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ANAEROBIC DEGRADATION OF MUNICIPAL WASTES IN LANDFILL

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ABSTRACT

The objective of this study was to analyze the degree of decomposition of municipal solid waste (MSW) placed in a landfill site and, based on this analysis, to propose an investigatory procedure to be used to assess the energetic potential of any site.

A sampling technique was developed in order to reduce the size of the MSW sample to 25-30 kg with an acceptable error of 20 %. Profiles of the strata were established which have shown a well ordered structure in horizontal layers corresponding to different MSW ages. The location of the two drill holes were chosen consequently. A sample per MSW age was carried out for each drill hole. Their degradation states were measured using an accelerated biodegradability test which also gives the methane potential.

For all samples, the evolution of four parameters, temperature, % CH_4, % VSS and methane potential, were analysed as a function of their age. Anaerobic microbial activity was detected in the top layer of the landfill, showing that refuse starts as soon as deposited to undergo anaerobic transformation. Indeed, the % CH_4 reaches its maximum value of 60 % between 5 and 10 m. Temperature increases from about 26°C to 50°C in the first 15 m and stays at this maximum value. That shows that municipal wastes are degraded under mesophilic and thermophilic conditions.

Two relations between waste age and % VSS, and waste age and the energetic potential have been demonstrated. The % VSS represents about 65 % of the dry mass for the fresh wastes and is quite low for the 6 year-old refuse. This rapid waste transformation rate could be due to optimal conditions for anaerobic activity existing in the landfill. The methane potential is proportional to waste age, almost zero for the 6 year-old refuse and greater than 45 $l.kg^{-1}$ for fresh wastes. These results show that a simple and rapid measurement of the % VSS of an unknown sample could be a good indication of its age and its degradation state.

As a result of this study, a two-step procedure has been developed that enables an evaluation of the energetic potential of a landfill site. The first step is to collect all the general information on the site, thus providing an initial estimate of the decomposition degree within the mass of the waste. The second step is then to confirm this estimation by sampling and analysing a few samples taken at shallow depths.

KEYWORDS

Municipal Solid Waste - Anaerobic decomposition - Landfill - energetic potential.

INTRODUCTION

Landfilling is still the most common method of disposing of Municipal Solid Waste (MSW). The techniques used to manage these landfill sites have changed considerably over the last decade. Originally, the waste was simply dumped without any special precautions while today strict procedures are applied to minimize the physical and biological changes in the waste. At present, placement techniques include spreading and compacting the waste, breaking it down into limited-size cells separated from each other by layers of earth, covering the zones filled each day, etc.
The biogas generated by anaerobic decomposition of the household waste is collected in bore holes in the mass of the waste, from where it is extracted under vacuum. At present, the biogas is burned off but it could be valuable as a source of energy since it is estimated that the 264 largest sites in France could produce roughly 50 000 tons oil equivalent. However, to take advantage of this source of energy, we need a more accurate knowledge of how the quantity of biogas produced varies with time. At present, only the instantaneous global flow, the weight of waste placed and the quantity of biogas and leachate produced are known.
To predict the energetic potential, we must no longer consider the site as a "black box" but need a better understanding of the way in which the waste placed in this special environment decomposes.

The purpose of this project is to be able to accurately estimate the degree of decomposition of waste in a site. The analysis must cover the complete mass of the waste. The final objective is to obtain sufficent data to define a procedure capable of determining the energetic potential of any landfill site.

METHOD

Description of the Studied Site : the Villeparisis Landfill

The Villeparisis technical landfill site (located in the Paris suburbs), opened in 1983, covers an area of 30 ha, of which 12 have already been rehabilitated. This study was restricted to a 3.4 ha zone still in operation where approximately 100 000 tons of wastes are disposed of annually. This zone is equipped with a biogas pumping system which, amongst other factors, allows the flow and quality of the gas to be determined. Leachates are collected and treated before release into the natural environment.

