Characterisation of treated wastes - headlines and more questions

Conference or Workshop Item

CHARACTERISATION OF TREATED WASTES – HEADLINES AND MORE QUESTIONS

K LEWIN *, J TURRELL*, A GODLEY**, J FREDERICKSON[+], N BLAKEY[o] and J GRONOW [oo]

** WRc plc, Frankland Road, Blagrove, Swindon, Wiltshire, SN5 8YF, U.K.*
*** AEA Technology plc, Harwell, Didcot, Oxfordshire OX11 0QJ, U.K.*
[+]Integrated Waste Systems, The Open University, Walton Hall, Milton Keynes, MK7 6AA, U.K.
°Waste Evidence Branch, 5D Ergon House, 17 Smith Square, London, SW1P 3JR, U.K.
°° Imperial College, Centre for Environmental Policy, South Kensington, London, SW7 2AZ, U.K.

Key words: waste characterisation, leachability, biodegradability, treatment, emissions

SUMMARY: Good quality waste characterisation data are fundamental to strategies to manage environmental challenges, yet the UK dataset for the new generation of treated wastes was poor. A three-year project funded by Defra, the UK Department for Environment, Food and Rural Affairs, aimed to fill some of the gaps in understanding the characteristics of residues from the treatment of municipal solid waste and industrial process wastes. The project has demonstrated the benefits of following a consistent sampling plan approach. It has generated a public domain characterisation database on composition, leaching behaviour and biodegradability for a diverse set of wastes, including kappa values (a way of defining the decreasing source term of a non-volatile contaminant) for a range of contaminants for landfill modelling. The project has also highlighted more questions that require further research e.g. in relation to the impact of application of partially stabilised wastes to land, leachability of organic materials and the longer-term monitoring of emissions and waste characteristics from organic waste treatment plant.

1. BACKGROUND

The waste hierarchy, landfill pre-treatment requirements and landfill diversion targets are among the drivers for increasing the range and quantity of residues from treatment. Information on the gross composition, leaching behaviour and biodegradability of UK residues from many treatment processes was poor, making it difficult to predict the behaviour of these residues with respect to release of metals, nutrients and greenhouse gases following recycling to land or landfilling.

Proceedings Sardinia 2009, Twelfth International Waste Management and Landfill Symposium
S. Margherita di Pula, Cagliari, Italy; 5 - 9 October 2009

A Defra funded project WR0110 “Characterisation of industrial process and treatment residues” aimed to fill some of the gaps in understanding the characteristics of treated wastes both from treatment of municipal solid waste (MSW) and residues from industrial processes. The project was multi-faceted with a consortium that consisted principally of WRc plc, Open University, Cranfield University, Golder Associates (UK) Ltd and ECN (Energy research Centre of the Netherlands. It had two key aims:

- provide “state of the art” data and information on the characteristics of pre/post-treatment wastes;
- provide a UK-wide data resource focusing on composition and leachability (through UK support to leachXS©);

This paper presents the ‘headlines’ from the three-year research programme as recently reported (Defra, 2009a). It also considers in more detail some themes that have not previously been presented at Sardinia conferences (e.g. Godley *et al.*, 2007 and Turrell *et al.*, 2007) including aspects relating to the application of biodegradability tests, generation of kappa values for organic wastes for landfill modelling, emissions from treatment plant and the characteristics of gasification residues (in comparison with incineration residues) and cement-stabilised wastes.

2. MANAGING THE TESTING PROGRAMME

2.1 Sampling and testing

The design of the sampling plans follows the guidance provided by the Framework Standard EN 14899:2005 and 5 supporting Technical Reports produced by CEN Technical Committee 292, Working Group 1. Two basic approaches have been used in sampling plan design.

The **organic waste programme** required collection of a wide range of organic residues to provide a calibration line for the biodegradability tests used to assess landfill diversion of biodegradable municipal waste (BMW). In the UK, these tests are the anaerobic 100-day BM100 test and aerobic 4-day DR4 test. For the initial test programme single snapshots were needed from a comprehensive set of processes, as opposed to repeat sampling for a small number of residues. To ensure compatibility between sample types and sampling events a generic sampling plan was produced, supported by site-specific sampling records. The 38 organic wastes tested include 18 BMW samples derived from mixed municipal solid waste (MSW) with the rest being specific organic wastes (e.g. feathers, pizza and fish wastes) many of which had undergone treatment by composting, anaerobic digestion or autoclaving (Godley *et al.*, 2007). Testing included general and elemental composition, biodegradability, biochemical composition and one-step compliance leaching at liquid-to-solid ratio 10 l/kg (L/S10) (BS EN 12457-2). In addition the upflow percolation test, BS DD CEN/TS 14405, was carried out on 5 selected organic wastes representing different stages of decomposition and/or the end-points of different treatment processes. These were: fully composted greenwaste, BMW from mechanical biological treatment (MBT) treated by anaerobic digestion (AD), fully composted BMW from MBT and partially composted BMW from MBT. Anaerobically digested sewage sludge was also included as there is an existing regulatory framework for its disposal to land and land application is a potential route for many of these other treatment residues.

Whilst every effort was made to collect representative samples, the study was limited to only a single sample per source in most cases. Therefore the results should not be taken as definitive characteristics of the wastes in question, but seen as an evaluation of the characterisation methods and the potential of the dataset for assisting future Defra research and policy development.

In contrast the **inorganic waste programme** was focused on collecting more comprehensive data for a smaller number of waste streams. This objective was achieved by selection of a discrete number of processes or plants, each of which handled a complex cocktail of input wastes and operated a suite of basic treatment recipes. A second objective of this testing programme was to obtain samples that represented the extremes and middle ground of waste inputs and outputs and encompassed the range of processes being undertaken at the selected plants. A number of site-specific sampling plans were produced that targeted each individual operating regime. Paired input/output samples were collected from a suitable fixed operating period determined after analysis of background testing data and discussions with plant personnel. The following treatment residues were tested:

- filter cakes from a 100,000 tonne per annum (tpa) continuous batch physico-chemical treatment process handling hazardous and non-hazardous liquid industrial effluents;
- residues from a 100,000 tpa continuous batch physico-chemical process treating air pollution control (APC) residues from MSW energy-from-waste (MSWI) plants;
- bottom ash and APC residues from a 35,000 tpa continuous batch full scale European MSW gasification plant, to provide data to assess comparability with traditional incineration residues; and
- cores from a European cement stabilization plant for hazardous wastes including APC residues from MSW energy-from-waste plants (MSWI APC) and metal filter cakes.

