The Role of MBT in Reducing Greenhouse Gas Emissions from Landfill Disposal of MSW

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Abstract

The Landfill Directive aims to reduce the negative environmental impacts of landfilling mainly by reducing the quantity of organic matter deposited, through measures such as the separate collection and recycling of the organic waste stream or pre-treatment of residual wastes before landfilling. Besides incineration or other thermal processes, mechanical biological treatment is playing an increasingly important role. This study has been conducted in order to seek the benefits of municipal solid waste (MSW) pre-treatment as well as the differences in methane production from the landfilling of untreated and mechanically/biologically treated (MBT) MSW using GasSim simulation. Results demonstrated that mechanical treatment alone produces organic-rich waste, which can be viewed as an organic content concentration process. MBT waste on the other hand, is both mechanically and biologically pre-treated, which differs significantly from untreated municipal waste. It is much more homogeneous, has a smaller average grain size, low biological activity and more soil like properties. This work demonstrated that if efficient mechanical-biological treatment is used, considerable reductions in biological activity, landfill gas production and energy content / total organic carbon could be achieved.

Keywords

waste stream, organic content, MBT, MSOR, MBP

1 Introduction

The EU Landfill Directive aims to improve standards of landfilling across Europe to minimise its negative environmental impacts. This goal is to be reached by reducing the quantity of organic matter deposited, through measures such as the separate collection and recycling of the organic waste stream or pre-treatment of residual wastes before landfilling (DETR, 2001). The UK waste management industry will be particularly affected by the requirements of the Directive due to a reliance on landfilling for waste disposal (Gronow *et al*, 2005). Besides incineration or other thermal process, mechanical/biological treatment (MBT) is playing an increasingly important role. Over the past year, MBT has developed as a very popular municipal waste management option in the UK. It is heralded as the solution to local authorities' waste problems, enabling them to meet targets for the diversion of biodegradable municipal waste from landfill. MBT is

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preferred by local councils partly due to poor public perception towards incineration. The largest MBT plant planned to be built at present is Herhof's 120,000 tonne per year facility in Lancashire. Several other plants will be operational by 2006, such as Cory's MBT plant.

The term MBT can be applied to a number of different combinations of mechanical sorting, drying and biological processes (Muller *et al*, 2003). The main distinction between different MBT systems concerns the sequence of process steps and whether the biological treatment is designed to produce stabilised waste or composted material. The target of residual waste composting is usually not the production of usable compost, but the reduction of residual waste quantities to be landfilled and the improvement of its landfilling characteristics (Muller *et al*, 2004).

Organic and easily-degradable materials (materials with high molecular weights) are directly linked with methane generation in landfills. There is an increasing level of concern about the uncontrolled release of landfill gas in the UK (Rosevear, *et al*, 2003). Many models have been developed both for predicting gas production over the lifetime of individual landfills and for estimating national contributions to global emissions. A commonly used approach in the UK for individual landfills is based on that of Coops *et al*. (1995)'s first order kinetic model (see Figure 1). This model is commonly used in combination with waste input predictions to produce a gas generation profile for the lifetime of the site. Such a multi-phase, first-order decay equation forms the core of the GasSim model (Environment Agency, 2002).

The study reported here uses GasSim to examine the benefits of municipal solid waste (MSW) pre-treatment as well as the differences in methane production by landfills containing untreated MSW and MSW following MBT. Two broad categories of organic residues from waste pre-treatment will be considered in this study: mechanically sorted organic residues (MSOR), and biologically treated residuals after mechanical sorting (MBP).

