the quarter for the current Level 2/3 monitoring quarter.

How we will handle the reporting delays due to testing

The results for the waste inputs and their linked outputs will be used to calculate the adjustment factor which will then be linked with the quarter's figures relating to the outputs for the quarter to determine the tonnes of BMW landfilled.

Where the BM_C test is used to determine biodegradability, the results for any quarter's sampling are unlikely to be available until after the end of the following quarter. Wherever possible the data will be entered into WasteDataFlow retrospectively, after the end of the following quarter, to try and ensure that the results used and the adjustment factor we calculate relate to the relevant throughputs and processing times.

8. Worked examples for BMW reduction calculations

8.1. Calculation of BMW landfilled following MBT or similar treatment for the initial quarter comprehensive Level 1 monitoring

The Level 1 monitoring is applied in the initial first quarter of the MBT following start-up. The data collected is used to calculate an adjustment factor (A_f) for each batch of linked input (s) and output (s) and hence a Mean adjustment factor (A_f) for the quarter.

The mean adjustment factor is then multiplied by the total tonnes of all landfilled outputs and the proportion of BMW input to the MBT plant derived from WDF (RB%/100) in order to calculate the tonnes of BMW landfilled in any MBT outputs (t BMW_L).

tonnes BMW_L = Σ tonnes $landfilled_{all\ outputs}$ x Mean A_f x (RB% /100)

Note that tonnes RB% used for the calculation is calculated in WDF.

Treatment changes the amount and characteristics of the biodegradable waste in each BMW-containing stream landfilled compared with the BMW of the untreated input. Some BMW may be diverted from landfill so that the BMW_O in each stream landfilled is only part of the input BMW, or it may have been dried or wetted, and may have lost some of its organic matter content due to microbial decomposition during any biological treatment. These changes will lead to reduction in the organic matter content (LOI reduction option) or reduce both the organic matter content and the biodegradability of the treated BMW (biogas production option).

BMW_O for LATS or LAS is not the weight of BMW sent to landfill but is corrected for the reduction in LOI or biodegradability and is independent of any differences in moisture content relative to the input, BMW_I.

The primary objective of monitoring a treatment process is to determine the total amount (in tonnes) of BMW sent to landfill (tonnes BMW_O) that is derived from the input BMW to the MBT in any quarter.

In practice, there may be a significant delay between the arrival of the input BMW to the MBT and the production of the MBT output, for example, if the MBT has an extended composting phase lasting several weeks. Also there may be a delay between the production of the MBT output and its actual landfilling if the output is stockpiled for any period prior to landfilling. These delays may mean that the actual landfilling of the MBT output may not take place in the same quarter as the MSW arrives as input to the MBT plant.

The input and output mass flow data for each quarter would be used with either the first quarter baseline mean A_f factor or mean A_f for the quarter in question if a change has been detected using the methodology outlined in section 6.4 and the baseline has been reset to calculate the BMW diversion for each quarter. Where outputs are landfilled in a

subsequent quarter, calculated diversion will be based on the quarter's waste input and the linked output mass flow data, which may be produced in a subsequent quarter and may therefore mean a correction of previous quarter's data is required.

8.1.1. Calculation of the adjustment factor based on LOI reduction option

The basis of the calculation is that the amount of biodegradable waste (measured as tonnes LOI) in the input and any landfilled outputs are estimated. Where more than one output is landfilled, the LOI is weighted according to the proportion of each output (based on mass flows) and the total tonnes of LOI landfilled is then calculated from the sum of the tonnes LOI landfilled in each output. This LOI value and the percentage BMW content of the input is then used to calculate the adjustment factor (A_f) for the MBT and hence the tonnes BMW output landfilled by the MBT plant.

Calculation of the proportion of LOI of the biodegradable fraction of the MBT input:

$LOI_I = (\%BMW_I /100) \times (\%DM_I/100) \times (\%LOI_I/100)$

This needs to be calculated for each input to derive the proportional ratio of each input.

Calculation of the proportion of LOI of the biodegradable fraction of the MBT outputs landfilled:

If more than one output stream is landfilled then the calculation is carried out on each output.

$LOI_O = \%BMW_O/100 \times \%DM_O/100 \times \%LOI_O/100$

Where more than one output is landfilled, a weighting is applied to each output which represents the ratio of that output to the overall total landfilled. This weighting is calculated using the following equation:

Weighted LOI per output = $LOI_{\text{per output}}$ x (tonnes landfilled $_{\text{per output}}$ / Σ tonnes landfilled $_{\text{all outputs}}$) (where tonnes landfilled is the weight of outputs landfilled)

Calculation of the adjustment factor:

The adjustment factor (A_f) for each batch of linked input (s) and outputs and the mean A_f for the quarter is then calculated from:

$A_f = LOI_O / LOI_I$ (for one input and output only), or

A_f = Σ weighted LOI of all outputs / LOI_I (for more than one output)

If there is more than one input, then

the A_f = Σ weighted LOI of all outputs / Σ LOI of all inputs

Mean $A_f = \Sigma A_{f(ALL)} / n$ where n is number of sampling events in the quarter

Calculation of tonnes BMW_O in outputs landfilled:

The tonnes BMW_O landfilled for the quarter is then calculated from:

tonnes BMW_L = Σ tonnes landfilled $_{\text{all outputs}}$ x Mean A_f x (RB% /100)

8.1.2. Calculation of the adjustment factor based on change in biogas production option

The change in biogas production option for monitoring the MBT requires the same data as used for the LOI reduction together with the anaerobic biodegradability (potential biogas production, l/kg LOI) of the input and output materials landfilled. The calculation of the adjustment factor is now based on calculating the potential biogas production (in l/kg LOI) of the MBT input and landfilled outputs.

The change in biogas production option can be used in cases where the anaerobic biodegradability has been determined directly by the BMc test or estimated from a correlation between the BMc test and an accepted alternative biodegradability test. Correlation data should have been previously submitted to the Environment Agency as part of the monitoring plan.

Calculation of the proportion of potential biogas produced by the biodegradable fraction of the MBT input:

The anaerobic BMc reports biodegradability in the units of l biogas/kg LOI.

The potential biogas (BG_I) from the MBT input is then calculated from:

$BG_I = LOI_I \times BMc_{(I)}$

where the LOI_I has been calculated as described in section 8.1.1 above. Where there is more than one input this calculation must be done for each input.

Calculation of the proportion of potential biogas produced by the biodegradable fraction of the MBT output landfilled:

The potential biogas for the MBT output landfilled (BG_O) is similarly calculated from the BMc test result and the LOI_O for the MBT output landfilled, as follows:

$BG_O = LOI_O \times BMc_{(O)}$

where the LOI_O has been calculated as described in section 8.1.1 above.

If more than one output stream is landfilled, then the calculation is carried out on each output landfilled.

Where more than one output is landfilled, a weighting factor is applied to each output which represents the ratio of that output to the overall total landfilled. This is calculated using the following equation:

Weighted BG = BG per output x (tonnes landfilled $_{\text{per output}}$ / Σ tonnes landfilled $_{\text{all outputs}}$) (where tonnes landfilled is the actual weight of outputs landfilled).

Calculation of the adjustment factor

The adjustment factor (A_f) for each batch of linked input (s) and outputs and the mean A_f for the quarter is then calculated from:

$A_f = BG_O / BG_I$ (for one output only)

A_f = Σ weighted BG of all outputs / BG_I (for more than one output)

That is, A_f = Σ weighted BG of all outputs / Σ BG_I all inputs

Mean $A_f = \Sigma A_{f(ALL)} / n$ where n is number of sampling events in the quarter

Calculation of BMW_O in outputs landfilled:

The tonnes BMW_O landfilled for the quarter is then calculated from:

t BMW_L = Σ tonnes $landfilled_{all\ outputs}$ x Mean A_f x (RB% /100)

8.1.3. Calculation of BMW_O landfilled based on change in biogas production and alternative biodegradability test

The biodegradability of the MBT input and landfilled output streams may have been determined by an agreed, alternative biodegradability test that is sufficiently correlated with the anaerobic BMc test (such as the aerobic DR4 biodegradability test). In this case the alternative biodegradability test results are converted to BMc test result values using the correlation between the two tests. The calculations are then carried out as described in section 8.1.2 above.

Further guidance on the application of alternative biodegradability tests is given in annex B.

8.2. Example calculation of BMW landfilled in MBT outputs from initial comprehensive Level 1 monitoring data

This example calculation is based on a hypothetical MBT process treating 10,000 tonnes of municipal waste during Level 1 monitoring and producing two MBT outputs (A and B) that are both landfilled.

The tonnes of BMW sent to the MBT plant (tonnes BMW_I) is taken directly from WasteDataFlow as 6500 tonnes (i.e, RB% = 65 per cent BMW).

8.2.1. Data collected from monitoring

The data in table 8.1 are for one linked batch of samples collected during Level 1 monitoring. In this case biodegradability testing was carried out by the BMc and rapid DR4 test. Where more than one sampling event occurs in the quarter, an A_f will be calculated for each batch of linked samples and a mean A_f derived from an average of all the calculated A_f values (see section 6.4.2).

Table 8.1 Example value for data collected from Level 1 monitoring.

Data	Units	MBT Input	MBT output A	MBT output B
Tonnes wet weight of municipal waste	tonnes	10,000	2,000	1,000
Percentage wet weight of biodegradable waste (BMW) fraction of the municipal waste	%BMW	67*	50	40
Percentage dry matter (DM) content of BMW fraction	%DM	50	70	70
Percentage organic matter (LOI) of the dry matter content of the BMW fraction	%LOI	70	40	50
Anaerobic biodegradability (BMc test) of the BMW fraction.	Litres /kg LOI	400	100	160
Alternative biodegradability test of the BMW fraction. (DR4 test for this example)	g O /kg LOI	250	50	80

* Note this is a measured value from the compositional analysis of the sample and not the RB% from WasteDataFlow..

8.2.2. Calculation of landfilled BMW based on LOI reduction

Proportion of LOI of the BMW of the MBT input (calculated as LOI_I)

= 67/100 x 50/100 x 70/100 = 0.235

Proportion of LOI of the BMW of MBT output A ($LOI_{O(A)}$)

= 50/100 x 70/100 x 40/100 = 0.14

Weighted LOI of the BMW of MBT output A (weighted $LOI_{O(A)}$)

= 0.14 x 2000/ (2000+1000) = 0.093

Proportion of LOI of the BMW of MBT output B ($LOI_{O(B)}$)

= 40/100 x 70/100 x 50/100 = 0.14

Weighted LOI of the BMW of MBT output B (weighted $LOI_{O(B)}$)

= 0.14 x 1000/ (2000+1000) = 0.047

Total proportion of organic matter landfilled from MBT outputs (total weighted LOI_O)

= weighted $LOI_{O(A)}$ + weighted $LOI_{O(B)}$ = 0.093 + 0.047 = 0.14

Adjustment factor (A_f) = Σ weighted $LOI_{O(all)}$ / LOI_I = 0.14/0.235 = 0.597

Mean adjustment factor (A_f) for this quarter

= Σ A_f /n = 0.597/1 = 0.597

The tonnes BMW in the MBT outputs sent to landfill (tonnes BMW_L)

= Σ tonnes $landfilled_{all\ outputs}$ x Mean A_f x (RB% /100)

= (2000+1000) x 0.597 x (65/100) = 1164t

8.2.3. Calculation of landfilled BMW based on change in biogas production

This example uses the BMc values from table 8.1 above. If an alternative biodegradability tests had been used that correlated with the BMc test, the alternative test results would provide BMc values via the correlation. The DR4 values in table 8.1 give the same BMc values as for the direct BMc test results when the default DR4-BMc correlation is applied (annex B).

The proportion of potential biogas produced by the BMW of the MBT input (BG_I)

= LOI_I x $BMc_{(I)}$ = 0.235 x 400 = 93.8 l/kg

The proportion of potential biogas produced by the BMW of the MBT output A ($BG_{O(A)}$)

= $LOI_{O(A)}$ x $BMc_{(O/A)}$ = 0.14 x 100 = 14 l/kg

Weighted proportion of potential biogas produced by the BMW of MBT output A (weighted $BG_{O(A)}$)

= 14 x 2000/ (2000+1000) = 9.333 l/kg

The proportion of potential biogas produced by the BMW of the MBT output B ($BG_{O(B)}$)

= $LOI_{O(B)}$ x $BMc_{(O/B)}$ = 0.14 x 160 = 22.4 l/kg

Weighted proportion of potential biogas produced by the BMW of MBT output B (weighted $BG_{O(B)}$)

= 22.4 x 1000/ (2000+1000) = 7.467 l/kg

Total proportion of potential biogas for MBT outputs landfilled (Σ weighted BG_O)

= weighted $BG_{O(A)}$ + weighted $BG_{O(B)}$ = 9.333 + 7.467 = 16.8 l/kg

Adjustment factor (A_f)= Σ weighted BG_O/BG_I = 16.8/ 93.8 = 0.179

Mean adjustment factor (A_f) for this quarter

= Σ A_f /n = 0.179/1 = 0.179

The tonnes BMW in the MBT outputs sent to landfill (t BMW_L)

= Σ tonnes $landfilled_{all\ outputs}$ x Mean A_f x (RB% /100)

= 3000 x 0.179 x (65/100) = 349 tonnes

8.3. Calculation of BMW in landfilled MBT outputs during onward Level 2 and Level 3 compliance monitoring

The initial comprehensive Level 1 monitoring will have established the MBT plant performance and the initial adjustment factor for the MBT output landfilled over the three-month period. This would be applied until a significant change in plant performance had occurred and the baseline is reset.

Level 2 /3 compliance monitoring would be applied to estimate the adjustment factors following the Level 1 monitoring. If a change in the quarterly mean A_f is detected, this would be taken as the new baseline for estimation of the BMW diversion and used for successive quarters until a change is detected between that value and a subsequent quarter. At the end of the first year of monitoring, a new A_f factor and baseline is calculated as outlined in section 9 and this may require a change in monitoring frequency.