A number of representative spot samples of the output wastes were taken within the identified period from a representative mix of process input wastes. Each spot sample comprised 20 increments to ensure that the sample was representative of the chosen scale of sampling, which in this case, was the size of the load of treated waste being taken off site for disposal. The samples were not designed to be linked. Instead the random sampling approach provides information on the wider population of waste that is not directly sampled.

A comprehensive dataset was required to avoid limiting secondary research. Therefore in addition to compositional analysis, the full toolbox of leaching behaviour tests was used as appropriate (compliance - BS EN 12457:2002, upflow percolation - BS DD CEN/TS 14405:2004, pH dependence - DD CEN/TS 14429:2005, maximum availability - EA NEN 7371:2004 and diffusion test for monolithic wastes - EA NEN 7375:2004). The MSW gasification residues and cement-stabilized 'monolithic' wastes were obtained from European plant and characterised by SINTEF and ECN respectively.

2.2 Data management

The test data have been exported to the national satellite database of the leachXS© system (van der Sloot, *et al.*, 2003 and http://www.leachxs.org/LeachXSFlyer.pdf, Defra, 2009(b)). The database can be interrogated at several levels by a range of users allowing the leaching behaviour and composition of specific plant outputs to be compared and the characteristics of generic waste streams to be evaluated on a national and, ultimately, European basis. Operationally, such powerful contextual information may reduce future requirements for plant-specific testing. LeachXS© is backed up by a powerful geochemical modelling framework, ORCHESTRA, which offers the potential for predicting long-term emissions as undertaken for the Sustainable Landfill project (van Zomeren *et al.*, 2005).

3. KEY THEMES

3.1 Biodegradability testing of organic wastes

3.1.1 Correlation between short-term aerobic and lon- term anaerobic tests (DR4 and BM100)

The current methodology for measuring BMW for the UK Landfill Allowance Trading Scheme (LATS) purposes is based on the total wet weight of the BMW, i.e. one LATS unit is equal to one tonne of wet weight of BMW. The aerobic DR4 and anaerobic BM100 biodegradability methods were developed as tests used in the MBT monitoring guidance (Environment Agency, 2005b) to measure the reduction in the biodegradable fraction of the organic matter that occurs during MBT. A correlation between the tests was established so that the quicker and less costly 4-day aerobic DR4 test could be used to give an estimate of the potential biogas production from the BM100 tests.

The biodegradability testing on the MSW-derived BMW samples together with other commercial BMW samples has been used to determine a more statistically valid correlation between the two tests which has been applied in the current revision of the Environment Agency MBT monitoring guidance (Environment Agency, 2009).

A good between-test correlation was exhibited by the MSW-derived BMW samples, but not by specific waste streams (e.g. feathers, card, food and greenwaste, (Godley *et al.*, 2007)). The use of the correlation between the two tests should therefore only be applied within its original design application, that is, for MSW-derived mixed BMW associated with MBT monitoring. If the BM100 test results for specific organic waste components of BMW are compared on a wet weight basis, the biogas production values do not match the biodegradability values currently applied to BMW components within LATS (Table 1). Whilst the BM100 data represent anaerobic biodegradation in the short term (100 days) they may not indicate ultimate biodegradability over an extended time-scale of several decades, but may represent the inherent biogas production potential risk when landfilled.

The authors recommend the use of actual rather than assumed biodegradability wastes within strategies to divert BMW from landfill. The application of actual biodegradability (biogas) production characteristics of organic wastes provides a better scientific base from which to take policy decisions that would reflect real risks from environmental emissions of methane.

Table 1. Comparison of measured anaerobic biodegradability of BMW components with UK LATS values

Sample	*BM100 l/kg LOI*	*% LOI*	*% DM*	*Biogas l/kg wet wt*	*LATS assumed bio-degradability factor (%)*
Feathers	375	97.9	56.6	208	100
Cardboard	210	90.0	92.3	174	100
BMW (1)*	385	67.4	50.0	130	100
BMW (2)**	312	71.6	53.6	120	100
Mixed food waste	489	91.8	26.8	120	100
Newspaper	130	94.0	90.1	110	100
Greenwaste	182	73.8	41.0	55	100
Mixed wood waste	27	99.1	94.4	25	100

* Biodegradable municipal waste input to MBT process 1 (BMW fraction 1)
** Biodegradable municipal waste input to MBT process 2 (BMW fraction 2)

3.1.2 Enzymatic hydrolysis test (EHT)

A novel non-microbial enzyme hydrolysis test (EHT) has been developed as a potential substitute for the DR4 test (Godley *et al.*, 2004; Wagland *et al.*, 2008). It was shown (Godley *et al.*, 2007 and Wagland *et al.*, 2009) that the EHT provided a better correlation with the BM100 than the DR4, and provided biodegradability data in much shorter time scales (24 hours) than other tests. However, further development of the EHT method is required to ensure its robustness and versatility.

3.2 Landfilling of MBT outputs

One measure for defining the decreasing source term of a non-volatile contaminant is to use kappa values. The Environment Agency's LandSim software tool for groundwater risk assessment for landfill design (Environment Agency, 2004) uses kappa values to describe the decline of the leachate source term with time for different contaminants. Wahlström, *et al.*, (2006), recommend the use of kappa values generated from column leaching tests. The upflow percolation test (BS DD CEN/TS 14405) was applied in duplicate to 5 selected organic wastes.

Samples were run in standardised anoxic/low redox conditions as far as possible. The application of the upflow percolation test proved feasible experimentally although some adaptations were required as the standard method does not cover some issues, in particular:

- the standard packing method is not applicable to sludges - the sewage sludge sample used an adapted procedure that would need further testing to be generally applicable;
- the standard column size and timing produces a low volume of eluate for the early fractions, limiting the number of analyses possible;
- the high dissolved organic content of eluates makes filtration difficult and complicates analysis.

