Environmental Impacts of Landfilling MBT Residues

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	"Theory on Brontosauruses by Ann Elk (Miss)
Miss Elk:	My theory by A. Elk brackets Miss, brackets. This theory goes as follows and begins now. All brontosauruses are thin at one end, much much thicker in the middle, and then thin again at the far end. That is my theory, it is mine, and belongs to me and I own it, and what it is too.
Presenter:	That's ***it***, is it?
Miss Elk:	Spot on, Chris
Presenter:	Well, er, this theory of yours appears to have hit the nail on the head."
	Monty Python's Flying Circus, Series 3, Episode 5, 1972

Abstract

The EU Landfill Directive seeks to reduce greenhouse gas missions by requiring Member States to reduce amounts of biodegradable wastes being landfilled. There is extensive evidence that MBT processes can be successful in achieving this, by significantly reducing overall emissions of carbon in gases and leachates, when residues are landfilled. This is important, since lack of markets is likely to mean that most such MBT residues are disposed of by this route. However, it has not yet been demonstrated whether landfills containing MBT wastes will exhibit reduced aftercare periods, when compared with normal MSW landfills. It is likely that waste components responsible for longer-term emissions of contaminants such as ammoniacal-N and "hard" COD, will not be readily-degraded during normal MBT processes. This paper discusses the issues involved, and illustrates these with results from a recent research study undertaken on behalf of the UK Environment Agency.

Keywords

MBT, processes, fate, nitrogen, carbon, outputs, landfill, leachate, timescales, wastes

1 Introduction

Although in the UK and many other countries, the proportion of the household waste stream that will be treated using MBT processes will rise rapidly during the next five years, nevertheless, much of the output from these plants is likely to continue to be landfilled into the future.

During the last decade, research has looked at the impact that MBT processes have on residues produced, and on their behaviour when disposed of in landfill sites. It is now widely recognised that such pre-treatment, even when undertaken in a relatively rudimentary way, will significantly reduce initial emissions from a landfill, in terms of acetogenic leachates, and of landfill gas emissions.

Nevertheless, much of this research has, inevitably, only been able to look at relatively short timescales for emissions, and has focussed on carbon-based emissions (methane, carbon dioxide, TOC, COD etc). This is inevitable for two main reasons:

(1) The force driving diversion of household wastes from landfills is primarily concern about greenhouse gas emissions of methane and carbon dioxide, and

(2) In general, when dealing with "composting processes" for most waste streams (manures, green wastes, sewage sludges etc), the objective is to produce an output of a compost product, that can be applied to land as a soil conditioner and fertiliser. In these circumstances the presence of nitrogenous compounds (ammoniacal-N, organic-N, oxidised-N) in compost is generally beneficial.

A different situation exists, however, when MBT outputs are to be landfilled. Here, long-term emission of ammoniacal-N in leachates is a major consideration, in terms of environmental risk and of post-closure monitoring and of maintenance requirements for the completed landfill.

Much less research has specifically examined the fate of nitrogen during composting processes undertaken as part of MBT of household wastes, and subsequently once the outputs from the process are landfilled. There is no guarantee that intensive composting processes which provide optimum removal of organic carbon compounds, will necessarily provide most efficient removal of nitrogenous compounds.

This paper outlines the basic issues involved in the fate of both carbon and nitrogen during MBT processes, and when outputs from such treatment are subsequently landfilled. The paper provides some results from a research project recently completed on behalf of the UK Environment Agency, to collect data and sample leachates from full-scale EU landfills that have received inputs of MSOR, or of MBT residues.

2 Introduction

Most people attending this conference, who have any sort of landfill experience, have been brought up on a long-term diet of "brontosaurus graphs". From the original and still valid graphs of Farquhar and Rovers, 1973, through various modified versions of these, the graphs retain several common features.

- A y-axis marked "concentration" or "emissions", usually without units or scales,
- A general x-axis marked "time" or "years", also without units, and
- Residual values of y, which continue beyond the right hand side of the graph.