8.4. BMW reduction calculation with two or more inputs to a process

Mechanical biological treatment and similar processes may have more than one input source. If all the inputs contain BMW, the calculation of the adjustment factor for the MBT needs to be based on the sum of the biodegradable waste for all the inputs (whether the MBT adjustment factor is based on LOI or potential biogas production). If one of the inputs is composed of biodegradable waste that is not from a municipal waste source, then once the different waste sources (municipal and non-municipal waste streams) have been mixed, it will not be possible to differentiate BMW from other biodegradable waste in the MBT outputs. An approach is therefore required to estimate the percentage of the treated BMW_O in such mixed source outputs so that the MBT adjustment factor relevant to BMW treatment can be calculated.

The principle applied is to determine the percentage contribution of the particular input stream to the biodegradable content of the total input stream. This may be in terms of either LOI or as potential biogas depending on which monitoring option is chosen. The same percentages are then applied to any output streams to apportion the contribution in the output stream to the LOI or potential biogas production from the non-municipal waste stream.

8.4.1. Situation where all inputs contain BMW

If the inputs are all municipal waste from different WDAs, they will almost certainly vary in the amount and type of BMW present and will therefore have to be sampled, analysed and assessed separately for LATS and LAS. The landfilled outputs will be sampled and the adjustment factor for the plant determined from the sum of the input streams and the landfilled output streams. This adjustment factor is then applied to the RB% from WasteDataFlow (WDF) for each WDA.

Example

This example is for an MBT process where the inputs are from three different WDAs and there is only one output landfilled. The WDAs need to know the BMW landfilled for each of their input streams and the calculation is based on LOI reduction only (figure 8.1).

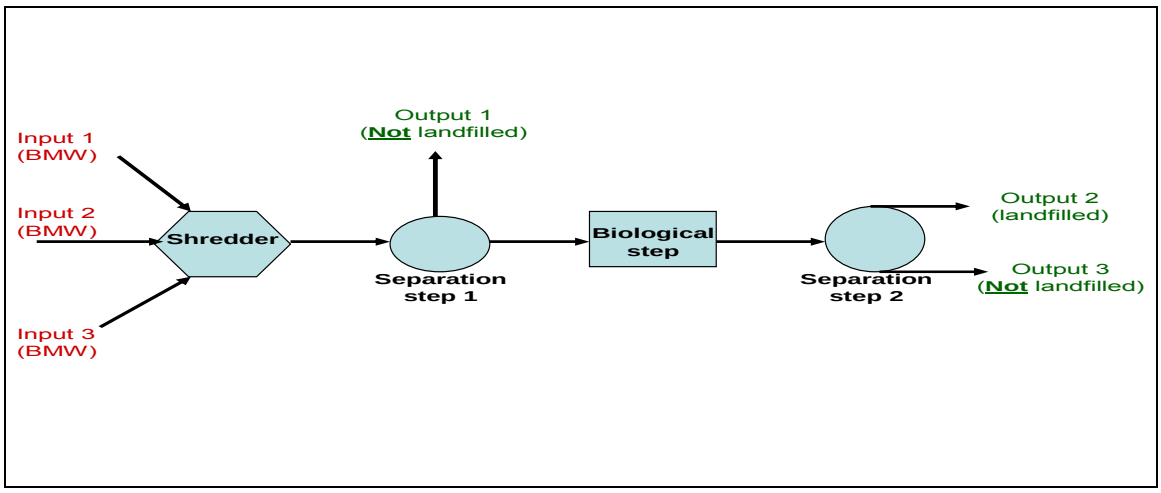


Figure 8.1 Schematic of MBT plant where all three inputs are derived from municipal waste.

The characteristics of all the inputs and landfilled output are shown in Table 8.2. The mass flow for inputs and outputs are for a linked set of samples and were taken in within the quarter.

Table 8.2 Calculation of adjustment factor and BMW landfilled for MBT with 3 BMW-containing inputs from different WDAs.

Data	Units	Total MBT input	MBT Input 1 (WDA 1)	MBT Input 2 (WDA 2)	MBT Input 3 (WDA 3)	MBT Output 2 landfilled
Tonnes wet weight of municipal waste sent to MBT in quarter	Tonnes	10000	2000	4000	4000	3000
Residual biodegradable percentage from MBT plant (from WasteDataFlow)	%		70	70	65	
Tonnes BMW sent to MBT from each WDA.	T $BMW_{I\ (WDF)}$		1400	2800	2600	
Percentage wet weight of BMW fraction of the municipal waste	%BMW		70	60	65	40
Percentage DM content of BMW fraction	%DM		50	45	55	70
Percentage LOI of the DM content of the BMW	%LOI		70	75	80	50

The proportions of LOI in each of the inputs ($LOI_{I(WDA)}$) are calculated from their respective %BMW, DM and LOI contents. As there is more than one input stream

source, the calculation is carried out on each input and the total ratio of LOI landfilled is calculated from summation of the results.

$LOI_{I(WDA)} = \%BMW_{I(WDA)}/100 \times \%DM_{I(WDA)}/100 \times \%LOI_{i(WDA)}/100$

$LOI_{I(WDA1)} = 70/100 \times 50/100 \times 70/100 = 0.245$

$LOI_{I(WDA2)} = 60/100 \times 45/100 \times 75/100 = 0.2025$

$LOI_{I(WDA3)} = 65/100 \times 55/100 \times 80/100 = 0.286$

The total proportion LOI is then estimated from the sum of the individual MBT input LOI:

Total LOI_{all} inputs $= LOI_{I(WDA1)} + LOI_{I(WDA2)} + LOI_{I(WDA3)}$

$= 0.245 + 0.2025 + 0.286 = 0.7335$

Each input is also weighted according to the BMW contribution of that input to the overall total landfilled. This weighting is calculated using the following equation:

Weighted LOI per input = $LOI_{per\ input}$ x (t mass flow $_{per\ input}$ / Σ tonnes mass $flow_{all\ inputs}$) (where tonnes mass flow is from MBT plant's mass flow data)

Weighted $LOI_{I(WDA1)} = 0.245 \times (2000 / (2000 + 4000 + 4000) = 0.049$

Weighted $LOI_{I(WDA2)} = 0.2025 \times (4000 / 10000) = 0.081$

Weighted $LOI_{I(WDA3)} = 0.286 \times (4000 / 10000) = 0.114$

The total weighted LOI is then estimated from the sum of the individual weighted LOI:

Total weighted LOI_{all} inputs = weighted $LOI_{I(WDA1)}$ + weighted $LOI_{I(WDA2)}$ + weighted $LOI_{I(WDA3)}$

$= 0.049 + 0.081 + 0.114 = 0.244$

The total proportion of LOI in the landfilled output is calculated from:

$LOI_O = \%BMW_O/100 \times \%DM_O/100 \times \%LOI_O/100$

$= 40/100 \times 70/100 \times 50/100 = 0.14$

The adjustment factor (A_f) for the sampling event is then calculated from:

$A_f = LOI_O / \Sigma$ LOI of all inputs

$= 0.14 / 0.7335 = 0.1909$

Mean adjustment factor (A_f) for the MBT in this quarter = $\Sigma A_f / n$

$= 0.1909/1 = 0.1909$

The tonnes BMW_O landfilled for the quarter is then calculated using %BMW values from WDF waste arisings as:

t BMW_L = {t $landfilled_{output}$ x Mean A_f x (RB% $_{(WDA1)}$ /100)} + {t $landfilled_{output}$ x Mean A_f x (RB%$_{(WDA2)}$ /100)} + {t $landfilled_{output}$ x Mean A_f x (RB% $_{(WDA3)}$ /100)}

= {3000 x 0.1909 x 70/100} + {3000 x 0.1909 x 70/100} + {3000 x 0.1909 x 65/100}

= 400.89 + 400.89 + 372.26 = 1174.04

To calculate the proportional contribution from each WDA to the total BMW_O landfilled, the tBMW landfilled is multiplied by the proportion of each weighted input LOI to the total weighted LOI of all the inputs.

tonnes BMW_O landfilled from each WDA For example, for input source 1:

tonnes BMW_O landfilled from WDA source 1 = tonnes BMW_L x (weighted $LOI_{I(WDAx)}$ / Σ weighted LOI_{all} inputs)

tonnes BMW_O landfilled from WDA source 1 = 1174.04 x (0.049/0.244) = 235.77

tonnes BMW_O landfilled from WDA source 2 =1174.04 x (0.081/0.244) = 389.74

tonnes BMW_O landfilled from WDA source 3 =1174.04 x (0.114/0.244) = 548.53

8.4.2. Situation where one or more of the biodegradable inputs are not municipal waste

Where an MBT plant accepts municipal waste and other non-municipal wastes that contain biodegradable material then the above approach would also apply. The characteristics of all the inputs to the total biodegradable input would need to be determined (from the input LOI or biogas potential) and therefore the contribution of each to the total tonnes of biodegradable waste landfilled for the MBT process in terms of LOI or potential biogas production (depending on which monitoring option was chosen).

If one or more of the inputs does not contain any biodegradable waste, all inputs should be sampled together with and any outputs that are landfilled and the percentage contribution from each source of municipal waste would then be applied to the entire output to determine the contribution of each input source.

Example - MBT plant with multiple inputs of which only one source is municipal waste

In this example an MBT plant receives three inputs only one of which is municipal waste containing BMW (the other two are not municipal waste (Figure 8.2)) and has one output landfilled. The adjustment factor is estimated using both the LOI reduction and the potential biogas reduction.

The characteristics of the inputs and output are shown in table 8.3 and the calculation of the adjustment factor and BMW_O for the input BMW stream in this example is carried out for both cases of monitoring, either by LOI reduction or by potential biogas reduction (table 8.4).

The proportion of LOI (or biogas) from each of the inputs and the percentage contribution from the BMW-containing input to the total proportion of input LOI (or biogas) is calculated. The next step is to calculate the LOI (or biogas) in the output landfilled. The adjustment factor is then calculated and applied to the % BMW_I

estimated for the BMW-containing input from WasteDataFlow to give the tonnes BMW_O landfilled and the proportion of this that is derived from the input BMW-containing source.

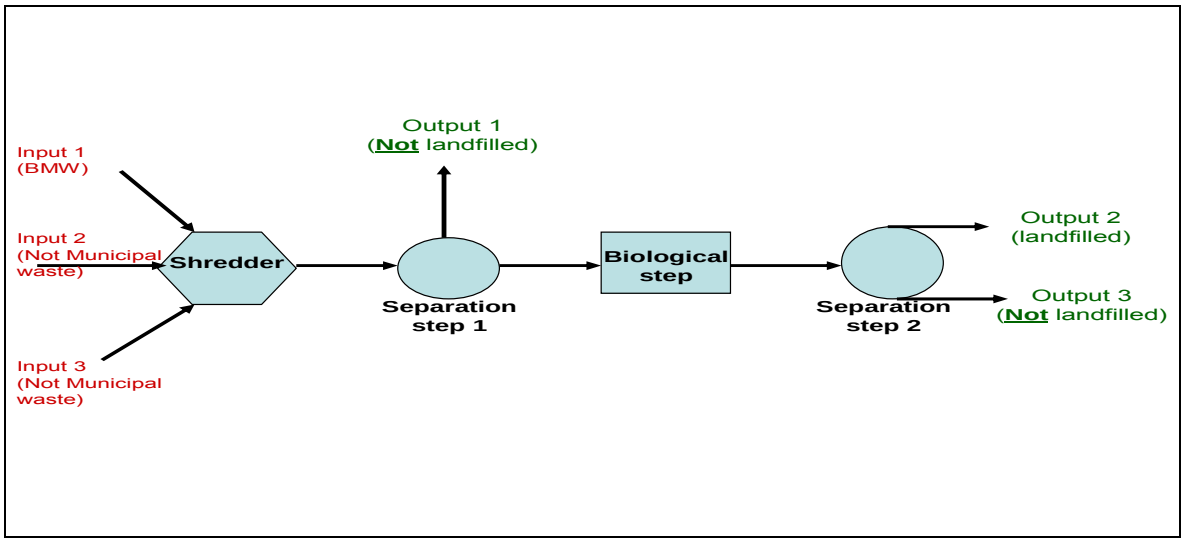


Figure 8.2 Example MBT with three inputs of which only one is municipal waste.

Table 8.3 Monitoring data for MBT with three inputs, one of which contains BMW.

Data	Units	Total MBT input	MBT input 1 +BMW	MBT input 2	MBT input 3	MBT output 2 landfilled
Tonnes wet weight of input waste in quarter	Tonnes	10,000	5,000	2,500	2,500	5,000
Tonnes BMW_I from WasteDataFlow	t BMW_I (WDF)		3,250			
Percentage wet weight of BMW from MBT plant (rolling average)	%BMW		70	0	0	70
Percentage DM content of BMW fraction	%DM		50	75	80	60
Percentage LOI of the DM content of the BMW	%LOI		70	65	55	50
Biodegradability BMc test value	l/kg LOI		400	100	50	200

Calculation BMW A_f and BMW landfilled by LOI method

The proportions of LOI in each of the inputs ($LOI_{I(WDA)}$) are calculated from their respective %BMW, DM and LOI contents. As there is more than one input stream source, the calculation is carried out on each input and the total ratio of LOI landfilled is calculated from summation of the results.

$LOI_{I(WDA1)}$ = 70/100 x 50/100 x 70/100 = 0.245

$LOI_{I(WDA2)}$ = 0/100 x 45/100 x 75/100 = 0

$LOI_{I(WDA3)}$ = 0/100 x 55/100 x 80/100 = 0

The total proportion LOI = 0.245 + 0 + 0 = 0.245

Each input is also weighted according to the BMW contribution of that input to the overall total landfilled. This weighting is calculated using the following equation.