Table 2 shows the kappa values and total amount of leached materials for DOC, NH_4^+ and Cl^- for the 5 selected wastes. These results show a similar amount of leaching at L/S10 from the one-step and upflow percolation test for most samples. Note also that, as expected, highly leachable NH_4^+ is present in the AD treated materials and poorly leachable NH_4^+ present in the extended composted samples. In general the higher the kappa value the more rapid the leaching of any particular parameter. The full significance of these results needs further evaluation and although there is some variation, the values do provide a starting point for further LandSim modelling of landfills with MBT outputs.

The full implications of this in terms of landfilling of wastes and the sustainability of landfills requires further investigation. It is inconceivable that landfills will not be required in the future as any waste resource management is likely to produce reject materials. These rejects are likely to contain higher levels of pollutants than the untreated waste they were derived from due to cherry-picking from the source waste of materials more amenable for recycling. The behaviour of such materials in landfills should be fully investigated, perhaps moving towards waste acceptance criteria for MBT outputs landfilled.

Table 2. Comparison of kappa values and leached ions for five organic wastes

Waste	*Greenwaste*	*ex-MBT biodegradable fraction of municipal waste*			*Sewage sludge*
Treatment	*Fully composted*	*AD treated*	*Fully composted*	*Partially composted*	*AD treated*
Parameters					
Kappa values					
DOC	0.38	0.37	0.17	0.30	0.22
NH_4^+	0.72	0.31	0.22	0.92	0.17
Cl^-	3.6	0.37	0.92	0.51	0.28
DOC leached mg C/kg					
One-step L/S10 test	2240	3510	1450	12100	3310
Upflow percolation	2890	3890	1100	8000	1190
NH_4^+ leached mg N/kg					
One-step L/S test	18	693	127	382	8170
Upflow percolation	96	2010	91	165	1370
Cl^- leached mg/kg					
One step L/S test	1890	1620	6600	2870	646
Upflow percolation	1920	2090	2790	3870	591

3.3 Recycling organic wastes to soil

3.3.1 Metal content of MSW derived BMW samples

The UK PAS100 standard is a benchmark for quality composts for all applications including preparation of horticultural growing media. The application of treated source-segregated BMW components such as PAS100-compliant greenwaste compost to agricultural soils is permitted where agricultural benefit is demonstrated. However lack of knowledge of potential contaminants prevents the application to agricultural soil of compost like outputs (CLOs) derived from MBT of mixed-source MSW.

Table 3 summarises metal concentrations for the organic wastes against PAS100 limit values for Cd, Cr, Cu, Ni, Pb, Zn and Hg and whether the waste samples exceed the PAS100 limits. A significant number of the BMW-derived samples failed the PAS 100 limits with 14 of 18 failing for Pb. Most samples derived from MSW exceeded the PAS 100 standard for metals.

However other wastes permitted to be applied to land, such as sewage sludge, often exceed the PAS100 standard for metals. Table 4 shows the PAS100 metal limits, average metal concentrations for 18 BMW-derived samples, and average metal concentrations for sewage sludge. The regulation of sewage sludge application to agricultural soils is focused on limiting the accumulation of metals in receiving soils rather that metal contents of the sewage sludges (SI 880:1990, Department of the Environment, 1996). The application of MBT-derived CLOs to agriculture might be similarly regulated, provided it is agreed that the sewage sludge application is acceptable.

Table 3. Heavy metal contents of the organic wastes characterised in this study

	Concentration mg/kg dry matter					*Number samples failing PAS 100*		*BMW-derived samples > PAS 100 limits*
Element	*Mean*	*StDev*	*Min-imum*	*Maxi-mum*	*PAS 100 Limit values*	*Total*	*BMW-derived*	
Al	6963	4343	192	16795	-	-	-	-
Fe	10042	8375	70	40840	-	-	-	-
Mn	229	135	14	537	-	-	-	-
Cd	0.8	0.5	0.1	2.1	1.5	2	2	11%
Cr	81	82	10	365	100	8	7	39%
Cu	132	157	7	660	200	7	6	33%
Ni	58	52	3	179	50	16	14	78%
Pb	465	931	32	4251	200	14	14	78%
Zn	283	214	36	1103	400	10	9	50%
Hg	*	*	<0.09	2.5	1.0	3.0	2.0	11%
As	6.5	2.9	2.4	12.6	-	-	-	-
Ba	137	96	3	355	-	-	-	-
Mo	6.3	6.3	0.7	24.3	-	-	-	-
Sb	5.2	4.9	0.1	19.3	-	-	-	-
Se	0.8	0.6	0.1	2.8	-	-	-	-
Ag	1.4	1.6	0.3	8.0	-	-	-	-
Co	5.4	3.3	0.3	17.3	-	-	-	-
Sr	-	-	2.0	>360	-	-	-	-
V	-	-	3.0	>40	-	-	-	-

*Concentrations <detection limits for 10 samples: Mean and StDev not calculated

Table 4. Comparison of MSW derived BMW samples with sewage sludge metal contents (mg/kg)

Source	Zn	Cu	Ni	Cd	Cr	Pb	Hg
PAS100:2005	400	200	50	1.5	100	200	1
Sewage sludge 1996/7*	792	568	57	3.3	157	221	2.4
BMW (18 samples)	412	197	93	1	116	769	n.d.

Note *: Source of sewage sludge data: Gendebien *et al.,* 1999.

3.3.2 Nitrogen fertilizer value of organic wastes

Application of organic wastes to agricultural land may be carried out to provide N fertilizer. Anaerobically digested sewage sludge has been applied to agricultural land for many years due to its high N fertilizer value; it is therefore useful to compare the recycling to land of sewage sludge and other treated organic wastes in terms of their relative N fertiliser value. A worked example for a sandy soil (Defra 2009a) showed that the total N and free NH_4^+ content of the sewage sludge was much higher and the C/N ratio much lower than the other organic wastes considered. The sewage sludge was also not fully stabilized as indicated by the DR4 and BM100 biodegradability tests. This means that the sewage sludge provides an immediate source of N as free NH_4^+ and some slow release N by mineralisation of the decomposable fraction of the organic matter, typically considered to be about 15% of the total N made available in the first year of application (Defra, 2000).