2 Methodology

The most common means of estimating rates of gas production used for individual landfill in the UK is a first order kinetic model (i.e. exponential decline), with no lag or rise period, and with waste fractions categorised as being of rapid, medium or slow degradability (Environment Agency, 2002, Golder Associates, 2004). This model is outlined in Figure 1.

$$a_t = \sum_{i=1}^{n} 1.0846.A.C_i.k_i.e^{-k_i t}$$

Where:

a_t = gas formation rate at time t, (m^3/year)

A = mass of waste in place (tonne)

C_i =carbon content in fraction 'i' (kg/tonne)

K_i =rate constant for fraction 'i' (year/tonne)

K_1 =0.185 $year^{-1}$ (fast)

K_2 =0.100 $year^{-1}$ (medium)

K_3 =0.030 $year^{-1}$ (slow)

t = time elapsed since deposit (years)

n= the number of iterations (from 1 untill n = t)

Figure 1 First order kinetic model

In this study, the first order kinetic model has been applied to a chosen sample site by GasSim (Monte Carlo simulation) to demonstrate hypothesised situations designed for the experiment.

In GasSim, the input data contains compulsory variables which have a direct influence upon the quantity and quality of landfill gas production. The input screen requires the quantity and composition of waste deposited for each operational year in a landfill site (Golder Associates, 2004). Based on the default waste stream composition, changes were made for each hypothesis (according to experimental design). Simulation was conducted for a 'simulation period' of 100 years and iterated 100 times. Moreover, re-calculation and statistical analysis of output data was performed for 100 groups of data.

The typical landfill environment chosen, based on the predefined 'Bucks landfill' provided in the GasSim package, accepted two million tonnes of domestic waste in 8 years. The testing landfill period was operated from 1978 to 1985. This study was conducted to examine the impact of MBT on the waste. Simulation of methane production was compared amongst MSOR, untreated MSW and MBP waste by GasSim.

3 Results and Discussion

Mechanical and biological pre-treatment of MSW has been required through national legislation in a number of EU member states for several years (Stegmann *et al*, 2003), therefore, much useful data has been generated from pilot studies in the Netherlands, Austria and Germany. According to VAM, (now ESSENT; one of the largest waste management companies in the Netherlands, presently handling about 0.8 Mt of domestic and industrial solid waste each year) MSOR comprises vegetable, fruit and garden wastes not separately collected from households, plus inert fractions of sand, glass and gravel, with small amounts of paper and plastic particles. It is characterised by its relatively small particle size and its homogeneity, compared with normal MSW, and typically contains about 40 – 50% moisture, 25-30% inert, and 25-35% dry organic material (all percentages by weight) (Woelders *et al*, 1993). Table 1 shows a typical composition of MSOR, for an (assumed) separate collection of biowaste, where the MSOR represents 30 percent by weight of total MSW.

Table 1 Mechanically Sorted Organic Residuals (MSOR) Composition (in weight by percentage)

Fractions	% of wet MSOR
water	40
Organic fraction	36
Grit/sand/inorganic	10.8
Glass	6
Stones	3.6
Paper	2.4
Rigid plastics	0.6
Residual	0.4
Non-ferrous metals	0.12
Ferrous metals	0.06
TOTAL (approximately)	100

Source: Woelders *et al*, 1993

GasSim simulation of a 100 year period demonstrated noticeable differences in landfill gas production between MSOR and untreated MSW (Table 2, Figure 2). The amount of methane produced by MSOR is more than 1.5 times that produced from current MSW (1980-2010 waste streams). It is also more than 4 times that produced by 2020 waste streams. This shift in methane production is mainly due to the high decomposition rate and organic content as illustrated in Table 1 (dry weight of organic content is 64%, decomposition rate of 78.4%). Therefore, mechanical pre-treatment alone can be viewed as a concentrating process which results in homogeneous pieces of high decomposition rate organic fractions. As Figure 2 illustrates, MSOR and the putrescible fraction had very similar methane production behaviour in the first 10-year period. GasSim simulation also demonstrated that they reach their peak methane production rate at the same year. However, their behaviours after the peak were very different. This variation maybe due to the differences in cellulose and hemi-cellulose content between MSOR and putrescible fractions.