Weighted LOI per input = $LOI_{per\ input}$ x (t mass flow $_{per\ input}$ / Σ tonnes mass $flow_{all\ inputs}$) (where tonnes massflow is from MBT plant's mass flow data)

Weighted $LOI_{I(WDA1)}$ = 0.245 x (5000 / (5000 + 2500 + 2500) =0.1225

As only input 1 contains BMW, all other input values are equal to zero

The total weighted LOI = 0.1225 + 0 + 0 = 0.1225

The total proportion of LOI in the landfilled output is calculated from

LOI_O = 70/100 x 60/100 x 50/100 = 0.21

The adjustment factor (A_f) for the sampling event is then calculated from

A_f = LOI_O/ Σ LOI of all inputs

= 0.21 / 0.245 = 0.8571

Mean adjustment factor (A_f) for the MBT in this quarter = Σ A_f /n

= 0.8571/1 = 0.8571

The tonnes BMW_O landfilled for the quarter is then calculated using %BMW values from WDF waste arisings as

t BMW_L = {t $landfilled_{output}$ x Mean A_f x (RB% $_{(WDA1)}$ /100)} + {t $landfilled_{output}$ x Mean A_f x (RB%$_{(WDA2)}$ /100)} + {t $landfilled_{output}$ x Mean A_f x (RB% $_{(WDA3)}$ /100)}

= {5000 x 0.8571 x 65/100} + {5000 x 0.8571 x 0} + {5000 x 0.8571 x 0}

= 2785.6 + 0 + 0 = 2785.6

To calculate the proportional contribution from each WDA to the total BMW_O landfilled, the tBMW landfilled is multiplied by the proportion of each weighted input LOI to the total weighted LOI of all the inputs. Note that inputs 2 and 3 are not municipal waste and therefore cannot contain any BMW:

tonnes BMW_O landfilled from WDA source 1 = 2785.6 x (0.1225/0.1225) = 2785.6

tonnes BMW_O landfilled from WDA source 2 = 0

tonnes BMW_O landfilled from WDA source 3 =0

Calculation BMW A_f and BMW landfilled by biogas method

The potential biogas (BG_I) from each MBT input is calculated from

$BG_I = LOI_I \times BMc_{(I)}$

where the LOI_I has been calculated as described in Section 8.1.1 above. Where there is more than one input this calculation must be done for each input.

$BG_{I\,(WDA1)} = 0.245 \times 400 = 98$ l/kg

$BG_{I\,(WDA2)} = 0 \times 100 = 0$

$BG_{I\,(WDA3)} = 0 \times 50 = 0$

The potential biogas for the MBT output landfilled (BG_O) is similarly calculated from the BMc test result and the LOI_O for the MBT output landfilled.

$BG_O = LOI_O \times BMc_{(O)} = 0.21 \times 200 = 42$ l/kg

where the LOI_O has been calculated as described in Section 8.1.1 above.

Weighted $BG_{I\,(WDA1)} = 98 \times (5000 / (5000 + 2500 + 2500) = 49$ l/kg

As only input 1 contains BMW, all other input values are equal to zero

The total weighted $BG_I = 49 + 0 + 0 = 49$

The adjustment factor (A_f) for the sampling event is then calculated from

$A_f = BG_O / BG_I$ of all inputs

$= 42 / 98 = 0.4286$

Mean adjustment factor (A_f) for the MBT in this quarter = $\Sigma A_f / n$

$= 0.4286/1 = 0.4286$

The tonnes BMW_O landfilled for the quarter is then calculated using %BMW values from WDF waste arisings as

$t\,BMW_L = \{t\,landfilled_{output} \times Mean\,A_f \times (RB\%_{(WDA1)}/100)\} + \{t\,landfilled_{output} \times Mean\,A_f \times (RB\%_{((WDA2)}/100)\} + \{t\,landfilled_{output} \times Mean\,A_f \times (RB\%_{(WDA3)}/100)\}$

$= \{5000 \times 0.4286 \times 65/100\} + \{5000 \times 0.4286 \times 0\} + \{5000 \times 0.4286 \times 0\}$

$= 1392.95 + 0 + 0 = 1392.95$

To calculate the proportional contribution from each WDA to the total BMW_O landfilled, the tBMW landfilled is multiplied by the proportion of each weighted input BG to the total weighted BG of all the inputs. Note that inputs 2 and 3 do not contain any BMW therefore:

tonnes BMW_O landfilled from WDA source 1 = $1392.95 \times (49/49) = 1392.95$

tonnes BMW_O landfilled from WDA source 2 = 0

tonnes BMW_O landfilled from WDA source 3 =0

Table 8.4 Summary of calculation of adjustment factor and BMW landfilled for MBT with three inputs, one of which contains BMW.

Data	Units	Total MBT input	MBT input 1 +BMW	MBT input 2	MBT input 3	MBT output 2 landfilled
Calculation BMW A_f and BMW landfilled by LOI method						
Percentage wet weight of BMW calculated from WasteDataFlow	$\%BMW_{I\ (WDF)}$		65	0	0	
Proportion BMW-LOI			0.245	0	0	0.21
Proportion BMW-LOI contributed by each input to total input LOI		0.1225	0.1225	0	0	
MBT adjustment factor	A_f	0.8571				
BMW_O landfilled	$tBMW_O$	2,785.7				
Proportion of BMW landfilled from each input			2,785.7	0	0	
Calculation BMW A_f and BMW landfilled by biogas method						
Proportion BMc			98	0	0	42
Proportion BMc contributed by each input to total input BMc		49				
MBT adjustment factor	A_f	0.4286				
BMW_O landfilled	$tBMW_O$	1,392.9				
Proportion of BMW landfilled from each input			1,392.9	0	0	

8.5. Calculations for all MBT configurations

The principles above can be applied to any configuration, for example where there is one input but two outputs landfilled, one of which is prior to any biological treatment.

The calculation proposed for determining the adjustment factor should be included in the monitoring plans. The calculations should be based on the principles shown in the examples above.

Annex A - Analytical methods

A1 Determination of biodegradable municipal waste content (compositional analysis)

A1.1 Introduction

The determination of the percentage biodegradable waste (BMW) content of waste is usually performed by manual sorting as described here. The separated BMW fraction may then be further analysed according to the protocols described in this guidance for other relevant parameters such as dry matter, loss on ignition and biodegradability.

A1.2 Scope

This technical specification describes a method for the separation and determination of the percentage BMW content of MBT and other treatment process input and output samples containing a mixture of BMW and other typical non-BMW components of municipal waste such as plastics, glass, metal objects, stones and ceramics.

The sorting method described here is to separate the BMW fraction from the non-BMW fraction and weigh fractions to determine the %BMW content. Additional sorting of the BMW and non-BMW fractions into other waste classes may provide the operator with additional information on the process performance.

A1.3 Principle

The method is based on handpicking the BMW fraction from the municipal waste sample, and then weighing the amount of BMW sorted and expressing this as a percentage on a wet weight basis of the weight of the whole municipal waste sample.

A1.4 Equipment

Weighing scales – capable of weighing from a few grams to several kilograms with an accuracy of +/- 1 g.

5 mm sieve – a large 5 mm sieve can be helpful as a container in which to sort the municipal waste especially when there is a high proportion of fines.

A1.5 Procedure

The municipal waste sample is weighed before sorting and the weight recorded (M_{msw}). The weight of sample should be selected from the default minimum sample weights provided in table 7.1.

The municipal waste sample should be spread out in a large container to aid manual sorting. Recognisable fragments of BMW materials are retained in a separate container. The non-BMW materials are discarded unless required for some other purpose.

Periodically check the sieved portion of the sample for identifiable fragments and place these into the appropriate buckets.

The BMW fraction is then weighed and the weight recorded (M_{BMW}).

A1.6 Expression of results

The %BMW content is then calculated from M_{BMW}/M_{msw} x 100%

A2 Biodegradable sample preparation for laboratory analysis

A2.1 Introduction

Accurate determination of the dry matter, loss on ignition and biodegradability of the biodegradable waste fraction of municipal waste samples will often require sample preparation involving shredding, maceration, mixing and sub-sampling to provide a smaller representative sub-sample. Depending on available equipment for macerating the BMW, the samples may need to be bulk dried as some equipment does not effectively macerate wet material. This section provides guidance on the preparation of the BMW fraction material for further analysis.

A2.2 Scope

This technical specification describes a method for the drying, maceration and sample size reduction of large BMW samples composed of large particle material derived from the municipal waste sorting protocol described in section A1. This procedure is required in order to prepare a representative and stable BMW sub-sample of particle size <10 mm suitable for further analysis for parameters relevant to determining the adjustment factor for the MBT. Some MBT-derived BMW samples may already be of a small particle size and dryness that can either be used directly (it has a particle size <10 mm) or can be shredded to <10 mm without any prior preparation.

Several procedures to obtain a BMW preparation of particle size <10 mm may be applicable depending on the available laboratory equipment. Alternative biodegradability tests to the BMc and DR4 may require different sample preparation procedures.

All methods of sample preparation need to be described in the monitoring/sampling plans submitted to the Environment Agency for approval.

A2.3 Principle

The methods are based on shredding, macerating and grinding representative BMW samples to a smaller particle size so that the sample can be mixed and then representative sub-samples taken for further preparation and/or analysis. Preliminary drying may be required as part of this preparation as most equipment for reducing particle size does not work effectively on moist samples. The moisture loss by such drying is also measured in order to calculate the dry matter content of the BMW on an ‘as received’ basis. For estimating adjustment factors for MBT processes, the key objective is to obtain a representative sample with a particle size of <10 mm which is then suitable for analysis of its DM, LOI and biodegradability.

A2.4 Equipment

Drying ovens – capable of drying several kilograms of waste at temperatures up to 100°C.

Bulk BMW shredder – capable of shredding and macerating large items down to a particle size of <30 mm diameter.

Weighing scales – capable of weighing from a few grams to several kilograms with an accuracy of ± 1 g.

Small scale shredder/grinder – capable of shredding a sample of up to 2 kg in weight to a minimum particle size of <10 mm.

A2.5 Procedure

Bulk shredding to <30 mm particle size

Samples consisting of large particles of BMW require bulk shredding to a smaller particle size of about <30 mm. Most bulk shredders are capable of effectively shredding moist BMW. The shredded BMW is then well mixed to give a <30 mm preparation available for further processing.

Bulk drying

If the <30 mm shredded BMW sample is moist then bulk drying may be required so that it can be effectively shredded to the required particle size in a smaller scale shredder/grinder.

The bulk shredded <30 mm preparation is sub-sampled by cone and quartering to give about 10 kg of material for drying.

Weigh a sufficient number of large trays each of which can contain upto 1.5 kg of wet sample to a depth of no more than 10 cm. Record the weight of the empty trays (W_T).

Add the wet BMW to each tray and reweigh and record the weight of each tray plus wet BMW (W_{T+BMW}).

The trays are incubated for a sufficient time period at temperatures of 70°C to dry the waste to a suitable dryness for effective further grinding. The incubation time may depend on the type of waste and the target dryness required for the grinding equipment. Re-weigh and record the weight of the trays after drying the BMW (W_{T+DRY}).

Small scale shredding/grinding to <10 mm particle size

The bulk dried material is mixed and cone and quartered to give a 2 kg sub-sample for further particle size reduction by shredding/grinding to a particle size of <10 mm. This sample is then used to determine the dry matter (DM) and organic matter (LOI) content as described in section A3, and the biodegradability as described in section A4 for the BMc test and section A5 for the DR4 test.

A2.6 Calculation and expression of results

Moisture loss during bulk drying

The calculation of the moisture loss during any bulk drying stage is required in order to calculate the dry matter content of the BMW fraction as described in annex A.3 determination of DM and LOI.

The moisture lost (kg) by bulk drying ($W_{Moisture}$) is calculated as the sum of the moisture losses for each tray from:

$W_{Moisture} = \sum(W_{T+BMW} – W_{T+DRY})$.

The total weight of the sub-sample before drying (W_{Waste}) is calculated from the sum of the differences in weights of the empty trays and the trays filled with the pre-dried waste sample:

$W_{Waste} = \sum(W_{T+BMW} – W_{T})$.

The moisture loss by the bulk drying ($\%MLoss_{BD}$) is then expressed as a percentage of the wet waste mass as follows:

$\%MLoss_{BD} = W_{Moisture}/W_{Waste} \times 100\%$

A3 Determination of dry matter (DM) and organic matter (LOI) content

A3.1 Introduction

The determination of the percentage dry matter (DM) and organic matter (as loss on ignition, LOI) of the BMW fraction are required in order to calculate the adjustment factor for the MBT process. The DM and LOI determinations are carried out on BMW samples of particle size <10 mm or less.

A3.2 Scope

This technical specification describes a method for the determination of the DM and LOI content of BMW samples comprising material with a particle size of <10 mm. Such material may have been prepared according to sections A1 and A2 above or by other methods approved by the Environment Agency, or may have already comprised material of <10 mm particle size and have undergone no prior size reduction.

Where there has been a bulk drying stage during the preparation of the samples the moisture loss during the bulk drying ($\%MLoss_{BD}$) needs to be taken into account in order to calculate the DM content of the BMW material on an 'as received' basis. A method for the calculation of the DM content when sample preparation involved a bulk drying step is also described here.

This procedure is based on CEN standard BS EN 13039:2000

A3.3 Principle

The method is based on drying replicate sub-samples at 105°C to constant weight and determining the DM content of the sub-samples by the loss in weight during drying. The dried replicate sub-samples are then combusted at a temperature of 550°C in order to burn off the organic matter in the sample. The weight loss during this combustion is referred to as the LOI and is expressed as a percentage of the DM.

A3.4 Equipment

Weighing scales – Capable of weighing from a few grams to several hundred grams to two decimal places and with an accuracy of ± 0.01 g.