Table 5. Comparison of N-fertilizer value for selected organic waste samples

Parameter	*Units*	*Composted Greenwaste*	*AD treated BMW*	*Fully Composted BMW*	*Partially Compostd BMW*	*AD treated Sewage Sludge*
Dry matter(DM) content	% wet wt	70.6	33.2	72.7	46.5	18.6
LOI content	%DM	30.2	60.6	25.4	64.9	60.9
Carbon content (LECO)	%DM	17.7	33.9	13.7	38.6	30.5
Total N content (LECO)	%DM	1.2	1.5	0.7	1.4	4.7
Leachable NH_4^+ at L/S10	mg N/kg DM	18	693	127	148	8170
C/N ratio		14.8	22.6	19.6	27.6	6.5
Zinc content	mg/kg DM	208	491	511	445	681

Table 5 shows that the N fertilizer value would be much less for the other wastes when compared with sewage sludge. For example the composted greenwaste is fully biostabilized; therefore there would be very little further decomposition and further N mineralisation. Although not fully stabilized, the partially composted BMW has a high C/N ratio and low N content. Therefore there would be little free NH_4^+ released during mineralisation as it would be re-fixed into microbial biomass. Significantly higher application rates of the other wastes would be needed to achieve the same N fertilizer value as sewage sludge. This would have implications for the associated application of heavy metals and other contaminants to the soil.

3.3.3 Recycling organic wastes as soil conditioners

The same worked example for a sandy soil has been extended to demonstrate that if the same wastes were applied to land as a soil conditioner, e.g. with the aim of doubling the soil organic carbon content, then high tonnages would need to be applied, with concomitant increase in metal and nitrogen loading. In trials on the long-term effects of sewage sludge applications to soils, negative impacts on Rhizobia have been reported in study plots treated with high applications of sewage sludge of up to 80 tonnes C/ha (Defra, 2002). These responses seem to have been worse in plots also receiving high inputs of zinc or copper and it is possible that the high oxygen demand imparted by the addition of large amounts of organic matter may have enhanced potential toxic effects of the metals.

Fully stabilized wastes may contain significant amounts of leachable organic carbon. This is considered to consist mainly of humic material and to be of low biodegradability. This may be degraded in the soil, adsorbed by the soil or leached to contaminate surface and ground water, this may require some consideration, especially as soluble humic acids often chelate and solubilise metals. As soil restoration activities may apply organic wastes to several hectares the potential risk from stabilized organic matter may be significant. It is therefore recommended that the potential implications on soil quality and function and the affect on surface and groundwater quality as a result of applying large amounts of stabilized and un-stabilized organic wastes to land are investigated.

There have been recent developments in the testing of natural organic matter in soil and wastes (van Zomeren and Comans, 2007). Information on speciated organics could be used to assess the significance and potential impact of leachable organic compounds, including those originating from natural degradation and potentially hazardous compounds derived from anthropogenic activities.

3.4 MBT emissions to air

A scouting study was undertaken at a tunnel composting facility during its commissioning phase. This pilot study investigated the composting of both source-segregated household waste and residual waste. The aims were to assess the practical feasibility of monitoring emissions, to determine the level of emissions generated at key processing stages and to understand better the relationship between emissions and waste characteristics. At this site it was possible to undertake gas sampling at various key locations including the ambient air, the air within the composting hall, the process air following windrow composting, the compost hall air extraction system (switched on during windrow turning) and the exhaust gas from the gas treatment biofilter.

Measurable concentrations of targeted key gases (CH_4, N_2O, NH_3, CO_2, O_2) and VOCs were found in most gas samples taken, indicating that monitoring is feasible. The concentration of key gases was similar in the composting hall to the ambient air and only slightly enhanced following windrow turning. The process air (sucked through the windrow) was sampled from three windrows containing source-segregated household waste (2x2 days and 1x2 weeks old) and a fourth windrow containing residual waste (3 weeks old). Elevated levels of CH_4, N_2O, VOCs and NH_3 were found in the 2 day old and 2 week old source-segregated household waste windrows whilst levels were greatly reduced for the 3 week old residual waste windrow. In contrast the CO_2 was higher and the O_2 lower in the three week old windrow containing waste with the lowest oxygen demand, indicating that effective composting was taking place.

Table 6. Data from MBT operation

	Process air composition							*Waste characteristics*			
Windrow age	*CH_4*	*N_2O*	*FID**	*PID**	*NH_4*	*CO_2*	*O_2*	*DM*	*LOI*	*Respiration – DR4*	
	ppm	*ppm*	*ppm*	*ppm*	*ppm*	*%*	*%*	*%*	*%*	*g O/kg LOI*	*g O /kg DM*
3 weeks	106	0.32	149	8	3	3.4	17.8	59.9	56.4	138	77.8
2 days	426	1.34	1435	115	7	1.61	19.1	42.2	75.4	221	167
2 days	2372	2.16	2900	88	25	2.4	18.1	39.6	76.3	233	178
2 weeks	256	1.49	435	73	12	1.94	18.7	43.0	75.2	192	144

* FID = flame ionisation detector, mostly VOCs including methane

#PID = flame photoionisation detector, VOCs (not methane) and some inorganic compounds

The snapshot results shown in Table 6 suggest that the 3 week old windrow was utilising oxygen more effectively compared with the three windrows containing the more biologically active wastes (i.e. higher DR4 values) which could be considered to have a greater potential for emissions of CH_4 and VOCs. Hence, on the basis of CO_2 and O_2 levels, the younger windrows appeared to be insufficiently aerated to match their inherent oxygen demand and may be expected to be more anoxic compared with the 3 week old windrow. In practice this was found to be the case (Table 5). For the two windrows containing 2-day old waste, one windrow produced exceptionally high methane emissions while the other windrow had become so anoxic that the resulting highly acidic conditions actually inhibited high methane generation during the monitoring period (data not included). Elevated levels of methane were detected on the biofilter surface even though the composting facility was working very much under capacity during the monitoring period (data not included).