Table 2 Comparison of Annual Methane Productions for MSOR and Untreated MSW under Landfill Conditions

Waste Streams[1]	Annual average (m³/hr)	WSOR annual average (m³/hr)	Growth
1980-2010	162.8	282.7	73.6%
2010	123.1	282.7	129.7%
2015	81.8	282.7	245.5%
2020	57.1	282.7	395.2%

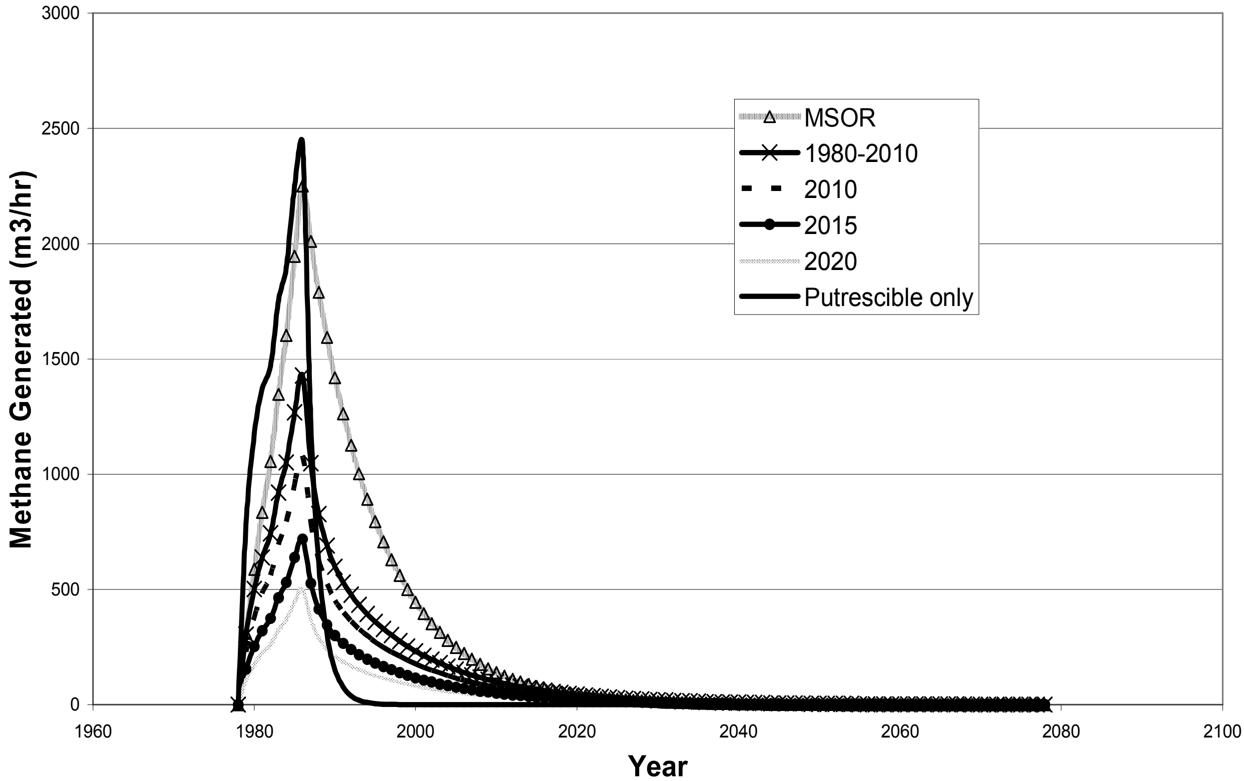

Figure 2 Comparison of CH_4 Generation from MSOR, Untreated MSW and Putrescible Fraction under Landfill Conditions

[1] Waste streams are defined by GasSim and their waste compositions are different in order to comply with the Landfill Directive.