Crucibles – Heat resistant crucibles that can withstand temperatures greater than 550°C and with capacity of at least 150 ml.

Drying oven – Set at a temperature of 102°C to 108°C.

Combustion furnace – Capable of slowly increasing the temperature from room temperature to 550°C over a minimum period of one hour and then maintaining that temperature.

A3.5 Procedure

The number of test crucibles required to determine the dry matter and LOI will depend on the particle size of the test material and its source. With the exception of SRF it is recommended that the total weight of sample tested for <10mm samples should be at least 100g and for <2 mm samples should be at least 20g. Where onward biological testing is to be undertaken on the BMW fraction the <10mm sample should be used. For SRF the100g <10mm sample can be reduced to 50g. A minimum of 5 appropriately sized crucibles should be used and care taken to avoid over-filling each crucible.

Weigh the required number of empty crucibles and record the weight of each (W_0).

Fill each crucible with a sub-sample of the BMW preparation and re-weigh to determine the weight of the crucible plus waste sample (W_1). Only fill the crucibles to two-thirds of their volume to avoid losses during combustion.

Calculate the exact amount of sub-sample in each crucible ($Ww = W_1 – W_0$) and sum the amounts for all the replicate crucibles. If less than 100g of sample in total has been used then set up additional crucibles until the minimum of 100g has been used.

Place the crucibles in the drying oven at 105°C and dry overnight (for at least 16 hours). Remove the crucibles from the oven and place them in a dessicator jar containing silica gel to cool down. Weigh the crucibles when cool. Record the weight of the completely dried crucibles (W_2).

Place the crucibles in the combustion furnace at room temperature. The furnace temperature should be slowly increased to 550°C for a minimum of one hour. The crucibles should be kept at 550°C for a further two to three hours and then removed.

The waste (material in the crucible) should be carefully stirred with a metal spatula or similar to check if combustion is complete. Incomplete combustion is indicated by the presence of black and/or smouldering material whilst complete combustion is indicated by the presence of only light grey and/or light brown ash. If combustion is incomplete, replace the crucibles in the furnace and heat for a further two hours and then repeat the inspection for complete combustion. Repeat this process until combustion is complete.

When combustion is complete take the crucibles out and place in a dessicator jar to cool down and then weigh the crucibles (W_3).

A3.6 Calculation and expression of results

Calculation of the dry matter (DM) content of <10 mm preparation

The DM content of each replicate sample is calculated as follows:

DM (as % wet weight) = $(W_2 - W_0)/(W_1 - W_0) \times 100\%$

The mean percentage dry matter and standard deviation for the <10 mm preparation is then calculated for all replicates ($\%DM_{<10}$).

Calculation of the BMW dry matter content if an additional bulk drying step was applied

If the BMW preparation procedure involved a bulk drying stage, the DM content of the BMW as received needs to be calculated from the DM content of the <10 mm preparation ($\%DM_{<10}$) and the moisture loss ($\%MLoss_{BD}$) from the bulk drying stage of the sample preparation (section 10.2):

$\%DM \text{ of BMW as received} = (100 - \%MLoss_{BD}) \times \%DM_{<10}/100$

Calculation of the loss on ignition (LOI) content of <10 mm preparation

The LOI content of the <10 mm preparation is the value for the biodegradable waste LOI content used in the MBT guidance calculation.

The percentage LOI content of each replicate sample is calculated as follows:

$LOI \text{ (as \% of DM)} = (W_2 – W_3)/(W_2 - W_0) \times 100\%$

The mean percentage LOI content and standard deviation for the <10 mm preparation is then calculated for all replicates (%LOI).

Reporting

Dry matter reporting requires:

- The percentage moisture lost ($\%MLoss_{BD}$) during any bulk drying stage if this took place.
- The mean percentage DM from at least 5 replicates.
- The mean percentage DM and standard deviation data of the all replicates.
- The 'as received' percentage dry matter (%DM) content of the BMW (based on the mean DM of all replicates and the moisture loss during bulk drying, if it was carried out).

LOI reporting requires:

- The mean percentage LOI from at least 5 replicates.
- The mean %LOI and standard deviation data of all replicates.

A4 BMc anaerobic biodegradability test

A4.1 Introduction

If the biogas reduction option has been chosen for MBT monitoring then the biodegradability of the prepared <10 mm BMW fraction should be determined by the anaerobic BMc test. This test provides a measure of the potential amount of biogas (carbon dioxide and methane) that might be released by the BMW if it is landfilled and decomposes under the anaerobic methanogenic conditions that occur in most landfills.

A4.2 Scope

This method describes the anaerobic biodegradation test (BMc) for the determination of the biodegradability of waste fractions with a typical size of <10mm. The BMc test reports biodegradability as litres of biogas per kg LOI (l/kg LOI) and may take 100 days or more to complete (that is, until biogas production ceases).

This test provides a measure of the potential amount of biogas (carbon dioxide and methane) that might be released by a waste material if it were landfilled and decomposed under the anaerobic methanogenic conditions that occur in most landfills.

This test method is based on the techniques described in: Amenability of Sewage Sludge to Anaerobic Digestion (1977) and The Assessment of Biodegradability in Anaerobic Digesting Sludge (1988).

A4.3 Principle

Under anaerobic methanogenic conditions the decomposition of organic matter proceeds by producing biogas (carbon dioxide and methane) from the organic carbon. The amount of biogas production therefore directly measures the organic carbon that is mineralised and the biodegradability. The test is set up in a small vessel containing the test substrate, an aqueous mineral medium and an innoculum of digested sludge (that contains methanogenic bacteria) taken from an active anaerobic digester. The test vessel is incubated at $35^{\circ}C \pm 2^{\circ}C$ and is monitored by collecting and recording the volume of biogas produced. This is then adjusted to standard temperature and pressure.

The test is incubated for an extended period until biogas production ceases, which may be less or more than 100 days depending on optimisation of the test. The test determines the potential amount of biogas production of the waste as a measure of biodegradation and the results are reported as litres of biogas (at standard temperature and pressure) per kg of waste LOI (l/kg LOI).

A4.4 Equipment

Biodegradation test vessels – A series of 1 pint (560 ml) ‘milk bottles’ each with a rubber bung and flexible plastic tubing to pass any produced biogas to the biogas collection cylinder.

Incubator or water bath - Set at 35°C ± 2°C for controlling the temperature of the biodegradation test vessels.

Biogas collection cylinder - With a valve at the top of the cylinder for connection to a vacuum pump for initial filling of the cylinder with liquid or subsequent removal of biogas from cylinder. Suitable dimensions for the cylinder are 50mm internal diameter and 1100mm height, which gives a working capacity for biogas collection of about 1500ml. The cylinder is marked in 1mm divisions along its whole length, which represent (for the 50mm diameter cylinder) a biogas volume of 1.964 ml/1mm division.

Water bath of salt-saturated acidified water - The biogas collection cylinders are inserted into the water bath and the saturated acidified water is sucked up by the vacuum pump into the cylinders. The biogas produced then displaces the saturated acidified water from the biogas collection cylinder. The water bath for collection of the biogas is saturated with table salt to address reported problems of carbon dioxide gas solubility and diffusion through the barrier liquid.

Vacuum pump - Connected to the valve at the top of the biogas collection cylinder in order to fill (and refill) the collection vessel with acidified water by suction.

A4.5 Reagents

0.2 molar sodium hydroxide

Weigh out 2.00 ± 0.2gm of anhydrous sodium hydroxide pellets and carefully dissolve in approximately 200ml of deionised water. Carefully dilute to 250 ± 10ml with deionised water. Store in a polythene bottle at room temperature (stable for six months).

Mineral salts medium

Weigh out:
0.27 ± 0.02gm of KH_2PO_4
0.35 ± 0.02gm of K_2HPO4
0.53 ± 0.02gm of NH_4Cl
0.075 ± 0.002gm of $CaCl_2.2H_2O$
0.10 ± 0.005gm of $MgCl_2.6H_2O$

Dissolve the above in approximately 500ml of deionised water. Add 10.0 ± 0.5ml of trace element medium (see 5.3) and dilute to 1000 ± 20ml with deionised water. Adjust the pH to 7.5 ± 0.05 with 0.2 molar NaOH (5.1). Store in a polythene bottle in the dark at 4°C (stable for three months).

Trace element medium

Weigh out 1.50 ± 0.06gm of $FeCl_2.4H_2O$ and dissolve in 5.10 ± 0.2ml of hydrochloric acid (36 per cent w/w).

Add:
0.06 ± 0.002gm of H_3BO_4
0.10 ± 0.004gm of $MnCl_2.4H_2O$
1.20 ± 0.06gm of $CoCl_2.6H_2O$
0.07 ± 0.003gm of $ZnCl_2$
0.025 ± 0.001gm of $NiCl_2.6H_2O$

0.015 ± 0.001gm of $CuCl_2.2H_2O$
0.025 ± 0.001gm of $Na_2MoO_4.2H_2O$

Make up to approximately 500ml of deionised water. Dilute to 1000 ± 20ml with deionised water. Store in the dark at 4°C (stable for three months).

Biogas displacement liquid

The displacement liquid is made up of tap water which has been fully saturated with salt such as common table salt. Add 270 ± 5gm of table salt per litre of tap water and stir until there is no further dissolution. The saturated water solution is then acidified to a pH of 2 to 2.5 with a few drops of concentrated HCl. Add a few drops of suitable pH indicator such as methyl orange to the mixture (if required). The aim is simply to make the saturated acidified water solution more visible in the transparent collection cylinder. The saturation and acidification helps prevents absorption of carbon dioxide into the collecting liquid thereby ensuring all the biogas (carbon dioxide and methane) production is measured.

Microbial seed

The microbial seed consists of digested anaerobic sewage sludge collected from a mesophilic sewage sludge digester. The seed should contain a significant population of methanogenic bacteria in an active form so that methanogenesis in the test system is ensured (that is, ensuring an active population that has not been starved of substrate for a significant length of time). If the methanogens have been starved of substrate they may be dormant and this may slow down or result in incomplete methanogenic fermentation during the test. However, if the seed digested sludge contains a significant amount of residual biodegradable organic matter then the seed controls may produce similar amounts of biogas compared to some test materials, thus enhancing the risk of error in the results from test materials of low biodegradability. A working seed solution of 5 to 6 per cent dry solids content (DM) ± 1 per cent should be produced from fresh digester sludge. A dry matter and LOI test should be undertaken on each new batch of digestate.

If a fresh source of seed is not readily available, a laboratory culture may be maintained by storage of a batch of seed at 35°C in 5L containers in a water bath. In order to ensure methanogenic activity in the seed, the culture should be dosed with 20 ± 5gm of solid sodium acetate and 20 ± 5gm of solid sodium formate per litre of seed on a weekly basis. Seed should be stored for a maximum of 60 days before replacement with fresh digestate from the sewage treatment works.

Test organic waste sample

This should comprise the prepared sample dried and ground to a suitable particle size (see 9.1 and 9.2). The dry matter content at 105°C and loss on ignition content at 550°C of the test material should be determined according to the procedures in section 9.3.

Control substrate

This should comprise a homogeneous and readily available biodegradable organic material that gives a mid-range biodegradability response in the BM100 test.

Saturated sodium carbonate solution

Weigh out 30 ± 5gm of anhydrous sodium carbonate into a 50ml bottle and add deionised water to nearly fill the bottle. Shake well and leave to settle. The supernatant will be saturated sodium carbonate solution. Top up the bottle with water or sodium carbonate as required, so that there is always solid material present. Store at room temperature.

A4.6 Procedure

Setting up the system

Assemble the apparatus as shown in figure A.1. Set up sufficient vessels to accommodate all of the samples under test, the control substrate, seed control and blank, according to the test worksheet.

Procedure to set up test reaction mixtures

Add the equivalent of 20 ± 2gm LOI of the prepared <10 mm waste sample to a biodegradation test vessel. Note that each waste sample is tested in triplicate. Record the vessel codes, sample codes and sample weights on the test worksheet.

Control substrate – set up three vessels containing 20 ± 2gm of control substrate as sample. The control substrate should give similar biogas production results for every batch of samples run on the BM100 test as an indication that the test run is valid. This should be monitored by the use of control charts.

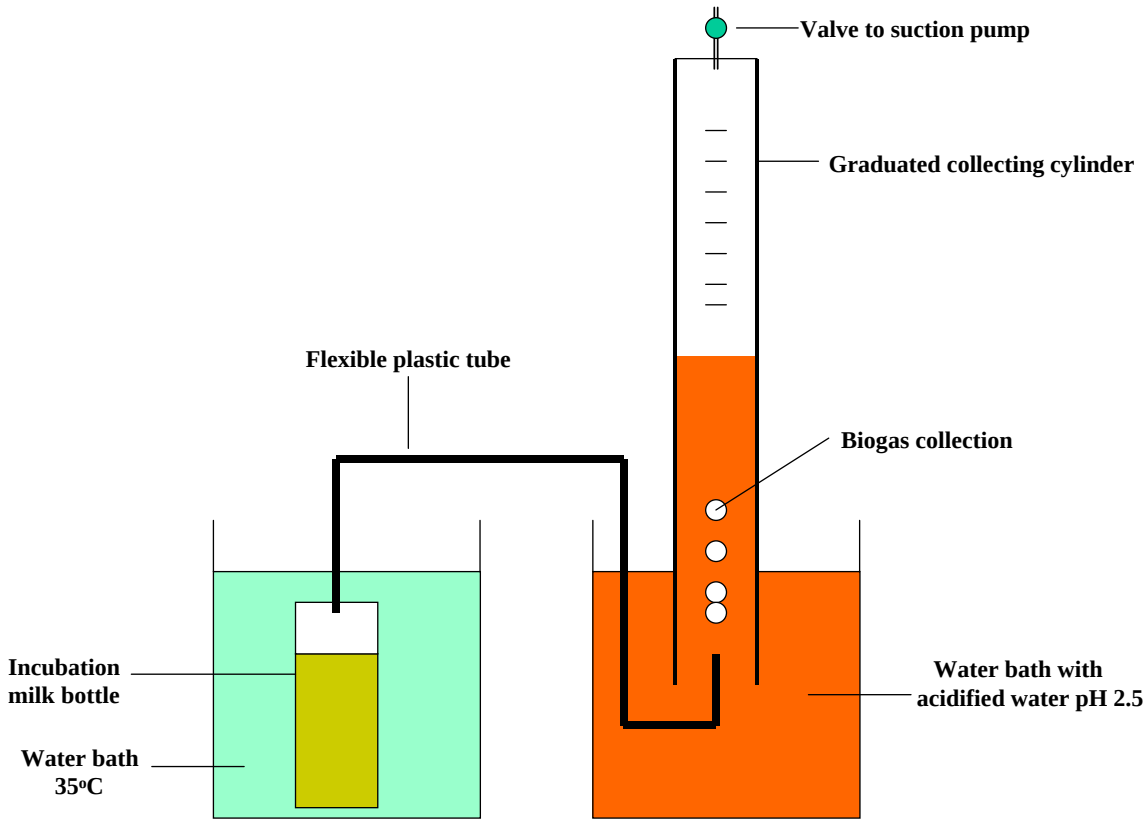


Figure A.1 Schematic of BM100 method set up.