It is clear from the pilot study that it is important to optimise processing conditions during the composting of fresh biodegradable waste, characterised by very high oxygen demand (DR4), since anoxic conditions in windrows can have the potential to produce very high levels of methane (organic carbon; TOC), which is not effectively ameliorated through biofiltration. Overall, assuming that dedicated MBT facilities using biofilters in the UK will produce similar findings, the study suggests that such facilities may have the potential to emit much greater loads of TOC to air compared with similar German facilities, which employ Regenerative Thermal Oxidation to treat plant emissions rather than biofilters.

These results indicate that matching the waste characteristics to emissions may indicate potential risks for enhanced greenhouse gas emissions from biological treatments. This approach may also provide the necessary data to model process conditions with the aim of maximising waste biodegradation while minimising environmental impact.

3.5 Characteristics of MSW gasification residues and treated air pollution control residues from MSW incineration (MSWI APC residues)

The inorganic waste streams tested were filter cakes and treated MSWI APC residues from physico-chemical treatment, MSW gasification bottom ash and APC residues and cement-stabilised hazardous wastes including MSWI APC residues and metal filter cakes.

The data management tool leachXS© has enabled a rapid comparison of data to indicate variability of waste streams and to compare new data on the characteristics of treatment residues with traditional wastes.

For example, although there is interest in MSW gasification in the UK, uptake of the technology is currently low and public domain information on the characteristics of the residues almost non-existent. Test data for both bottom ash and APC residues from a European gasification plant have been obtained as part of this study. To provide context, the data were plotted with the more extensive characterisation profile of MSW incineration bottom ash using leachXS©.

Figure 1 plots lead leachability concentrations in mg/kg from the pH dependence test against eluate pH for the gasification residue (large squares) and MSWI bottom ash. The similar leaching profiles indicate that the mechanism controlling lead leachability is likely to be the same for both generic residues but the plot also demonstrates that the pH dependent lead leachability of bottom ash from MSW gasification is at similar concentrations to that of MSW IBA (source of some data is leachXS©).

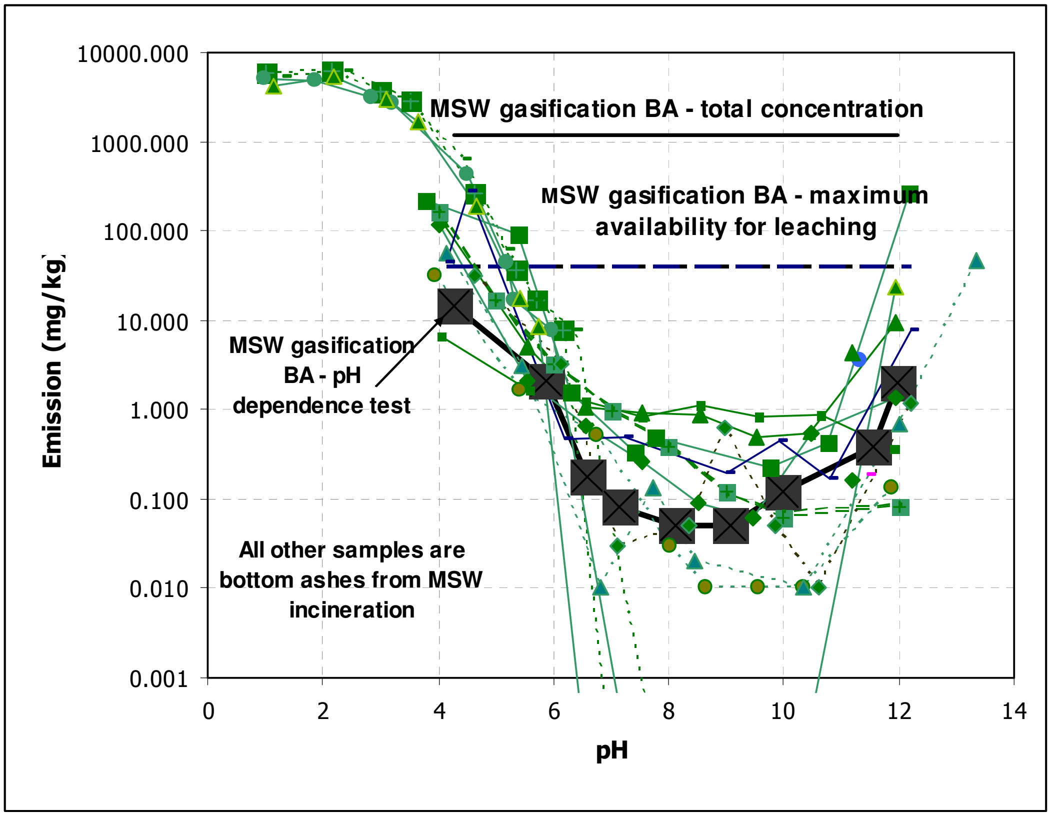

Figure 1. Lead leachability of MSW gasification bottom ash in context of leachXS© data for MSW incineration bottom ash

Similar comparisons of APC residues from MSW gasification, physico-chemically treated MSWI APC residues (all this study) and untreated MSWI APC residues also highlighted generic leaching profiles for many contaminants. In the key pH range (pH 6-12), the cadmium, copper and zinc leachability of untreated gasification APC residues was at least an order of magnitude lower than for untreated APC residues from MSW incineration, while data for treated MSWI APC residues fell between the two. Overall leachable concentrations were generally highest from the untreated MSWI APC residues, followed by the MSW gasification APC residue. The treated MSWI APC residues leached the lowest concentrations.

Full reporting and plotting of leachability data is presented in Defra, 2009a. In addition kappa values for landfill modelling have been derived using the leaching test concentrations from the column leaching test BS DD CEN/TS 14405 upflow percolation test. This includes values for those parameters for which little suitable leaching data exist to date, such as barium, molybdenum, fluoride, nickel, lead and zinc for the three inorganic treatment residues in addition to the 5 organic waste treatment residues.

3.6 Characteristics of 'monolithic' cement-stabilized wastes

Four cores of cement stabilised MSWI APC residues samples (with or without supplementary binders or metal sludge) were tested as granular and monolithic wastes. Duplicate testing of crushed cement-stabilized APC residues indicated that granular landfill waste acceptance criteria (WAC) for Cl and total dissolved solids (TDS) were exceeded by up to a factor of 1.7. The data for the wastes containing APC residues alone indicate that recipe modification to reduce leachability below granular WAC and therefore acceptance to hazardous waste landfill should be achievable. Recipes containing metal filter cake and the substitute binder present more of a challenge.