Whereas MSOR residues are produced by mechanical sorting, MBP residual is both mechanically and biologically pre-treated waste (principally composting), which differs significantly from untreated municipal waste. It is much more homogeneous, has a smaller average grain size, low biological activity and more soil like properties (Doedens, H and Kuehle-Weidemeier, M., 2003). Researchers at the University of Hanover have been working on the use of MBP of MSW as a means of improving control over their subsequent degradation in landfills. The MBP residual is intended to reduce production of strong leachates and extensive gas formation and reduce landfill settlement (Environment Agency, 2004).

Easily degradable fractions of the MSW are degraded during biological pre-treatment, resulting in lower emissions of organic leachate contaminants, landfill gas, and odours from the landfill (Bone *et al.*, 2003). Nevertheless, after biological pre-treatment the remaining wastes still contain refractory organic substances such as lignin, waxes, humic acids etc., and so biological processes will continue to be the dominant feature of their behaviour when landfilled. Muller *et al.* (2004) calculated that less than 10% of the biodegradable organic fraction might remain after effective pre-treatment. Using GasSim, reductions in methane production of more than 74% have been simulated if a 90% organic content reduction can be achieved on current MSW levels (as Table 3 illustrates). This emission figure should also match the 2020 Landfill Directive target.

Table 3 Methane Reductions by MBP (90% reduction)

Waste Streams	100-year's average (m^3/hr/yr)	MBP 100-year's average (m^3/hr/yr)	Reduction
1980-2010	162.8	41.8	74.3%
2010	123.1	41.8	66.0%
2015	81.8	41.8	48.9%
2020	57.1	41.8	26.8%

All properties of waste after MBT are heavily dependent on the waste composition. Therefore, only general estimates can be made on physical properties of the MBP waste. Table 4 presents another example from Doedens *et al* (2003).

Table 4 Effects of MBT on Physical Waste Properties

Property/influence	Mechanical treatment/grain size < 60 mm	Biological treatment	Mechanical and biological treatment
Calorific Value	~20% decrease	~15-40% decrease	~35-60% decrease
Subsidence	Decrease	Decrease	Decrease
Mass reduction	25-50%	~15-20%	40-70%

The 'calorific value' is the total available energy of waste to be extracted. In other words, it is the total energy from both organic and inorganic MSW fractions. The calorific value reduction for MBP is mainly due to the organic content rather than inorganic matter (as biological treatment reduces biodegradable content). Therefore, the organic content reduction achieved by MBT will be greater than 35% - 60% depending on the waste composition as well as the MBT processes (Doedens et al, 2003). Due to this uncertainty, various organic content reduction rates of 50%, 60%, 70% and 80% have been simulated using GasSim.

Table 5 Methane Reductions by MBP (continued)

Waste Streams/Organic content reduction	50% reduction	60% reduction	70% reduction	80% reduction	90% reduction
1980-2010	-	6.7%	25.5%	49.5%	74.3%
2010	-	-	1.5%	33.3%	66.0%
2015	-	-	-	-	48.9%
2020	-	-	-	-	26.8%

Table 6 Organic Content Reduction (Derived from Table 1)

Organic content reduction rate	**Organic content remain** (dry matter)
50%	47.1%
60%	41.6%
70%	34.8%
80%	26.2%
90%	15.1%

Cellulose and hemicellulose comprise 45 to 60% of the dry weight of MSW and are its major biodegradable constituents (Barlaz *et al.*, 1989). As the results from GasSim simulation demonstrate, 60% reduction in organic content will only result in a slight reduction in methane emissions (Table 5). Lower reduction rates of organic content did not show any effects. Figure 3 demonstrates that an organic reduction rate of over 70% began to show a significant methane emission reduction Since mechanical pre-treatment produces organic rich residuals (MSOR), a 50 to 60% organic content reduction by following biological treatment can only turn MSOR properties into normal MSW equivalent (see Table 6). The inefficient organic content reduction rate results in either insignificant methane reduction or levels insufficient to fulfil the future landfill standard. This is where a second mechanical treatment process after biological treatment is of benefit. This usually involves sieving to remove particles of less than 60 mm diameter (Doedens *et al*, 2003). MBT is acting as an important step in MSW organic content reduction and stabilisation. If a complete mechanical-biological treatment is used, a reduction in organic content of over 60% can be achieved, resulting in reductions in biological activity, landfill gas production and energy content / total organic carbon. Muller *et al.* (2004) also argued that MBT cannot only reduce the quantity of organic content, but can also reduce the actual biodegradability of the organic material which is processed.