Seed control – Set up one seed vessel. The biogas from this control is taken away from the biogas produced in all the other test vessels to take account of any biogas from the organic matter supplied in the seed.

Add 150 ± 10ml of the mineral salts medium and 150 ± 10ml of seed anaerobic sewage sludge to each test vessel and mix gently with the test sample. The seed control must be mixed continuously during the decanting process to avoid settlement of the dry solids. This can be achieved using a rotating paddle stirring device and use of a peristaltic pump to transfer the seed to a measuring cylinder. If the waste is fully submerged and free liquid is clearly visible then the test mixture is acceptable. If free liquid is not present then top-up with deionised water until free liquid is observed. Record the amount of additional liquid added and any other relevant information on the test worksheet.

Replace the headspace in the bottle with N_2 gas if available as this will help to quickly establish methanogenic conditions within the test vessel. Note however, that usually there are no problems encountered if the headspace is air, as long as the seed has a high active methanogenic bacterial population and is added in sufficient quantities. This is especially important for wastes that contain a high proportion of readily biodegradable material and are not stabilised.

Connect the bottle to the biogas collection vessel tubing by inserting the bung into the test vessel. Ensure the bung is airtight and that the test vessel is not leaking.

Incubate the test vessels at a temperature of 35 ± 2°C either in a water bath or incubator.

Some waste samples may be very water absorbent and swell up over the first few days leaving little, if any, free liquid. If this occurs then the test samples should be topped up with additional deionised water until free liquid is observed. Record this information on the worksheet.

Biogas collection system monitoring

The measurements required for the monitoring and calculation of results are shown in figure A.2 below:

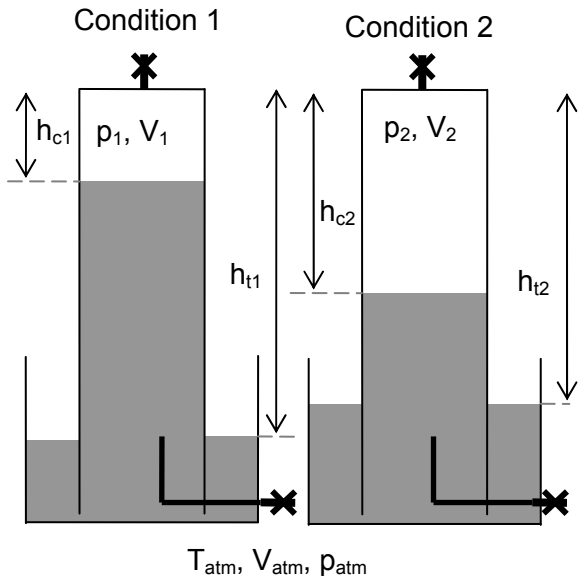


Figure A.2 Biogas collection system monitoring

Where:

V =	volume (m^3)
p =	pressure (Pa)
A =	cross-section of gasometer (m^2)
T =	temperature ($^{\circ}K$)
ρ =	density of barrier solution (kg m^{-3})
h =	distance from the top of the gasometer to the barrier solution level
1 =	subscript which refers to condition 1
2 =	subscript which refers to condition 2
stp =	standard temperature and pressure
atm =	atmospheric temperature and pressure
H_2O =	water
b =	barrier solution (saturated acidified water)
t =	trough height
c =	column height

Using the vacuum pump, remove gas from the gas collection system by suction from the top of the cylinder and set the level of water in the gas collection vessel to zero. This is the start of the incubation period (zero time).

Record the level of biogas collected in the gas collection system on the test worksheet. This should be carried out daily during the first few days of the test, as this may be a very active period with large amounts of biogas production. When the water level in the collection cylinder has reduced by over 500mm, reset the level of water in the biogas collection cylinder to zero and record this event on the worksheet. This may need to be done on several occasions during the test if there is high biogas production.

Mix the contents of the reaction vessels regularly by swirling as some waste materials may 'float' on the surface of the main liquid level due to the biogas production. During the period of the BMc test, especially in the first few weeks at the start, the test vessels should be shaken vigorously on a regular basis and prior to taking the readings to ensure that the sample is well mixed with the liquid media.

The test is monitored until there is no longer any biogas production, which indicates completion of the test. This usually takes about 100 days although it may be sooner or later depending on the waste sample.

A common problem with highly biodegradable wastes where an insufficient methanogen population has been added via the seed is that the test sample may become acidic due to the initial activity of fermentative (acetogenic) bacteria. Acidification may cause a shock to the methanogenic bacteria and inhibit the use of the fermentation products by these bacteria to produce biogas. If the gas production in the initial days of the test stalls, the pH of the reaction mixture should be checked and if the pH is below 6.5 - some saturated Na_2CO_3 solution should be added to bring the pH back to 7.5. Opening of the vessels to the air should only be undertaken as a last resort to avoid stress to the methanogen population.

The addition of carbonate may cause some immediate gas production (fizzing) and the bottles are reconnected after this initial "fizzing". It is assumed that the carbonate added makes little difference to the overall biogas measurement as the carbonate added is off-set by the carbon dioxide released by the drop in pH during the acidification phase.

A4.7 Calculation and expression of results

Calculation of biogas production

Each time the gas cylinder is emptied the biogas volume collected within it should be calculated and corrected to standard conditions.

The volume of gas produced is calculated by the following formula:

$$V_{stp} = \frac{T_{stp} A}{T_{atm} p_{stp}} \left(\left(p_{atm} - p_{H_2O}(T_{atm}) - \rho_b g \left(h_{t2} - h_{c2} \right) \right) h_{c2} - \left(p_{atm} - p_{H_2O}(T_{atm}) - \rho_b g \left(h_{t1} - h_{c1} \right) \right) h_{c1} \right)$$

Where $p_{H_2O}(T) = 101324.6 \times 10^{z}$

For the equation above, the following constants should be used:

Gravitational acceleration (g)	9.81 m/s²
STP temperature (T_{STP})	273.16 °K
STP pressure (P_{STP})	100 kPa

The value of the cross-sectional area of the collection cylinder (A) with a 0.05m internal diameter biogas collection vessel as described is = 0.00196 m^2

To convert to standard temperature and pressure (STP):

Step 1: Adjust for temperature variations in the biogas collection liquid.

Changes in the liquid level of the collection tank will change the levels in the tube due to the hydrostatic head pressure of the liquid. This needs to be compensated for prior to calculating the volume of biogas produced and is given by the equation:

$$p_{H_2O}(T) = 101324.6 \times 10^{z}$$

Where:

$$z = -7.90298\left(\frac{373.16}{T} - 1\right) + 5.02808\log_{10}\left(\frac{373.16}{T}\right)$$
$$- 0.00000013816\left(10^{11.34\left(1-\frac{373.16}{T}\right)} - 1\right) + 0.0081328\left(10^{\left(-3.49149\left(\frac{373.16}{T}-1\right)\right)} - 1\right)$$

Note that SVP of water at T of 100°C or 373.16K is equal to 1 atm or 101324.6 Pa

Step 2: Calculation of volume of gas produced at STP (V_{STP}) is by:

$$V_{stp} = \frac{T_{stp}A}{T_{atm}p_{stp}}\left(\left(p_{atm} - p_{H_2O}(T_{atm}) - \rho_b g\left(h_{t2} - h_{c2}\right)\right)h_{c2} - \left(p_{atm} - p_{H_2O}(T_{atm}) - \rho_b g\left(h_{t1} - h_{c1}\right)\right)h_{c1}\right)$$

Note that if the gas cylinder is completely evacuated each time it is used and the fill volume is to the bottom of the bung h_{c1} = 0. Also ht2=ht1 if there is no overflow in the tank.

Calculation of BMc test result:

The date and times are recorded at the start and continuously when a reading is taken. The difference is calculated as:

Day = Date + $\text{Time}_{\text{reading X}}$ – Date + $\text{Time}_{\text{start}}$

The cumulative biogas produced by each test vessel in L (B_C) is calculated as:

B_C = $\text{biogas volume}_{\text{day X}}$ – $\text{biogas volume}_{\text{start}}$

As the biogas collection cylinder may have been re-set several times during the BMc test period the calculation will vary slightly following a refill to the equation:

B_C = $\text{biogas volume}_{\text{day X}}$ – $\text{biogas volume}_{\text{refill day}}$ + cumulative biogas produced $_{\text{before refill}}$

The cumulative biogas production contribution of the seed sludge (B_S) is subtracted from the sample cumulative biogas production (B_C) to give the cumulative test substrate biogas production (B_T).

Test substrate biogas production (l) is given by:

$$B_T = B_C - B_S$$

The test material biogas production at STP is then normalised to the BMc units of l/kg LOI of waste.

BMc test value = (Test B_T /g LOI in test vessel)

The reported BMc value is the mean of the three replicates although all values from the replicates can be reported. If any one of the three replicates is a clear low value this can be considered as an outlier and the mean of the other two replicates should be used as mean BM100 value.

Validation by LOI loss during the BMc test:

The BMc values can be checked for validity by determining the reduction in organic matter as measured by the change in LOI during the test. The dry matter at 105°C and the loss on ignition at 550°C of the whole bottle contents at the end of the test are determined using the procedure given in section A3..

The LOI present in the seed sludge (LOI_S) controls is subtracted from the test vessel residual LOI result (LOI_T) and the answer subtracted from the initial LOI result (in gm) added to the test vessel (LOI_{In}) to give the LOI (in gm) 'consumed' during the test (LOI_C):

LOI consumed (LOI_C) = $LOI_{In} – (LOI_T – LOI_S)$

The biogas production is then calculated in terms of LOI consumed rather than the initial LOI added as follows:

Biogas on LOI consumption = Test B_T at STP/LOI_C

The standard volume of ideal gas is 22.4136 litres/mole at STP and therefore if the LOI of a waste typically contains 50 per cent carbon then the biogas production per kg LOI consumed should be about 930 l/kg LOI.

If there is any doubt about the performance of the seed material, it is advisable to carry out this validation test on at least two of the test samples set up in any particular batch of BMc tests. If the biogas production per kg LOI consumed is substantially less than 700 then the test result should be deemed invalid and the remaining samples in the batch should be tested for LOI to test their validity.

A5 DR4 aerobic biodegradability test

A5.1 Introduction

If the MBT monitoring plan requires performance to be assessed by the change in potential biogas production option then the biodegradability of the BMW is determined by the anaerobic BMc test (section A4). Where approved by the Environment Agency, it is permissible to use more rapid, alternative biodegradation tests that have been proven to correlate with the BMc test. This section describes the rapid four-day aerobic DR4 biodegradation test which has been approved by the Environment Agency for correlation with the BMc test. A general correlation between the DR4 and BMc tests has been established (annex B) and this may be used with Environment Agency approval as a default correlation until sufficient site specific data is available to produce a site-specific correlation.

A5.2 Scope

This technical specification describes the four-day aerobic DR4 biodegradability test method for the determination of the biodegradability of the <10 mm particle size BMW fraction prepared as in sections A2 and A3. The method has been adapted from the standard test method for measuring organic waste biodegradation (ASTM D5975-96). The test results are then used to estimate the anaerobic BMc test results by provisionally using the default correlation between the DR4 and BMc methods (annex B) and then by the determination of a site specific correlation developed from the initial first quarter Level 1 Comprehensive monitoring.

A5.3 Principle

The waste sample to be tested is prepared to give a fraction with a particle size of <10mm using the procedure detailed in sections A1, A2 and A3. A portion of this prepared sample is mixed with an equal amount (by dry weight) of mature green waste compost (seed), which provides a good source of micro-organisms that are able to biodegrade the test material. The mixture is supplemented with nitrogen and phosphorus nutrients, the moisture content is adjusted, and then the mix is placed in an incubation vessel. The mixture is incubated for four days at 35°C under aerobic conditions (by forced aeration).

Control vessels are also set up containing just the green waste seed material and a control substrate, and a blank vessel is used to determine any carbon dioxide in the air supply.

During the four days of the test, the micro-organisms in the green waste compost seed aerobically decompose some of the biodegradable organic carbon in the waste to CO_2. Consequently, the exhaust air leaving the reaction vessel is enriched with CO_2. The amount of CO_2 produced during the four-day test period is then measured by monitoring the output gases. The test results are converted to equivalent O_2 consumption values by assuming there is a 1:1 molar ratio of CO_2 to O_2.

The O_2 consumed by the test is adjusted for the O_2 consumption by the seed control and blank and then reported as the DR4 value in units of gm O/kg LOI, that is, mass of oxygen (in grammes) consumed over four days per kg of LOI of the test material.