In examining the leaching data from the tank test, EA NEN 7371, the leaching behaviour of chloride was of the greatest significance. The cement stabilization process was not able to reduce the mobility of the high levels of Cl present in MSWI APC residues, as demonstrated in Figure 2. Both the UK (SI 1640:2005) and the (less strict) proposed Dutch limits were exceeded within a few days of the test commencing.

The testing has demonstrated that the dominant leaching mechanisms were dissolution and contaminant depletion rather than diffusion. This suggests that the stabilized waste samples tested were not true monolithic waste samples and supports research undertaken for Defra by the University of Dundee on Waste Solidification Methods and Stability Assessment (Defra, 2009(c)). Testing as granular materials rather than as monolithic wastes could therefore be more appropriate. This concurs with the recommendation of the Nordic Council of Minsters (Helmar *et al.*, 2006) which considers that there should be no differences between the compliance testing of granular and monolithic wastes for landfill acceptance. The current regulatory position in the UK is that monolithic wastes can be crushed and assessed against the granular waste acceptance criteria or assessed against the monolithic waste acceptance criteria using the tank test. This work suggests that there is no need for a change.

The chemistry of the stabilization process has been assessed in greater detail by ECN using the geochemical modelling functions of ORCHESTRA within leachXS© (Defra, 2009(a) and (b)).

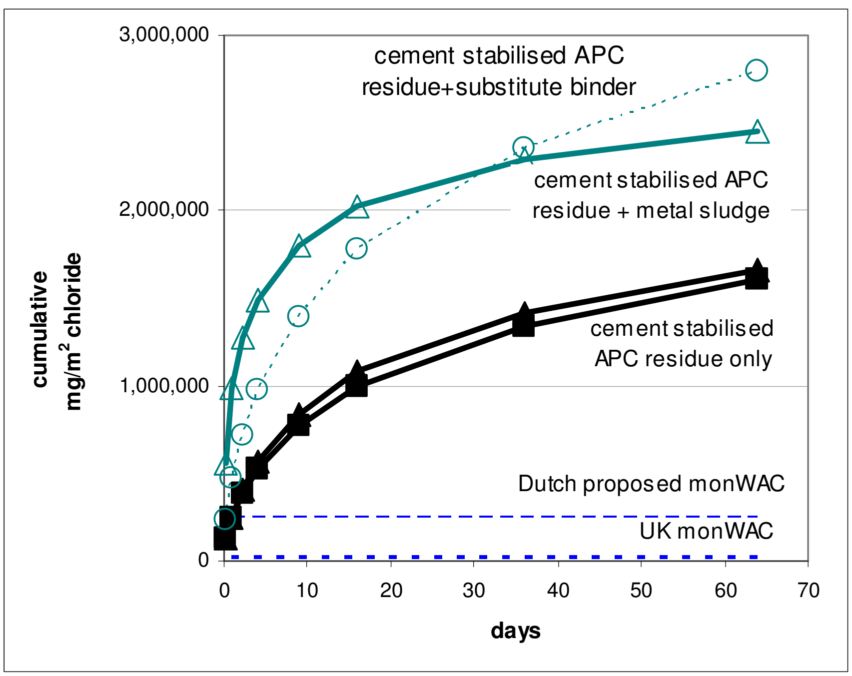

Figure 2. Cumulative chloride release from stabilized APC residues using EA NEN 7375.

4. HEADLINES

4.1 Application of sampling and testing toolbox

- A valuable new public domain dataset on the composition, leachability and biodegradability of waste treatment residues has been generated to increase the evidence base for policy makers and waste management specialists. The dataset is now available for secondary research on inputs and outputs from the treatment of a range of mixed and single-stream organic wastes as well as waste treatment filter cakes, municipal solid waste gasification residues and cement-stabilized incineration residues from an operational European stabilization plant.
- The project has demonstrated the benefits of taking a consistent approach to sampling and testing. The series of sampling plans developed for this project allows replication of the sampling approach to aid interpretation and trend-analysis. The full characterisation toolbox has been used as appropriate. Waste output quality from a single plant can be variable. However, the leaching behaviour of generic wastes between plants can be comparable. Where waste streams can be shown to exhibit a common leaching fingerprint, more extensive, EU-wide test data, for example as held in LeachXS©, can be used to put limited site-specific data into context. The benefits of this data management and expert tool to technical specialists and policy developers can be seen, for example it allows the rapid comparison of the characteristics of the new generation of treatment residues with more traditional waste streams.
- The upflow percolation leaching test has been successfully applied to organic waste streams although the standard method presented technical challenges. Further method development on sample preparation, especially related to moisture content and column packing methods, is recommended. Data from the upflow leaching test enabled kappa values to be obtained for the 5 key organic waste streams (each representing different stages or types of treatment) and for the inorganic treatment residue for future fate and behaviour modelling of key contaminants. In addition to kappa values for major ions, it was possible to generate tentative values for a range of trace determinands for which values are scarce or missing. Further testing is recommended to validate these values and to extend the range of treatment residues for which kappa values can be calculated.
- Calculations for landfill diversion of biodegradable municipal waste require reliable data on dry matter content and loss on ignition as well as consistent sample preparation methods for obtaining homogenised BMW sample from untreated material (e.g. MSW or MBT residues). Between-laboratory comparisons show that the base datasets are robust. Sample preparation procedures for large mixed municipal waste samples should be agreed before testing commences.
- The two biodegradability tests used to assess biodegradable municipal waste diversion (Environment Agency, 2005b) are the 4-day and 100-day DR4 and BM100 biodegradability tests. A statistically valid correlation between the tests has been achieved for BMW derived from mixed inputs but not for specific waste streams such as feathers and food waste. This correlation should therefore only be applied for mixed-source BMW associated with monitoring mechanical-biological treatment plant.
- Data from the BM100 test represent anaerobic biodegradation in the short term (100 days). This may not indicate ultimate biodegradability over an extended time-scale of several decades, but may represent the inherent risk of potential biogas production when landfilled.
- Data from the 24-hour non-biological enzyme hydrolysis test (EHT) correlate well with the more time consuming and costly 100-day BM100 test. However, further research is in progress to improve its versatility and validity.