Even for untreated MSW in large landfills, the area of the graph to the right hand side, beyond about 30 years after wastes have been landfilled, remains an area of uncertainty. For one thing, few landfills exist that were operated to modern day standards before the late 1970s. Earlier landfill sites were generally smaller, less-well contained and controlled, and also often contained different waste materials – the open fire was much more common in people's homes, for example.

Although hundreds of millions of Euros have been invested in extraction and utilisation of landfill gas in Europe, at modern landfills containing untreated MSW, few data exist which demonstrate reductions in landfill gas yield, or even quantify accurately the overall yield of gas from specific waste inputs at specific landfills.

Long-term data for reduction in concentrations of contaminants in leachate from full-scale modern landfills are equally lacking, in spite of extensive monitoring and characterisation of leachate quality, in many studies (eg Robinson, 1995; 2005; Robinson and Knox, 2001; Ehrig, 1983; Ehrig and Kruempelbeck, 2001).

"Accelerated" laboratory and pilot-scale data for long-term emissions from landfilled wastes have provided little comfort to site operators. Although studies have often indicated that the majority of gas production may be completed within a period of 30 years (eg see Knox, 2005), they have equally demonstrated that very strong and contaminated leachates generally remain at this stage, and that soluble contaminants released during wastes decomposition and gas production will continue to be released for centuries, rather than decades. During this period they will require active management at containment landfills. Water may take many decades to pass once through a modern landfill (eg see Robinson and Latham, 1993), and many bed volumes of water will be required to flush decomposing wastes, such that leachates require no further active management.

3 The Effects of MBT on Landfill Leachate Quality

The European Council Directive on the Landfill of Wastes 1993/31/EEC (LFD), places a requirement on Member States to draw up strategies that ensure the amount of biodegradable municipal waste deposited at landfill progressively reduces over a 15 year period to only 35% of the total amount produced in 1995. The LFD also requires Member States to only landfill wastes that have been subjected to treatment and incineration, leading to a reduction in their quantity, or in hazard to human health or the environment. It is anticipated that Mechanical and Biological Treatment (MBT), and incineration of municipal waste will increase substantially in the UK, in order to achieve these objectives.

In some other EU Member States, composting is already a much more common pre-treatment technique for household waste fractions, where it accounts for quantities of waste at least as high as those hoped to be reached in the UK. Experience has been that, in spite of great efforts to encourage markets for it, only a limited proportion of the compost produced from the organic fractions of MSW can be sold, or even given away, for use as soil conditioner. Markets for MSW derived compost are unlikely to be greater in the UK than elsewhere.

It therefore seems inevitable that significant quantities of composted fractions of MSW will have to be landfilled in the UK, as they have been for many years in other EU countries. This may well often be undertaken in the guise of being used as daily cover for the landfilling of other wastes. It is therefore important to consider the environmental impacts of this material within landfills, particularly on emissions of leachate and landfill gas.

In 2001 the UK Environment Agency began a research project to consider the potential impact of the Council Directive, on the quality of leachate that will be produced in the future from UK landfills (Environment Agency R&D Project P1-494). Work included investigations into the landfilling of municipal solid wastes (MSW) that have been subjected to mechanical biological treatment (MBT), and the impacts that this has on leachate quality. Work involved collection of data from published papers, and from European experts in this field, and also the collection of leachate samples for analysis, from a number of European landfills that have received varying proportions of MBP wastes.

The objectives of the study were to provide data and guidance for UK landfill operators, on the impact which the landfilling of MSW fractions, or composted MBT wastes, might have on leachate quality at their sites. This information is necessary to allow them to:

- Define a leachate source term for groundwater risk assessments;
- Assess the implications of waste pre-treatment on timescales, and long-term liabilities, for the landfilling of pretreated waste materials;
- Make appropriate and adequate provisions for leachate management, treatment and off-site disposal;
- Consider the effects of changes in leachate quality on landfill liners and leachate drainage blankets and systems.