A5.4 Equipment

Air flow control equipment - Gas flow control meters capable of controlling the air flow to each individual reaction vessel at a rate of 400ml/min.

Composting vessels - Cylindrical reaction vessels of 100-120 mm diameter and 2.5 litres volume with a perforated false bottom that allows even gas flow in an upward direction. The vessel has an inlet gas port below the false bottom and an exhaust gas port at the top of the vessel. Such vessels may be constructed of glass with the perforated false bottom made of sintered glass and the outlet port, for the exhaust gas, of glass tubing inserted through a rubber bung. However vessels constructed from other suitable materials may be used.

Input air humidifier/carbon dioxide removal vessels - Cylindrical glass vessels large enough to hold 200 ml of liquid with a headspace of at least 5 cm and sealed with a bung at the top. A sintered glass air sparger is inserted through the bung to the bottom of the vessel as the air input to the humidifier vessel. The bung is also pierced by a short length of tubing that extends into the headspace of the vessel. These vessels, if filled with 150 ml of 0.25 molar sodium hydroxide will moisten the air supply to the test reaction vessels which reduces the risk of the test sample drying out, and will also remove carbon dioxide from the air supply which makes analysis of the produced carbon dioxide in the effluent gas more reliable.

Incubator - Incubators or temperature controlled room held at a temperature of 35°C.

Gas monitoring equipment - Suitable equipment for monitoring the consumption of oxygen or the production of carbon dioxide is required. These may be on-line gas analyser systems such as infra-red for carbon dioxide, paramagnetic for oxygen, or mass spectroscopy for both oxygen and carbon dioxide. These systems measure the gas composition and therefore need to be combined with accurate gas mass flow measurements.

A simpler alternative is the sodium hydroxide alkaline trap method. The gas streams are passed through glass spargers inserted into vessels containing a known volume of 2 molar sodium hydroxide. The sodium hydroxide reacts with the carbon dioxide thereby removing the carbon dioxide from the exhaust gas and trapping it in the liquid sodium hydroxide solution. The reaction between the acidic carbon dioxide and the alkaline sodium hydroxide results in partial neutralisation of the sodium hydroxide. The amount of neutralisation is measured by titration with standardised 1 molar hydrochloric acid and from this the amount of carbon dioxide trapped can be calculated.

Titration equipment - Burette (0 to 50 ml), measuring cylinder and volumetric flasks.

Magnetic stirrer and followers.

A5.5 Reagents

Test materials

Seed compost: The seed compost should be mature green waste compost derived from a commercial composting site. A seed prepared from a laboratory scale composting unit would be acceptable if it performed satisfactorily with the control substrate. The compost seed is stored in the composting unit at room temperature and should be rotated regularly to mix the contents.

The seed compost should be sieved through a 5-6 mm sieve to remove all large particles and the dry matter content and loss on ignition (LOI) determined as described in section A3. The seed compost should have an LOI content of between 20 and 40 per cent of the dry matter content.

The biodegradability (DR4 value) of the seed compost should be measured and should be between 2 and 20 gm O/kg LOI. If the seed LOI content is above 40 per cent and/or the DR4 value above 20 gm O/kg LOI, then the seed may be too active which would increase the risk of large errors in the measurement of poorly biodegradable test samples. Seed compost with a high activity may be diluted by mixing with fine sand and then re-tested for its dry matter content, LOI and activity (DR4 value). Alternatively the seed compost may be incubated for several weeks so that it naturally undergoes further composting to reduce its LOI content and DR4 value.

Test sample: This should comprise the sample to be tested, prepared to a particle size of <10 mm (unless otherwise specified). The dry matter at 105°C and loss on ignition at 550°C content of the test material should be determined according to the procedure in section A2.

Control substrate: This should comprise of a homogeneous and readily available biodegradable organic material, which gives a mid-range biodegradability response (DR4 value) in the test.

Reagents for monitoring carbon dioxide production by the alkaline trap-titration method

2 molar sodium hydroxide. Carefully dissolve 2000 ± 20 gm of NaOH pellets in approximately 10 litres of deionised water, allow to cool and dilute to 25 litres ± 500 ml with water. Store in a polythene bottle at room temperature. Stable for 12 months.

1 molar hydrochloric acid. Carefully add 101 ± 1 g of concentrated HCl (36% w/w) to approximately 500 ml of deionised water, allow to cool and then dilute to 1 litre in a volumetric flask. Store in a polythene bottle at room temperature. Stable for 12 months. The hydrochloric acid should be standardised before each use.

1 molar barium chloride solution. Dissolve 120 ± 2 gm of solid $BaCl_2.2H_2O$ in 1000 ± 20 ml of deionised water. Store in a polythene bottle at room temperature. Stable for 12 months.

Phenolphthalein indicator solution. Dissolve 0.5 ± 0.05 g of solid phenolphthalein in 50 ± 2 ml of absolute ethanol. Add 50 ± 2 ml of deionised water and mix well. Store in a polythene bottle at room temperature. Stable for 12 months.

0.3 molar sodium carbonate solution. Dissolve 32.0 ± 0.05 gm of anhydrous Na_2CO_3 in approximately 250 ml of deionised water, and dilute to 1 litre in a volumetric flask. Store in a polythene bottle at room temperature. Stable for 6 months.

2 molar ammonium chloride solution. Dissolve 107 ± 1 gm of anhydrous NH_4Cl in about 500 ml of deionised water and then dilute to 1000 ± 10 ml with water. Store in a polythene bottle at room temperature. Stable for 6 months.

2 molar potassium dihydrogen orthophosphate (adjusted to pH 7.0 with NaOH). Dissolve 272 ± 2 gm of anhydrous KH_2PO_4 in about 500 ml of deionised water and then dilute to 1000 ± 10 ml with water. Adjust to pH 7.0 ± 1 by the addition of small aliquots of 1 molar NaOH solution, mixing well after each addition and monitoring the pH using a suitable pH meter. Store in a polythene bottle at room temperature. Stable for 6 months.

1 molar sodium hydroxide. Carefully dissolve 80 ± 1 gm of NaOH pellets in about 800 ml of deionised water, allow to cool and dilute to 2 litres ± 100 ml with water. Store in a polythene bottle at room temperature. Stable for 12 months. Commercial NaOH standard solutions are also available.

pH 4.5 Indicator solution. Dissolve 0.200 ± 0.005 gm of bromocresol green powder and 0.015 ± 0.002 gm of methyl red powder in 100 ± 2 ml of absolute ethanol. Store in an amber glass bottle at room temperature. Stable for 3 months.

0.25 molar sodium hydroxide. Carefully dissolve 20 ± 1 gm of NaOH pellets in about 800 ml of deionised water, allow to cool and dilute to 2 litres ± 100 ml with water. Store in a polythene bottle at room temperature. Stable for 12 months.

A5.6 Procedure

The information below gives generic details for the preparation of the seed control, the quality control sample and the test sample. The actual weights taken for the test should then be entered onto an appropriate test worksheet.

If any of the mixtures described below form a low porosity sticky paste then it is advised to reduce the moisture content by reducing the amount of water added. These details must be entered onto the worksheet.

Green waste seed control preparation

A green waste seed control should be prepared, sufficient to allow the sample to be tested in duplicate. The mixture is prepared by mixing thoroughly 400 ± 10 gm (by dry matter) of seed, 20 ± 1 ml of 2 molar NH_4Cl (5.2.6), 4.0 ± 0.2 ml of 2 molar KH_2PO_4 and sufficient de-ionised water to give a final moisture content of 50 per cent by wet weight. The amount of water to be added is calculated from:

Water to be added (gm) = 400 - [wt of moisture in seed (gm) + 24]

If this seed mixture forms a low-porosity sticky paste, the moisture content should be reduced to, for example, 40 per cent. The amount of water to be added is then calculated from:

Water to be added (gm) = 267 - [Wt of moisture in seed (gm) + 24]

Quality control sample preparation

A mixture of quality control sample and green waste compost seed should be prepared, sufficient for three replicates, by mixing thoroughly 400 ± 5 gm (by dry matter) of control sample, 400 ± 10 gm (by dry matter) of green waste compost seed, 40 ± 1 ml of 2 molar NH_4Cl, 8.0 ± 0.2ml of 2 molar KH_2PO_4 and sufficient de-ionised water to give a final moisture content of 50 per cent by wet weight. The amount of water to be added is calculated from:

Water to be added (gm) = 800 - [wt of moisture in seed (gm) + wt of moisture in control substrate (gm) + 48]

A5.6.1 Test sample preparation

A mixture of the sample to be tested and green waste compost seed is prepared sufficient for three replicate test vessels. The test mixture is prepared by mixing

thoroughly 400 ± 10 gm (by dry matter) of test sample, 400 ± 10 gm (by dry matter) of seed compost, 40 ± 2 ml of 2 molar NH_4Cl as a source of nitrogen, 8 ± 0.5 ml of 2 molar KH_2PO_4 as a source of phosphorus, and sufficient de-ionised water to give a final moisture content of 50 per cent by wet weight. The amount of water to be added is calculated from:

Water to be added (gm) = 800 - [wt of moisture in seed (gm) + wt of moisture in test sample (gm) + 48]

For some wastes, particularly those with a low LOI content, the resulting mixture may be too moist and result in a sticky paste with low porosity, which is not amenable to effective aeration. In such cases the moisture content should be reduced to, for example, 40 per cent. The amount of water to be added is then calculated from:

Water to be added (gm) = 533 - [wt of moisture in seed (gm) + wt of moisture in test sample (gm) + 48]

A5.6.2 Setting up the system

A typical configuration is shown schematically in figure A3 and consists in series of the air humidifier, the reaction vessel and the gas monitoring equipment (which may be either an on-line monitor or a NaOH alkaline trap), with all connected by the air supply tubing. All information regarding setting up the test run should be recorded on the test worksheet.

160 ± 10 ml of 0.25 molar NaOH is added to each air humidifier.

Each composting test vessel is filled with 400 gm of prepared test mixture with a moisture content of 50 per cent (that is, 200 gm dry matter). If the moisture content has been reduced then the amount of test material should be reduced so that the dry matter content added remains at 200 gm.

Two replicate vessels are required for the seed control, and three each for the quality control substrate and for thesample test substrate mixtures. In addition at least one vessel is also set up with no waste as a completely blank vessel.

The reaction vessels are placed in either an incubator or controlled temperature room at 35 ± 2°C and the air lines connected from the humidifier outlet port to the test vessel input port and from the test vessel outlet port to the gas monitoring system.

The air inlet port is connected to the air supply and the flow set at 400 ± 100 ml/min. The system is checked for leaks and to ensure that the outlet gas flow rate from the reaction vessel is 400 ± 100 ml/min.

The test vessels are incubated for four days (96 ± 2 hours) during which the total amount of O_2 consumed (as mg O) or CO_2 produced (as mg CO_2-C) is monitored.

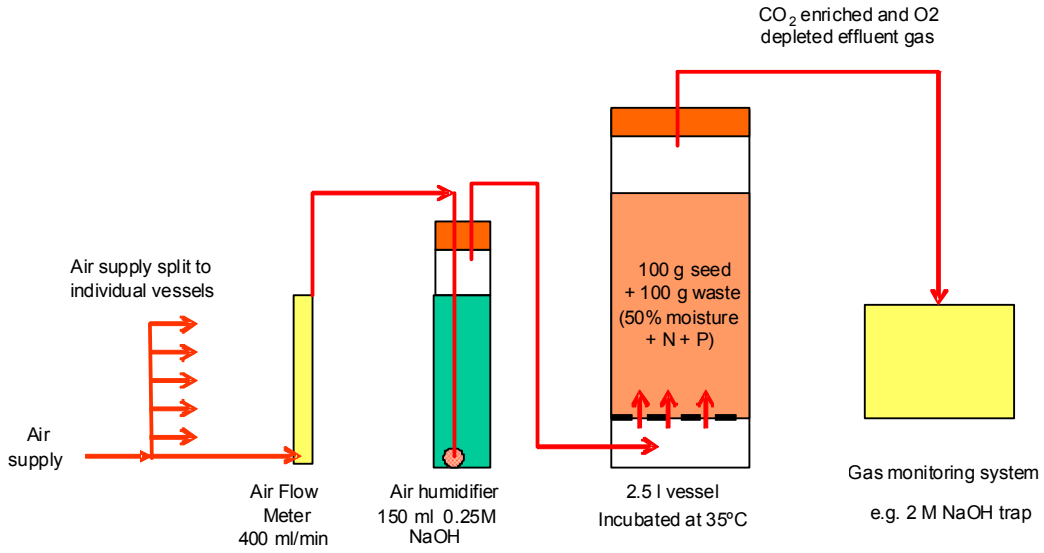


Figure A3 Schematic diagram of aerobic DR4 test set up

A5.6.3 Monitoring carbon dioxide production using the alkaline trap method

The alkaline trap is a simple method for monitoring CO_2 production during the test. The trap consists of a cylindrical vessel, with a capacity of approximately 1000 ml, containing 850 ± 5 ml of 2 molar NaOH.

Principle of the alkaline trap:

Carbon dioxide is an acidic gas and therefore reacts with the alkaline NaOH producing Na_2CO_3. This results in the capture of the CO_2 from the air stream into the NaOH.

$2NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O$ (CO_2 absorption is 1 mole : 2 mole NaOH)

This reaction part-neutralises the NaOH and therefore titration of the remaining hydroxide with 1 molar HCl allows estimation of the amount of CO_2 captured by the trap.

Each vessel contains a sintered glass sparger at the bottom, and these should be connected to the exhaust gas streams from the DR4 test reactor vessels.

850 ± 5 ml of 2 molar NaOH solution is added to each of the cylindrical trap vessels.