- The leaching data for cement-stabilized wastes showed that generally the contaminant release from the wastes was not controlled by diffusion i.e. that the wasteforms did not perform as monoliths. Assessment of cement-stabilized air pollution control residues as granular wastes rather than as monolithic wastes may therefore be more appropriate.

4.2 Potential impact from treatment process or management of treatment residues

- The nitrogen fertilizer value of most organic wastes is much lower than that of sewage sludge. More organic waste would therefore be needed to be applied to soils to provide the same fertiliser value as sewage sludge. The partially stabilized organic wastes have a high requirement for oxygen. There is a risk that the soil system would be unable to sustain the oxygen needed for respiration by the *in situ* microbial population and so adverse anoxic conditions might then exist in the soil.
- As with sewage sludge, most of the organic wastes derived from mixed municipal waste contained levels of metals that exceeded PAS100 limits for metals in quality compost. Where the material is to be applied to land, it may be more appropriate to use limit values for sewage sludge application to land (Department of the Environment, 1996) where sludge application is considered acceptable. A comparison of the metal concentrations with PAS100 limits indicated that the majority of the wastes which failed the limits for Cd, Cr, Cu, Ni, Pb and Zn were derived from MSW. Where the material is to be applied to land rather than for use as a quality compost, it may be more appropriate to use limit values for sewage sludge application to land where sludge application is considered acceptable. Further research is needed to establish the impact of these anoxic soil conditions on the leachability of contaminants within the treated wastes.
- Fully stabilized composted wastes contain high levels of dissolved organic carbon. Further research is needed to determine the risk to groundwater and surface water from dissolved organic components in the treated wastes, including potentially toxic/ecotoxic compounds derived from anthropogenic activity.
- Mechanical biological treatment of biodegradable municipal waste results in the concentration of metals in the treated residues. There is tentative evidence that MBT also brings about short-term stabilization of metals although this requires verification. There may be a benefit in landfilling MBT residues if the stabilization is permanent. This would be in line with the aims of operating sustainable landfills.
- Pilot study monitoring of an MBT plant showed the importance of optimising processing conditions during the composting of fresh biodegradable waste. The study suggests that such facilities with biofilters may have the potential to emit much greater loads of total organic carbon to air compared with facilities employing Regenerative Thermal Oxidation to treat plant emissions. Matching the waste characteristics to emissions may indicate potential risks for enhanced greenhouse gas emissions from biological treatments. This approach may also provide the necessary data to model process conditions with the aim of maximising waste biodegradation while minimising environmental impact. There is a need to close the extensive knowledge gaps on the most efficient use of biofilters for MBT and there is scope for improved regulation, such as the adoption of a standard suite of analysis.

5. KEY RECOMMENDATIONS

When interpreting waste characterisation data it is important to understand the source, scale, timescales and operational factors of relevance to the sample. The use of sampling plans according to EN 14899 is therefore recommended to ensure replication of the sampling approach. Waste producers need to be encouraged to use the full characterisation toolbox relevant to their waste stream rather than relying only upon tests required for compliance monitoring. A wider uptake of upflow percolation leach testing will provide further data to verify the kappa values reported here and to extend the range of waste streams for which they are available.

The most appropriate criteria for assessing the performance of the cement-stabilized wastes collected for this report were the landfill waste acceptance criteria for granular wastes, not for monolithic wastes.

The characterisation of organic wastes has highlighted some intriguing issues related to the landfilling and land application of the treated residues. We therefore recommend further research in the following areas.

- *Long-term leaching of metals from landfilled MBT residues:* assessing the leachability of carefully linked inputs and outputs to residues from a number of MBT plants will demonstrate whether or not MBT affects the short-term stabilization of metals.
- *Impact of soil application of partially treated wastes on the biological oxygen demand in soils:* investigation is needed to determine whether detrimental effects are observed and whether organic waste applications to soil should be limited by biological oxygen demand.
- *Leachable organic compounds from partially stabilized or stabilized organic waste applied to soil:* information on dissolved organic carbon, an indicator of the total load to surface and groundwater, needs to be extended through assessments of specific organic contaminants, including potentially hazardous compounds derived from anthropogenic activities.
- *Longer-term monitoring of emissions and waste characteristics from organic waste treatment plant:* mass–balance calculations require rigorous linked monitoring of inputs and output wastes and gaseous and liquid emissions. This should incorporate seasonal and operational variations at a number or plants representing different treatment operations. Matching the waste characteristics to emissions may indicate potential risks for enhanced greenhouse gas emissions from biological treatments It is recommended that further work is carried out to verify these initial findings through a full study of emissions and characterisation of waste from treatment plant to support the design and adoption of a risk-based regulatory approach for monitoring emissions from MBT and composting processes.

ACKNOWLEDGEMENTS

The authors wish to thank the treatment plant operators for their cooperation in preparing sampling plans and providing samples. We also acknowledge the contribution of Hans van der Sloot and André van Zomeren of ECN for access to, and training in, leachXS© and for the characterisation of the stabilized wastes; the teams at SINTEF and the Open University for their analytical support, in particular Graham Howell; and Richard Smith and Stuart Wagland, formerly of Cranfield University. Finally we thank our peer reviewers David Hall of Golder Associates (UK) Ltd and Keith Knox of Knox Associates (UK) Ltd for input at critical decision points in the project.

REFERENCES

BS EN 12457-2:2002 Characterization of waste - leaching - Compliance test for leaching of granular waste materials and sludges – Part 2: One stage batch test at a liquid to solid ratio of 10 l/kg for materials with particle size below 4 mm (without or with size reduction). British Standards Institute, London.

BS EN 12457-3:2002 Characterisation of waste. Leaching. Compliance test for leaching of granular waste materials and sludges. Two stage batch test at a liquid to solid ratio of 2 l/kg and 8 l/kg for materials with a high solid content and with a particle size below 4 mm (with or without size reduction). British Standards Institute, London.

BS EN 14899:2005 Characterisation of waste – Sampling of waste materials – Framework for the preparation of a Sampling Plan. British Standards Institute, London.