Results from the study were published in late 2004 (Robinson et al, 2004), and demonstrated that there is a very wide range in the concentrations of ammoniacal nitrogen, in leachates from composted MSW that has been landfilled. In some cases, values for "hard" COD are considerably higher than from conventional methanogenic MSW landfills. Concentrations of ammoniacal-N are generally at much lower values in leachates from wastes that have been subjected to controlled composting processes, than in normal leachates, but nevertheless exhibit a wide range of values.

These results confirm several earlier studies, (eg Danhamer and Jager, 1999), and indicate that it is far from proven that MBT of MSW fractions will significantly reduce the length of aftercare periods, compared to those required when untreated MSW is landfilled.

4 Landfill Aftercare Periods for MBT Wastes

Table 1 compares results for concentrations of sanitary parameters and metals in leachates from landfills containing MBT wastes that had been subjected to a wide range of MBT processes. These ranged from landfilling of untreated MSOR, and include sites where waste fractions had been subjected to various combinations and extents of “intensive” and “secondary”, or “maturation” treatment.

These results have significant implications for the long-term management of landfills containing MBT wastes, and also for the determination of criteria for optimum and environmentally-sound MBT process designs. As the release and leaching of ammoniacal nitrogen is usually the factor that determines the timescales during which active aftercare must be maintained for leachate at most landfill sites (whether these contain crude MSW or MBT wastes), it is clear that there has to date been no convincing demonstration that MBT will lead to significant reduction in aftercare periods at such landfills.

Figure 1 below is a generic summary of the nature of emissions from landfilled wastes. While it most readily can be applied to release of contaminants in leachates, it is also valid for generation and release of landfill gas. Although one can debate the precise shape of curves, and must recognise that individual contaminants will not all fall within specific categories, the figure helps to understand the key long-term issues that are most important.

Table 1 Composition of leachates from landfills containing MBT wastes subjected to a wide range of pre-treatment regimes (Robinson et al, 2004)

Waste Inputs	**MSOR**	**Composted MSOR, various sources**					
Composting processes	**None**	**Passive windrows**	**Passive windrows**	**Turned windrows**	**Turned windrows**	**Container**	**Container + windrows**
Sample number	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Period (weeks)							
Intensive	0	0	0	0	0	16	2
Secondary	0	12	30	25	8	0	30
COD	15590	582	4670	228	1620	869	1020
BOD_{20}	7840	>157	843	82	130	59	24
BOD_5	4240	46	202	3	35	6	3
TOC	4694	180	1480	78	543	308	340
fatty acids (as C)	707	<20	<10	<20	<10	<10	<10
ammoniacal-N	4024	195	1130	286	197	34.2	1.8
oxidised-N	<1	10.3	<1	16.1	<1	7.3	5.0
phosphate (P)	8.2	1.1	12.4	0.3	2.8	0.4	0.3
sulphate (SO_4)	423	433	117	18	449	414	878
chloride	6000	612	2270	384	2290	901	1090
NH_4-N/cl ratio	***0.671***	***0.319***	***0.498***	***0.745***	***0.086***	***0.038***	***0.002***
conductivity	39400	4960	14000	3210	9540	4860	5900
alkalinity	1740	879	6120	1100	2010	1670	895
pH-value	8.3	8.1	8.3	7.9	7.9	8.4	8.5
sodium	4080	509	1520	419	1250	622	789
magnesium	77	91	88	47	104	64	67
potassium	1310	328	728	211	777	393	387
calcium	27	122	176	84	329	232	255
chromium	13100	110	870	<50	<250	<250	<250
manganese	380	460	1380	320	2940	1450	1610
iron	4310	960	19500	1050	13900	2590	1310
nickel	<100	30	210	<10	<50	<50	<50
copper	325	22	374	6	89	55	152
zinc	174	115	1032	<5	232	225	705
cadmium	<60	<6	<30	<6	<30	<30	<30
lead	<500	<50	<250	<150	<250	<250	<250
arsenic	<50	18	61	<10	<10	<1	<10
mercury	<1	<1	<1	<1	<1	<10	<1