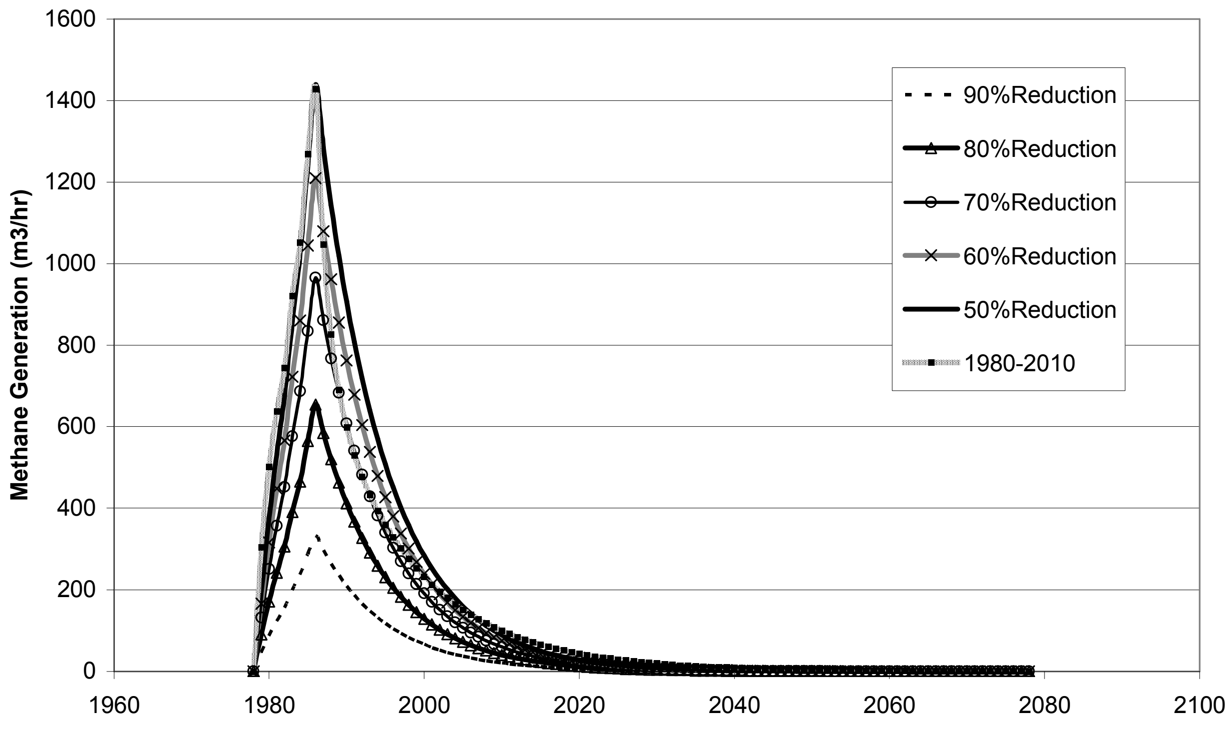

Figure 3 Comparison of CH_4 produced by MBT Waste and Current MSW under Landfill Conditions

Pre-treatment of those targeted fractions of waste will be of great benefit for local councils in meeting their landfill content targets. On the other hand, MBT reduces biodegradable waste to meet the targets as well as providing the opportunity for raising the waste-recycling rate and therefore meeting recycling targets. The government's landfill allowance trading scheme is in operation and Councils will face heavy penalties for each tonne of biodegradable waste consigned to landfill in breach of Government targets. This scheme encourages councils to put their efforts into the minimisation of BMW as well as recycling.