BS DD CEN/TS 14405:2004 Characterisation of waste – leaching behaviour tests – Upflow percolation test (under specified conditions). British Standards Institute, London.

BS DD CEN/TS 14429:2005 Characterization of waste. Leaching behaviour tests. Influence of pH on leaching with initial acid/base addition. British Standards Institute, London.

EA NEN 7371:2004 Determination of the availability of inorganic components for leaching. – solid earthy and stony materials Environment Agency translation based on the Netherlands Normalisation Institute standard NEN 7371. http://www.environment-agency.gov.uk/static/documents/Business/ea_nen_7371_2004_1026067.pdf *Accessed April 2009.*

EA NEN 7375:2004 Leaching characteristics – determination of the leaching of inorganic components from moulded or monolithic materials with a diffusion test – solid earthy and stony materials. Environment Agency translation based on the Netherlands Normalisation Institute Standard NEN 7375. Environment Agency, Bristol

Defra (2000) Fertiliser recommendations for agricultural and horticultural crops (RB209): Seventh edition. http://www.defra.gov.uk/FARM/environment/land-manage/nutrient/fert/rb209/. *Last accessed April 2009.*

Defra (2002). Effects of sewage sludge applications to agricultural soils on soil microbial activity and the implications for agricultural productivity and long term fertility. Report ref: SP0125, CSA4751, 31 July 2002. http://tinyurl.com/d5cdyu *Last accessed March 2009.*

Defra (2009a) Characterisation of industrial process and treatment residues. Final report of project WR0110. (*in prep*).

Defra (2009b) UK support for EU LEACHXS expert database on waste characterisation. Final report of project WR0108. (*in prep*).

Defra (2009c) Non-Radioactive Waste Solidification Methods and Stability Assessment. Final report of project WR0603. (*in prep*). http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=14748.

Department of the Environment (1996). Code of practice for agricultural use of sewage sludge. http://www.defra.gov.uk/environment/water/quality/sewage/pdf/sludge-cop.pdf. *Last accessed March 2009.*

Environment Agency (2004). LandSim v 2.5: Landfill performance simulation. Available from Golder Associates (UK) Ltd, Nottingham. www.landsim.com/

Environment Agency (2005). Guidance on monitoring MBT and other processes for the landfill allowances schemes (England and Wales). Environment Agency, Bristol. http://environment-agency.resultspage.com/search?p=Q&ts=ev2&w=+Guidance+on+monitoring+MBT+and+other+processes+for+the+landfill+allowances+schemes&x=13&y=8. *Last accessed March 2009*

Environment Agency (*2009*). Guidance on monitoring of MBT and other treatment processes for landfill allowances (England and Wales) for LATS and LAS. Environment Agency, Bristol, in preparation. http://environment-agency.resultspage.com/search?p=Q&ts=ev2&w=+Guidance+on+monitoring+MBT+and+other+processes+for+the+landfill+allowances+schemes&x=13&y=8 *Last accessed March 2009*

Gendebien, A., Carlton-Smith, C., Izzo, M. and Hall, J. (1999) UK Sewage Sludge Survey - National Presentation. Environment Agency R&D Technical Report P165, WRc Swindon 1999.

Godley, A., Frederickson, J., Lewin, K., Smith, R and Blakey, N. (2007). Characterisation of treated and untreated biodegradable wastes. *Proceedings Sardinia 2007: Eleventh International Waste Management and Landfill Symposium,* S Margherita di Pula, CISA Caglari, Italy.

Godley, AR., Lewin K., Graham, A., Barker, H and Smith, R (2004). Biodegradability determination of municipal waste: an evaluation of methods. In proceedings of *Waste 2004: Integrated Waste Management and Pollution Control: Policy, Practice, Research and Solution*. The Waste Conference Ltd., Coventry.

Hjelmar, O., Holm, J., and Gudbjerg, J. (2006) Development of criteria for acceptance of monolithic wastes at landfills. *Nordic Council of Ministers*. Copenhagen. ISBN 92-893-1379-X.

Turrell, J., Lewin, K., Godley, A., Smith., Fredrikson, J., Blakey, N. and Gronow, J. (2007) Characterisation of treated wastes to support sustainable waste management. *Proceedings Sardinia 2007: Eleventh International Waste Management and Landfill Symposium,* S Margherita di Pula, CISA Caglari, Italy.

SI 1640:2005 Landfill (England and Wales) (Amendment) Regulations, OPSI, London.

SI 880:1990 Sludge Use in Agriculture (Amendment) Regulations, OPSI, London.

Van der Sloot, H.A., Seignette, P., Comans, R.N.J., van Zomeren, A., Dijkstra, J.J., Meeussen, J.C.L., Kosson, D.S., and Hjelmar, O. (2003). Evaluation of environmental aspects of alternative materials using an integrated approach assisted by a database/expert system. Advances in Waste Management and Recycling, Dundee, Scotland, pp. 769-790.

Van Zomeren, A., van der Sloot, H.A., Meeussen, J.C.L., Jacobs, J. and Scharff, H (2005). Prediction of the long-term leaching behaviour of a sustainable landfill containing predominantly inorganic waste. *Proceedings Sardinia 2005, Tenth Sardinia International Waste Management and Landfill Symposium.* S. Margherita di Pula, CISA, Cagliari.

van Zomeren, A and Comans, R.N.J (2007) Measurement of humic and fulvic acid concentrations and dissolution properties by a rapid batch method, *Environmental Science and Technology*, 2007, **41**, pp. 6755-6761.

Wahlström, M., Laine-Ylijoki, J., Hjelmar, O., Bendz, D. and Rosqvist, H. (2006). Models For Impact Evaluation On Landfill - Aspects for appropriate modelling. Nordic Innovation Centre, Oslo.

Wagland, S.T., Tyrrel, S.F., Godley, A.R. and Smith, R. (2009). Test methods to aid in the evaluation of the diversion of biodegradable municipal waste (BMW) from landfill. *Waste Management*, **29** (3) pp1218-1226.

Wagland, ST., Godley, AR., Frederickson, J., Smith, R. and Tyrrel., SF (2008). Comparison of a Novel Enzymatic Biodegradability Test Method With Microbial Degradation Methods *Communications in Waste and Resource management,* **9** (3) pp.80-86.