Notes:
- Heavy metals and iron in µg/l; Alkalinity expressed as mg/l of $CaCO_3$
- All other results in mg/l, except pH-value and conductivity (µS/cm), and where shown
- Alkalinity expressed as mg/l of $CaCO_3$

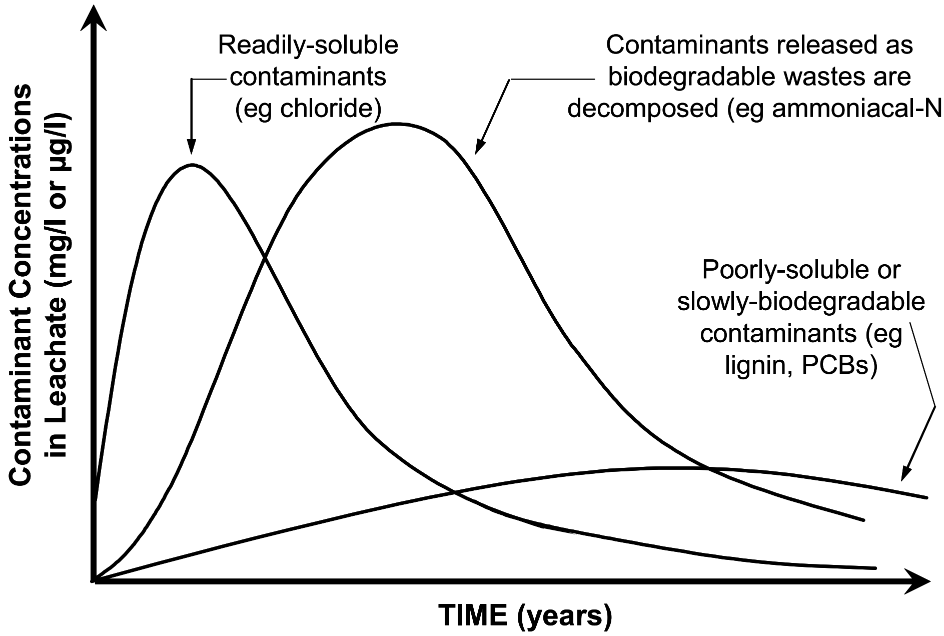

Figure 1 Generic summary of contaminant releases from landfilled wastes

Release of contaminants has been nominally divided into 3 categories:

a) ***Readily-soluble contaminants*** comprise those materials which are primarily emitted from landfills by dissolution and leaching. Chloride is the most obvious example, although degrading wastes will continue to release chloride to some extent as biological cell walls are broken down, and their contents released.

b) ***Contaminants released as biodegradable wastes are decomposed***. This forms the most significant source of long-term emissions from landfilled wastes. As organic materials degrade anaerobically, inorganic compounds and elements (such as ammoniacal-N) are generated and released, as are soluble organic compounds – many of which will be rapidly converted into the methane and carbon dioxide of landfill gas. Although landfill gases may relatively rapidly be extracted or diffuse from landfilled wastes, for contaminants such as ammoniacal-N, emission from the landfill will be over far longer timescales, subjected to the limits of extended mean hydraulic retention periods (of many decades – see Figure 1 earlier), and of uneven and inefficient passage of water through wastes.

c) ***Poorly soluble or slowly-biodegradable contaminants***. Typical components of landfilled MSW streams that fall into the category of slowly-biodegradable wastes would include cellulose and lignin within paper, wood and other biomass streams, some food wastes, and also other household items such as fabrics, rags, etc. Even relatively-degradable foodstuffs such as vegetables and meats, will leave residues of less-degradable humic materials, which may continue to release leachate organic contaminants and ammoniacal-N, for many decades. Other trace organic contaminants in household waste streams, such as pesticides etc, may be poorly-soluble and take centuries to leach from a landfill.

To look at other extreme, but potentially-significant components of MBT or MSW waste streams, heavy metals that may be immobilised within an anaerobic and methanogenic landfill, may ultimately be resolubilised and released as redox conditions change in the very long term.