The 2 molar NaOH has a limited capacity to absorb CO_2 and therefore the NaOH may need to be changed with fresh 2 molar NaOH in the trap during the test. For most wastes, changing the NaOH in the trap after two days is sufficient but for very active tests producing large amounts of CO2, the NaOH may need to be changed on a daily basis.

At the end of the DR4 test, and whenever NaOH is changed during the test, the volume of the NaOH solution remaining in the trap should be measured and the data recorded on the worksheet. The volume may change from the volume originally introduced due to evaporation of water or condensation of water from the air stream. 150 ± 50 ml of the NaOH solution is decanted into a 250 ml screw cap glass bottle and retained for titration.

A5.6.4 Determination of the residual hydroxide by titration

Titration principle:

The carbonate formed by the absorption of CO_2 is first precipitated as insoluble barium carbonate ($BaCO_3$) by the addition of barium chloride:
$Na_2CO_3 + BaCl_2 \rightarrow BaCO_3 + 2NaCl$

The remaining NaOH is then titrated with HCl:
$NaOH + HCl \rightarrow NaCl + H_2O$

The difference between the volume of 1 molar HCl required to neutralise the alkaline trap NaOH and fresh 2 molar NaOH is then a measure of the amount of NaOH neutralised by the adsorbed CO_2.

Standardisation of the 1 molar HCl

Fill the burette with the 1 molar HCl and set the liquid level to the burette zero mark. Pipette 25.0 $\pm$ 0.2 ml of sodium carbonate solution into a 250 ml conical flask. Add 3 drops of pH 4.5 indicator solution, which turns the solution greenish-blue, place a magnetic follower in the flask and place on a magnetic stirrer.

Titrate the sodium carbonate with 1 molar HCl until the greenish-blue colour changes to greyish-pink with the addition of one drop of HCl. The titre is recorded on the test worksheet.

Repeat steps 7.5.2.1 to 7.5.2.5 for a further portion of sodium carbonate. If the two titres differ by more than 0.5 ml, titrate a further portion of sodium carbonate. Record all of the titres on the test worksheet.

The molarity of the hydrochloric acid is calculated from the equation:

Molarity = 15.096/Mean titre

Titration of fresh 2 molar NaOH solution

Fill the burette with the 1 molar HCl and set the liquid level to the burette zero mark. Pipette 25.0 $\pm$ 0.5 ml of fresh NaOH solution into a 250 ml conical flask and add 25 $\pm$ 5 ml of water. Add several drops of phenolphthalein indicator solution, which turns the solution pink, and a magnetic follower and place the flask on a magnetic stirrer. Titrate the solution with standardised 1 molar HCl until the pink colour disappears with the addition of one drop of HCl. Record the titre (ml) on the test worksheet.

Titration of NaOH solution from the gas collection vessels

Fill the burette with the standardised 1 molar HCl and set the liquid level to the burette zero mark. Pipette 25.0 $\pm$ 0.5 ml of NaOH solution from into a 250 ml conical flask and add 25 $\pm$ 5 ml of deionised water. Add 20 $\pm$ 2 ml barium chloride solution and mix well to precipitate the absorbed CO_2 as barium carbonate. Add several drops of phenolphthalein indicator solution, which turns the solution pink, and a magnetic follower and place the flask on a magnetic stirrer. Titrate the solution with standardised 1 molar HCl until the pink colour disappears with the addition of one drop of HCl. Record the titre (ml) on the test worksheet.

Repeat the steps above until all of the samples have been titrated.

Calculation of CO_2 production

The difference in 1 molar HCl titres between the fresh 2 molar NaOH reading and the CO_2 trap (X ml) is then an estimate of the trapped CO_2.

The titration volume (X ml) is first adjusted for any change in volume of the NaOH solution used in the trap to account for any concentration due to evaporation or dilution due to condensation of moisture in the NaOH.

X_{adj} = X*[Vol in trap at end/Vol in trap at start]

The amount of CO_2-C (mg) trapped in each trap is therefore:

(50 – X_{adj}) x 6 x (Vol in trap at start/50)

The total amount of CO_2-C produced is the sum of the CO_2-C caught in all the traps used over the four days.

Blank adjustment

The blank test (containing no waste test material) measures any CO_2 already present in the gas flowing through the system. The CO_2-C in this blank is then taken away from all the test and seed control readings.

Seed adjusted for blank (S_{adj}) = seed CO_2-C – blank CO_2-C

Test adjusted for blank (T_{adj}) = test CO_2-C – blank CO_2-C

Seed adjustment

The test results are then adjusted for the CO_2 production from the seed.

The first step is to calculate the mean CO_2-C production from the two seed control tests (mS_{adj}).

The next step is to adjust the test vessel CO_2-C production (T_{adj}) for the mean seed CO_2-C production (mS_{adj}). As only half the amount of seed is used in the tests compared with the seed control, the test results are adjusted by taking away half of the mean seed control CO_2-C production to give the CO_2-C production from the test material.

Test adjusted for seed ($T_{CO2\text{-}C}$) = T_{adj} – mS_{adj}/2

A5.7 Expression of results

Whichever method of monitoring is applied, adjustment of either the CO_2-C produced or O_2 consumed from the test vessels is required for the blank empty vessel and the seed control in a similar way as for the alkaline NaOH trap method described above.

Step 1. Subtract the O_2 or CO_2 of the blank from all the seed control and test vessels.

Step 2. Subtract half the mean seed O_2 consumption or CO_2 production from the test vessels.

All of the calculations described below are easily carried out by entering the relevant data into an electronic version of the test worksheet.

Conversion to oxygen consumption

If the test has been monitored by CO_2 production the mg CO_2-C produced can be converted to mg O by assuming a 1:1 molar ratio of CO_2 to O_2; that is, by multiplying by 32/12.

Expression of results in DR4 value units

The results can then be expressed in terms of a DR4 value (four day cumulative oxygen consumption) by summing the data of the four days and expressing the results in terms of LOI (that is, gm O/kg LOI). This is calculated from:

DR4 value (gm O/kg LOI) = gm O consumed/ gm LOI

Where the gm LOI = gm DM of test material added x %LOI/100

Dealing with replicates

Figures for all three replicates should be calculated and the final test result is the mean of the three replicates unless there is clear doubt as to the validity of one of the replicates. In this case the mean of the other two replicates is accepted.

Annex B - Alternative tests for the determination of biogas reduction

B1 Alternative tests for the determination of biogas reduction

B1.1 Introduction

If the change in biogas production option for monitoring an MBT to determine the adjustment factor has been chosen, there may be a delay in obtaining the BMc test value results due to the test taking up to 100 days or more to complete. Alternative biodegradability tests may be used that correlate with the BMc test so that the alternative test can be used to generate BMc test result values much quicker.

An acceptable correlation between the alternative test and the BMc should be established and demonstrated to the Environment Agency prior to its approval as a component of monitoring plans. The initial quarter Level 1 sampling and analysis would then be used to derive a site-specific correlation between the alternative and BMc test which may be used for onward Level 2/3 compliance monitoring.

A provisional estimation of the BMc values may be made from a correlation derived from historical data for the initial quarter monitoring if the timescale for reporting actual BMc values from the first quarter is too late for reporting purposes. Such estimates may be revised by the Environment Agency when the data from the Level 1 monitoring is completed.

The aerobic DR4 test has been approved by the Environment Agency as an alternative biodegradation test and a correlation between the DR4 and BMc has been established which may be used for such provisional estimation of BMc values. Other tests may be proposed but suitable correlation data would be needed for them to be accepted by the Environment Agency prior to use of the test in preference to the BMc.

B1.2 Scope

This technical specification provides guidance for the default correlation between the DR4 and BMc tests. Results from the more rapid DR4 test may then be used to give a provisional assessment of the BMc value and hence BMW reduction before sufficient site specific data is available.

B1.3 Default correlation between DR4 and BMc tests

The four-day aerobic DR4 test (see section A5) is one rapid alternative to the BMc test. The correlation between the DR4 and BMc tests has been established using a dataset of over 140 municipal waste samples from different MBT inputs and outputs. The data were fitted to a simple piecewise model consisting of a linear relationship up to a break point after which the correlation plateaus. This model displayed similar accuracy to other relationships and has been chosen for the default DR4-BMc correlation, as it is the same format as in the previous MBT monitoring guidance.

The piecewise model default correlation between the DR4 and BMc tests is described by the following equation for DR4 values up to 200 g O/kg LOI:

BMc = 2 x DR4

The BMc value at a DR4 value of 200 g O/kg LOI is therefore 400 l/kg LOI and this is applied to all DR4 values greater than 200 g O/kg LOI.

This default correlation is shown in figure B.1.

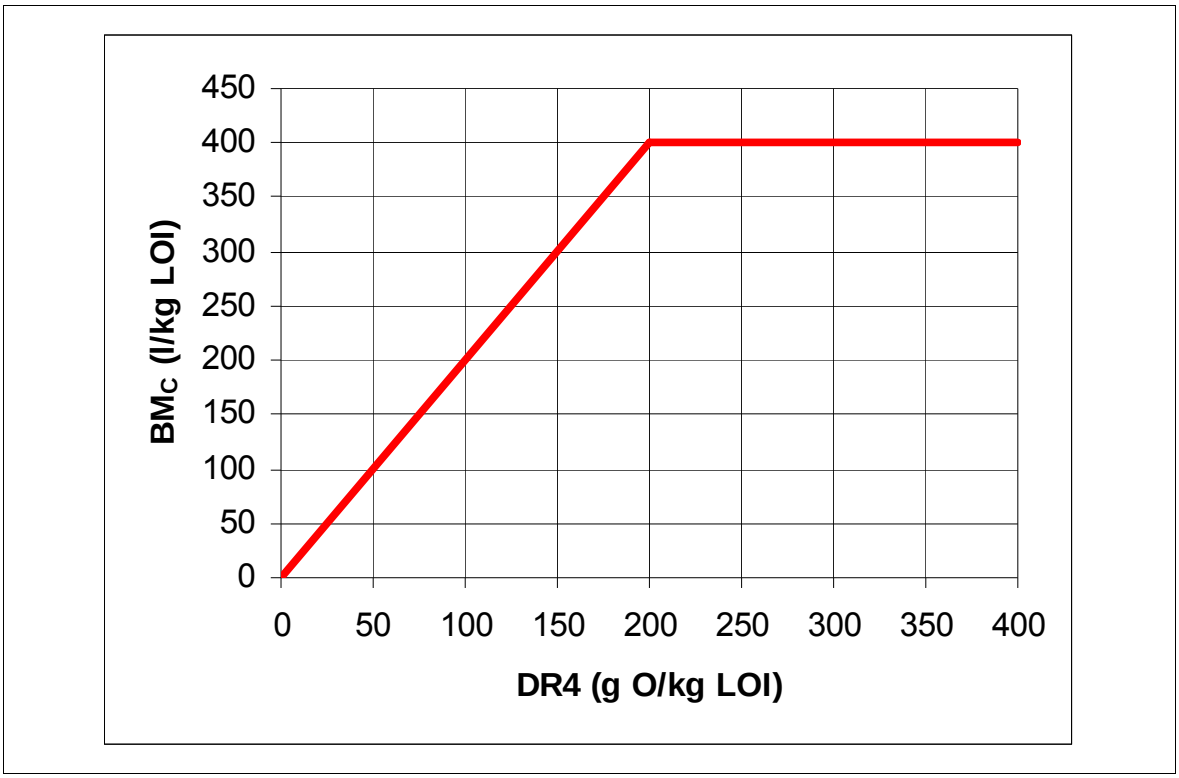


Figure B.1 Default correlation between the aerobic DR4 and anaerobic BMc biodegradability tests.

B1.4 Guidance for development of correlation of alternative biodegradability tests with the BMc test

An acceptable correlation between an alternative biodegradability test and the BMc test should be submitted to the Environment Agency for approval for application in this guidance.

The correlation in figure B.1 above between the DR4 and BMc tests is based on linear regression analysis of samples collected from a wide variety of MBT plants that have different degrees of biological treatment. Consequently the spread of the data covers all degrees of waste biodegradability from very stabilised material to raw untreated material. The Environment Agency would accept a similar regression comprised of at least 30 data points evenly distributed across the range and that has a correlation coefficient (r) of 0.9 or above.

For most MBT plants however, there may be only an untreated input and one or two outputs landfilled. The biodegradability of any particular input and output would be expected to be within a narrow range and therefore development of a correlation based on regression of this limited range of data would not be appropriate.

The approach therefore is to develop correlations for site-specific waste streams (input or output) in order to develop conversion factors (C_f) to calculate the BMc value from the alternative test value.

$BMc = C_f \times$ Alternative test value

The conversion factor for any input or output waste stream should be based on a minimum of 12 samples of the particular input and/or output stream. These samples would be those collected during the Level 1 monitoring, though data collected during commissioning of the plant can be used to develop site-specific correlations if available.

The data for the 12 samples would be analysed to determine the range, mean and relative standard deviation for the alternative test and the BMc test. The conversion factor is then calculated for each sample and the mean C_f calculated for application in the guidance (table B.1).

The use of this conversion factor is accepted if:

- The relative standard deviation (%RSD) of both the alternative and BMc test is ≤ 20 per cent.

- The alternative test value is within the 99 per cent confidence limits for the BMc test values used to develop the conversion factor.

  The 99% confidence limits are calculated from:

  Mean ± (t value) x SE

  Where SE is the standard error of the mean = $\sigma\sqrt{n}$ and t value is the t distribution statistic for 99 per cent confidence limits at (n -1) degrees of freedom. For 12 samples n = 12 and t = 3.106.

If the alternative test value falls outside the confidence range then use of the conversion factor would not be permitted and the samples would need to be tested by the BMc test.

The Level 2/3 monitoring requires that a minimum of one sample per quarter is analysed by both the alternative and BMc test to ensure that the conversion factor is still appropriate. This is tested by determining the 99 per cent confidence limits for the conversion factor (table B.1).