4 Conclusion

It is very important to understand the contribution to methane production of easily-biodegradable MSW fractions. Waste management is about much more than providing bins and landfills. Different kinds of waste require different solutions - and often have significant costs attached.

However, different MBT processes vary from each other. Only the ones which can meet both current and future landfill standards should be practiced. A reduction of organic content of 60% or more must be achieved during biological treatment as a minimum requirement. This would result in the production of stabilized residuals for sustainable landfill practice in terms of methane generation. This reduction rate can be achieved either by proper biological pre-treatment (principally composting for the required treatment period) or mechanical sieving after the biological process.

5 References

Barlaz, M.A., Ham, R.K., and Schaefer, D.M., (1989) *Mass balance analysis of decomposed refused in laboratory scale lysimeters*, ASCE J. Environ. Eng., p115, 1088.

Bone, B.D., Knox, K., Picken, A. and Robinson H.D. (2003) *The effect of mechanical and biological pretreatment on landfill leachate quality*. Paper 454, 12pp, in proceedings of the 9th International Waste Management and Landfill Symposium, Sardinia. CISA, Cagliari.

Coops, O.; Luning Oonk, H. and Weenk, A. (1995) *Validation of landfill gas formation models, In proceedings of Fifth International Landfill Conference*, Sardinia. CISA, Cagliari.

Department of the Environment Transport and the Regions. (2000) *Waste Strategy 2000* **–** England and Wales Part 1.

Department of the Environment, Transport and the Regions (2001) *Guidance on municipal waste management strategies*, DETR, London.

Doedens, H. and Kuehle-Weidemeier, M. (2003) *Landfilling and Properties of MBP waste, ISAH, Institute for water quality and waste management*, University of hanover, Germany.

Environment Agency (2002) *Guidance of Management of Landfill Gas, Draft for consultation*, Environment Agency, Bristol.

Environment Agency (2004) *Improved definition of leachate source term from landfills*, Environment Agency, Bristol, ISBN: 1 844 32 3269.

Golder Associates (2004), *GasSim user manual*, Golder Associates.

Gronow, J., Hall, D. and Knox, K. (2005) *Landfill- The Road Less Travelled*, Environment Agency, Bristol.

Muller, W., Niesar, M and Turk, T. (2003) *Optimised mechanical treatment and material segregation through ballistic separation within mechanical biological waste treatment,* Paper 100, in proceedings of the 9th International Waste Management and Landfill Symposium, Sardinia. CISA, Cagliari.

Muller, W. and Bulson, H. (2004) *Significance of bio-mechanical waste treatment in Europe,* , in proceedings of the Intergrated waste management and pollution control: policy and practice, research and solutions. Stratford-upon-Avon, Warwickshire, UK.

Rosevear, A., Deed, C., Gronow, J., Smith, R. and Braithwaite, P (2003) *A strategy for emissions based regulation of landfill gas*, Paper 429, in proceedings of the 9th International Waste Management and Landfill Symposium, Sardinia. CISA, Cagliari.

Stegmann, R., Cossu, R. and Heerenklage, J. (2003) *Tendences in future waste management* Paper 569, in proceedings of the 9th International Waste Management and Landfill Symposium, Sardinia. CISA, Cagliari.

Woelders, J.A., Moorman, F.J.A., Van Der Ven, B.L., Glas, H. and Coops, O. (1993) *Landfilling of MSW after separation of biowaste and RDF: Emission control.* In Proceedings of Sardinia '93, Fourth International Waste Management and Landfill Symposium, S. Margherita di Pula. CISA, Cagliari, Italy; 11-15 October 1993.

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