An issue which has critical implications for aftercare periods at landfills receiving MBT residues, is the extent to which the composting processes will degrade and break down waste components that fall into category c) above. The likely reality is that the MBT processing will primarily affect waste components in category b), the relatively readily-degradable organic materials that would otherwise release soluble contaminants at early stages in the decomposition of the landfilled wastes.

Much more slowly-degradable waste components, in category c), will be treated far less effectively by MBT processes, and will retain their polluting potential once MBT outputs are landfilled.

Figure 2 below summarises the uncertainty which therefore remains.

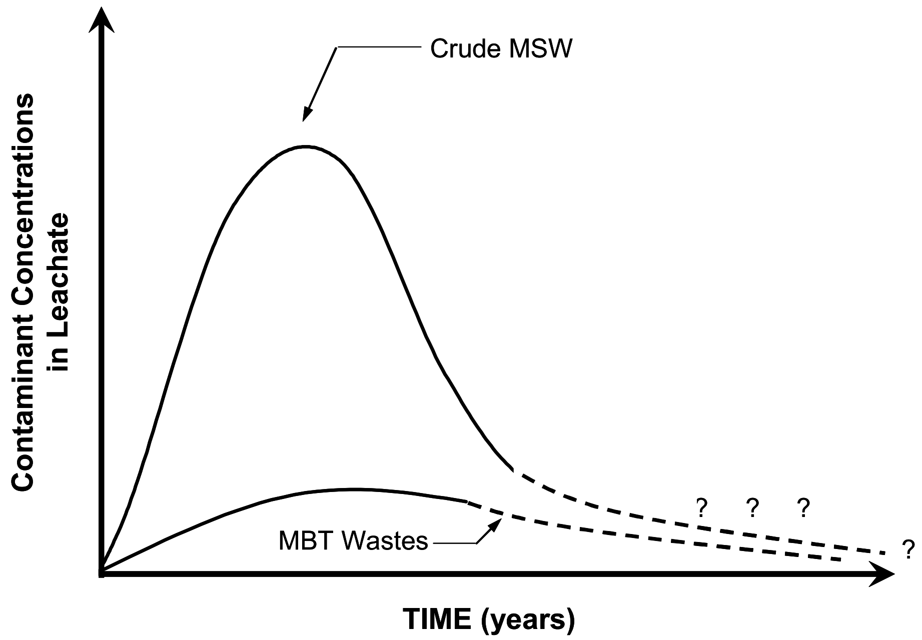

Figure 2 Generic comparison of contaminant emissions in leachates from crude MSW and from MBT wastes

There is extensive evidence, and no doubt many papers being presented at this conference, to demonstrate the extent to which landfilling of MSW fractions that have been subjected to MBT processes dramatically reduces emissions of landfill gas, concentrations of contaminants in leachates during initial years, or even decades, after emplacement.

To the extent that the driving force encouraging implementation of MBT schemes is reduction in generation of greenhouse gases, and in carbon emissions, then this is justification enough for such pre-treatment of wastes before residues are landfilled. Many other papers will no doubt have detailed focus on analytical techniques such as the BODAT4 test, to provide estimates of the extent to which composting has reduced biodegradable carbon levels in the MBT materials. However, in terms of benefits related to reduction in aftercare periods at landfill sites containing MBT residues, there is very little evidence that significant benefits have been demonstrated. It remains a possibility that over timescales in excess of 50 years after waste decomposition, concentrations of contaminants such as ammoniacal-N and “hard” COD in leachates may remain similar.

5 Behaviour of Nitrogen Compounds during MBT Processes

There remains a lack of knowledge about how levels of “available nitrogen” in MBT residues may be minimised by control of process variables, such as temperature, duration, moisture content or aeration intensity. Many possible nitrogen transformations can occur within different composting processes, and these are not well-understood. Reactions include mineralization, volatilisation of ammonia gas during high temperatures achieved during composting processes, nitrification and denitrification by various routes, and incorporation into stable organic compounds that effectively sequester nitrogen. Much better understanding of these processes is essential, if they are to be optimised by operators, and if real progress is to be made in terms of benefits in reduction in aftercare periods for landfills into which MBT wastes are disposed.