If the conversion factor calculated from the Level 2/3 monitoring sample falls outside these limits then the conversion factor may not be valid and all the samples would need to be measured by the BMc for the quarter.

Table B.1 Example calculation of alternative biodegradability test conversion factor from Level 1 data.

	Input MSW		
	DR4 g/kg LOI	BM_C l/kg LOI	Conversion factor C_F
12 Level 1 sample data (n=12)	173	302	1.746
	204	433	2.123
	176	317	1.801
	175	335	1.914
	172	324	1.884
	173	363	2.098
	174	337	1.937
	161	292	1.814
	153	272	1.778
	187	267	1.428
	172	226	1.314
	177	272	1.537
Mean	175	312	1.781
Stdev σ	12.4	53.7	0.2
%RSD	7.1	17.2	13.9
Mean C_f			**1.781**
Standard error of mean (SE)	3.585	15.493	0.072
t-value at 99%confidence (11 d.f)	3.106	3.106	3.106
SE x t-value	11.134	48.121	0.222
Maximum value at 99% confidence	186	360	2.00

Annex C - Example sampling plan and site check list

Table C.1 Example Sampling Plan.

LEVEL 1 INITIAL CHARACTERISATION SAMPLING PLAN	
GENERAL INFORMATION	
Project Code:	
Sampling plan completed by: A. Person	On behalf of: Client
Site Name and operator: Contact: Tel:	Material producer: Contact: Tel:
Other involved parties: Agreement of overall monitoring plan required by Environment Agency	
Sampling to be carried out by: (Consultant/ Operator)	Specify name of sampler: A N Other
SPECIFY THE OBJECTIVE OF THE TESTING PROGRAMME	
Overall Sampling Objective: To determine the A_f and hence BMW diversion tonnage during the initial three-month characterisation period. **Technical Goal:** To collect a sample of each waste input and associated outputs which contain BMW and which are intended for landfill that are representative of a single day's operation. It is intended that the chosen day should be representative of operating conditions within the initial characterisation quarter and that testing will produce a measure of the average quality characteristics within the period rather than information on the extremes. This activity will be repeated within the quarter according to the sampling frequency laid out in the Guidance and the results would be used to determine a mean A_f.	
Background information: Wastes are collected from domestic dwellings and commercial properties Monday to Saturday. The daily average composition of the waste delivered to the waste reception hall is envisaged to change from day to day, and week to week. In accordance with the guidance, wastes will be sampled on each day of the week for the X and Y weeks of this initial period. Output samples will be matched to the corresponding input days waste. This means that some samples will be taken on the same day as the inputs e.g. reject streams, but for others there will be a lag time introduced by the treatment process which is taken into account below. Each set of samples represents a spot sample in time – a day, and should provide a sample that is suitably representative of the average properties of the residues on that day.	
DEVELOPING THE PRACTICAL INSTRUCTION	
SAMPLE POINT 1	
• **Type of material**: Waste received at the Plant	Location: Waste Reception Hall
Form and nature of arising: Short-term stockpiles of input wastes in the collection hall.	
Background information: Wastes are collected from domestic dwellings and commercial properties Monday to Saturday. The daily average composition of the waste delivered to the waste reception hall is envisaged to change from day to day, and week to week. In accordance with the guidance, wastes will be sampled on each day of the week for the X and Y weeks of this initial period.	
Access problems that may affect sampling programme: Delivery vehicles to be excluded from the hall during increment collection. Detailed stock control required to ensure each load is delivered to a separate area prior to the collection of an increment and then moved to a central stockpile area.	
SAMPLING METHODOLOGY	
Scale: Sample to be collected from a volume of waste representative of a days delivery of waste.	
Sampling population: Sampling to be carried out on wastes generated over a single operating day.	
Specify detailed sampling location: Input sample stream to be sampled from selected loads that are tipped in isolation.	
Specify date and time(s) of sampling: Samples taken each day (Mon-Sat) of weeks X and Y. A random time selected to collect the first sample. Further samples to be collected across the operating day as waste is delivered. An average of 20 deliveries are expected each day (except Saturdays when	

an average of ten deliveries are expected).
Specify persons to be present: A N Other
Identify equipment: Mechanical shovel and a stainless steel spade.
Specify no. of samples to be collected: 12 samples to be collected.
Specify no. of increments per sample: 20
Specify increment size/sample size: The primary sample shall consist of at least 20 mechanical grab increment samples that are combined and mixed. The final sample size shall be ~400 kg.
Description of sampling event: Sampling should be carried out across the entire operational day. **Input samples:** A primary sample shall be collected that consists of at least 20 grab samples taken using a mechanical excavator. If the number of input loads exceeds 20, then loads for sampling shall be selected at random to give a total of 20 but these should represent inputs throughout the day. Following deposition of the load in the collection hall, a mechanical excavator shall be used to mix the load prior to taking a single grab which shall be placed to one side. This operation will be repeated on 20 occasions until a primary sample consisting of 20 grab samples has been produced. If the number of loads received is less than twenty (Saturdays), two grabs shall be taken from each load (which may mean the primary sample consists of more than 20 grab samples).
Detail requirements for on-site determinations: Visual examination only.
Identify safety precautions: Site specific health and safety requirements should be adhered to at all times.
SUB-SAMPLING
Detail procedure: Approximately 20 mechanical grab samples should be collected for each sample. Mix the primary sample material by forming a conical heap using a mechanical excavator by taking material from the bottom and placing it on the top of the preceding one. Repeat this action at least 10 times. Flatten the cone to a uniform thickness and diameter. The height shall be less than or equal to the height of a hand held shovel blade. Divide the heap into theoretical quarters Produce the necessary size of laboratory sample by taking spadesful from alternate quarters and transferring each increment into the sample container(s).
Sample coding methodology: Each sample shall have an indelible label on the outside of the container and a paper label sealed inside a polythene bag placed inside the main collection bag prior to sealing. The following coding should be adopted: Residue code: Site/ Producer: Identification of any treatment: Initial Characterisation (IC): Sample collection number (S1.1, S1.2, …, S1.12): Time (of sample collection): Date: Initial of Sampler.
SAMPLE POINT 2
• **Type of material**: Large Screening Rejects to Landfill — Location: Large Screening Rejects Bin
Form and nature of arising: Large screening rejects deposited in a storage bin by screening process.
Background information: Wastes are shredded and screened on the day of receipt. The process includes over-band magnet and blowers to remove paper and plastic. These streams are recovered as recyclables and as a source of RDF. Output samples will be matched to the corresponding input days waste due to the same day operations.
Access problems that may affect sampling programme: The bin is filled during the day, and at least two bins are required for the days operations. Sampling from the bin will required the process to be stopped and mechanical grab-samples to be obtained. The configuration of the plant does not allow collection of the material from any other point.
SAMPLING METHODOLOGY
Scale: Sample to be collected from a volume of waste representative of a days large screening rejects.
Sampling population: Sampling to be carried out on wastes generated over a single operating day.
Specify detailed sampling location: Large reject screening bin.

Specify date and time(s) of sampling: Samples taken each day (Mon-Sat) of weeks X and Y. A random time selected to collect the first sample. Further samples to be collected across the operating day as the reject bin is filled.
Specify persons to be present: A N Other
Identify equipment: Mechanical grab and a stainless steel spade.
Specify no. of samples to be collected: 12 samples to be collected.
Specify no. of increments per sample: 20
Specify increment size/sample size: The primary sample shall consist of at least 20 mechanical grab increment samples that are combined and mixed. The final sample size shall be ~400 kg
Description of sampling event: Sampling should be carried out across the entire operational day. **Large screening rejects:** As the waste to be sampled is discharged into a bin it is important to sample all the material from different depths and not just the most accessible. 20 grab samples will be taken at set intervals as the container is being filled.
Detail requirements for on-site determinations: Visual examination only.
Identify safety precautions: Site specific health and safety requirements should be adhered to at all times.
SUB-SAMPLING
Detail procedure: Approximately 20 mechanical grab samples should be collected for each sample. Mix the primary sample material by forming a conical heap using a mechanical excavator by taking material from the bottom and placing it on the top of the preceding one. Repeat this action at least 10 times. Flatten the cone to a uniform thickness and diameter. The height shall be less than or equal to the height of a hand held shovel blade. Divide the heap into theoretical quarters Produce the necessary size of laboratory sample by taking spadesful from alternate quarters and transferring each increment into the sample container(s).
Sample coding methodology: Each sample shall have an indelible label on the outside of the bag and a paper label sealed inside a polythene bag placed inside the main collection bag pre-sealing. The following coding should be adopted: Residue code: Site/ Producer: Identification of any treatment: Initial Characterisation (IC): Sample collection number (S2.1, S2.2, … S2.12): Time (of sample collection): Date: Initial of Sampler.
SAMPLE POINT 3
• **Type of material**: Composted stabilised material | Location: Composting hall
Form and nature of arising: The compost rows are built up over a week of processed waste inputs. The rows are matured over a six-week period (from first day of inputs) prior to being transferred to landfill. Rows are mechanically turned and aerated twice weekly over the six week period.
Background information: The processing of the waste within the compost hall allows the matching of the weeks input wastes to the compost final output, six weeks later. Whilst the compost is turned several times during the process, the days inputs should be approximately located by the distance along the compost row.
Identify access problems that may affect sampling programme: N/A
Scale: Each sample to be collected from a volume of waste representative of a days waste input.
Sampling population: Sampling to be carried out on wastes generated over the operating input weeks X and Y, following the six week composting period.
Specify detailed sampling location: At regular intervals along the weekly compost row
Specify date and time(s) of sampling: Sampling shall occur at the end of the composting period, six weeks after in was deposited.
Specify persons to be present: A N Other
Identify equipment: Mechanical shovel and a stainless steel shovel.

Specify no. of samples to be collected: 12 samples to be collected
Specify no. of increments per sample: 20
Specify increment size/sample size: The primary sample shall consist of at least 20 increment spade loads and the sample size shall be 20kg.
Description of sampling event: Sampling shall be carried out prior to the composted material being transferred to landfill. Six samples (matched to the 6 days of waste input for that weeks stockpile) shall be collected during the single sampling event. **Output samples:** The compost row shall be levelled out prior to commencement of sampling, to a depth equivalent to a shade-blade. The row shall be divided into six portions representing the matched Monday to Saturday's waste inputs. Twenty shovel loads shall be collected randomly over the full width, breadth and depth of a portion and combined to form the primary sample. The process shall be repeated on the other five portions until six primary sample piles have been formed.
Detail requirements for on-site determinations: Visual examination only.
Identify safety precautions: Site specific health and safety requirements should be adhered to at all times.
SUB-SAMPLING
Detail procedure: Approximately 20 spade loads shall be collected for each primary sample. For each primary sample, mix the material by forming a conical heap using the stainless steel shovel by taking material from the bottom and placing it on the top of the preceding one. Repeat this action at least 10 times. Flatten the cone to a uniform thickness and diameter. Divide the heap into theoretical quarters Produce the necessary size of laboratory sample by taking trowel loads from alternate quarters and transferring each increment into the sample container. At the end of the sampling exercise there shall be six samples of 20kg of composted material. These match (as far as is practicable) to a weeks waste input sampled at sample point 1. **Identify sample coding methodology:** Each sample should have an indelible label on the outside of the bag and a paper label sealed inside a polythene bag placed inside the main collection bag pre-sealing. The following coding should be adopted: Residue code: Site/ Producer: Identification of any treatment: Initial Characterisation (IC): Sample collection number (S3.1, S3.2 …S3.12): Time (of sample collection): Date: Initial of Sampler.

Table C.2 Points to be addressed for sample collection and delivery of samples to the test laboratory.

Taking the sample	• The sample(s) should be taken in accordance with all instructions provided in the sampling plan. Before sampling, undertake a visual check of the material to be sampled and compare against any information in the sampling plan. Potential problems should be discussed with the person responsible for implementing the plan prior to sampling.
	• A record should be made of the location and status of the material to be sampled, a photograph may be useful.
	• Having obtained the sample, it should be either directly stored in a suitable sample container or stored after appropriate sub-sampling in the field.
Delivery	• The sample(s) need to be delivered to the testing laboratory at the address provided in the sampling plan, with a copy of the chain of custody form and the sampling record.
Reporting	• On completion of sampling a sampling record and chain of custody form should be completed by the sampler. The sampling record should document all procedures undertaken and any observations from the sampling exercise. It will reiterate much of the sampling plan but contains space for recording visual observations made in the field and any deviations from those procedures identified in the sampling plan. Key information that should be recorded includes: • A unique sampling number (for example reflecting site location, material and date). • Date and time of sampling • Place and point of sampling. • Persons present (if witnesses are present, including name and address). • Difficulty of access (obstacles), including information on those areas or volumes of the material that were not sampled. • Condition of material. o Colour. • Consistency/homogeneity/grain size (uniform or diverse). • Observations during sampling (for example gassing out, reactions, development of heat, odour). • Details of on-site determinations. • Identify sample amount (estimate volume and mass). • Sub-sampling methodology (if undertaken - recording which samples are mixed, in what volumes, time and date). • Name of sampling personnel. • Place, date and signature.
Documentation of variations	• Any changes to the agreed final sampling plan should be recorded in the sampling record. Such alterations to the sampling plan can be categorised in two ways: • Changes which do not affect the objective of the testing programme in that the required samples are obtained and remain representative at the pre-defined level. The sampler in the field may carry out this level of change. • Changes which (could) affect the objective of the testing programme (for example resulting in a different quality of samples/results). This level of alteration to the sampling plan should only be carried out with prior written agreement. If, due to unforeseen circumstances, changes are required to the sampling plan at the time of sampling, verbal confirmation of any changes should be recorded in writing on the sampling record and authorised on return from the field. Unforeseen practical considerations can make it necessary to make changes to the sampling plan in order to carry out the sampling activity. It is therefore important that the person undertaking sampling is in a position to know what changes are possible without affecting the testing programme.

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