6 Conclusions

The UK project has confirmed existing knowledge, derived over longer periods by other countries, related to the benefits of MBT processes in reducing emissions of landfill gas, and of organic compounds in leachates, when such residues are landfilled.

Nevertheless, levels of “hard” COD in these leachates, not readily biodegradable by aerobic or anaerobic processes, can remain at least as strong as, and often stronger than, those found in methanogenic leachates – often in the range 1000 to 4000 mg/l, in spite of BOD values which are frequently less than 100 mg/l.

Concentrations of ammoniacal-N and Kjeldahl-N in MBT leachates may be significantly lower than those from conventional MSW landfills, but the extent to which this occurs is variable, and not easily related to the design of specific composting and pretreatment processes. The biochemical transformations involved are not well understood, and the influence of nitrification/denitrification, incorporation within stable organic fractions (possibly related to the elevated “hard COD” values), and other processes, require further research.

An outline source-term spreadsheet, for concentrations of sanitary parameters and metals in leachates from MSOR and MBT wastes, has been prepared during the UK study (see Table 2), to be used as a generic database for groundwater risk assessments, and as a tool to allow appropriate leachate management schemes to be developed at landfills that will receive MBT wastes.

Table 2 Source-term spreadsheet for ranges of concentrations of sanitary parameters and metals in leachates from landfilled MSOR and MBT wastes

Degree of Composting	**NONE**		**HIGH**		**LOW-MEDIUM**
Stage of Sampling	**acetogenic**	**methanogenic**	**initial**	**later**	**general range**
determinand					
pH-value	6	8	7.5	8	7.5 - 8.5
conductivity (µS/cm)	40000	40000	6000	10000	10000 - 20000
COD	150000	10000	2000	1500	1000 - 5000
BOD_5	100000	4000	50	30	20 - 200
TOC	50000	4000	500	500	500 - 2000
chloride	8000	6000	1000	2000	4000 - 8000
sulphate (as SO_4)	1000	400	500	500	1000 - 5000
phosphate (as P)	10	20	0.5	3.0	1.0 - 15
alkalinity (as $CaCO_3$)	20000	18000	1000	2000	2000 - 6000
ammoniacal-N	4000	4000	30	200	50 - 1000
Kjeldahl-N	4200	4200	40	-	100 - 1300
total oxidised-N	<1	<1	5	<1	<1
sodium	4000	4000	800	1200	2000 - 4000
magnesium	1000	100	60	100	100 - 400
potassium	2000	2000	400	800	1000 - 2000
calcium	6000	50	250	300	100 - 800
chromium	0.6	5	0.05	0.1	0.1 - 0.5
manganese	1.0	0.5	2	3	1 - 2
iron	300	5	2	10	5 - 20
nickel	1	0.5	0.1	0.1	0.1 - 0.7
copper	0.5	0.5	0.2	0.2	0.2 - 0.5
zinc	10	0.5	0.5	0.2	0.5 - 3.0
cadmium	1	<0.001	0.003	0.003	0.005 - 0.1
lead	0.3	<0.1	0.02	0.04	0.1 - 0.4
arsenic	0.04	0.1	0.004	0.006	0.01 - 0.1
mercury	0.0001	0.0001	0.0001	0.0001	0.0001 - 0.01

Notes:
- All results in mg/l except pH-value, and conductivity (µS/cm)
- Results represent typical values, derived from a range of source data
- Initial stage for leachates from wastes with high MB pre-treatment typically represents up to 2 or 3 years

In general terms, many landfills receiving MBT wastes will continue to pose risks to groundwater, and require aftercare periods similar to conventional MSW landfills that have become methanogenic. There is no doubt that MBT processes have potential to reduce both organic strength, and concentrations of ammoniacal-N in leachates from such landfills, as well as the total mass release of these and other contaminants. However, even at such landfills, the extent to which timescales during which leachates will require management can be reduced significantly, remains to be determined.

7 Acknowledgements and Disclaimer

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The views expressed in this paper are those of the author alone.

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