The height of the waste mounds are regularly measured and recorded on half-yearly topographical drawings. These drawings were used to prepare profiles of the strata in the zone studied, indicating layers of wastes with different ages. The thickness of each layer is the difference between two successive dimensions measured at the same points. The measurement reference points are generally the biogas collection bores.

Sampling Technique

The sampling technique discussed here is heavily based on that Clin (Clin et al, 1983) proposed for sampling a heterogeneous medium. It has been adapted in this study to the estimation of the landfill energetic potential. The Clin method basically involves estimating the error due to the size of the sample allowing for the characteristics of the material sampled.

$$\sigma^2 = \left(\frac{1}{M_e} - \frac{1}{M_l}\right) \sum_i t_i \, m_i \left(\frac{a_i - a_l}{a_l}\right)^2$$

σ^2 = Relative variance of the error
M_e = Waste specimen mass (kg)
M_l = Total landfill site mass (kg)
i = Wastes family
m_i = Maximum weight of each family (kg)
a_i = Methane potential for each family ($l.kg^{-1}$ of fresh waste)
a_l = Methane potential of the landfill ($l.kg^{-1}$ of fresh waste)
t_i = Percentage (by weight) of each family in the specimen (%)

Since the landfill mass is much higher than that of the specimen, equation (1) becomes :

$$\sigma^2 = \frac{1}{M_e} \sum_i t_i \; m_i \left(\frac{a_i - a_1}{a_1}\right)^2 \qquad (2)$$

$$\text{with} \quad K = \sum_i t_i \; m_i \left(\frac{a_i - a_1}{a_1}\right)^2 = \text{cste} \qquad (3)$$

$$\text{then,} \quad \sigma^2 = \frac{1}{M_e} \,.\, K \qquad (4)$$

These parameters were determined experimentally using a 200 kg specimen (M_e), a size considered sufficiently large based on the Clin criteria that the sample must be at least three times larger than its largest component.

The specimen is classified by hand into 9 families which are paper, leaf/grass, plastic material, glass, wood, food residue, metal, textile/leather, other/fine. The percentage by weight of each family (t_i) is determined by weighing, m_i being the maximum weight of each family. The methane potential of each family (a_i) is measured using the accelerated biodegradability test. A mixture of the different families is then realised respecting the proportions of each of them defined in the specimen. The landfill methane potential is estimated with the accelerated biodegradability test of this mixture.

Estimation of the MSW Methane Potential

The method used to determine the decomposition degree of solid wastes is an adaptation of the biochemical methane potential test which has been used to determine the biodegradability of liquid effluents (Owen et al, 1979 ; Shelton and Tiedje, 1984). Originally proposed by Baubeau (1989) and Bogner et al (1989), it was modified to take into account the work of Barlaz et al (1987) on the optimal physico-chemical conditions of fermentation.

The accelerated biodegradability test. In order to improve the accessibility of MSW to biological activity, the samples were coarsely sorted to eliminate hard materials such as glass and metal, dried in open air and ground over a 2mm-mesh screen (IKA M20 grinder). The pretreated samples were stored in plastic bags at 4°C.
The organic matter quantity of the pretreated MSW was estimated by the volatile suspended solid percentage (% VSS) obtained after calcination at 550°C of the dry sample.

The pretreated sample was placed in 1 litre plasma flasks and diluted to 12 % with a mineral complement as described by Shelton and Tiedje (1984). Initial seeding with digested sludge is required only if the wastes are less than 1 year old. The flasks were purged with nitrogen, hermetically sealed, incubated at 55°C and constantly agitated. Daily samples (both gas and liquid) were taken to monitor the fermentation.

Analysis of the gaseous phase. A 0.4 ml gaseous sample was injected into a gas chromatograph (Packard 427) equipped with a packed column (Porapak R) to analyze the methane, carbon dioxide, hydrogen and nitrogen contents. The quantity of biogas produced was calculated from the volume and composition of the gaseous phase.

Analysis of the liquid phase. A 3 ml sample of the liquid phase was also taken to analyze the volatile fatty acids (VFA). This sample was centrifuged, acidified and then injected into a gas chromatograph (Carlo Erba Vega Serie 6300) equipped with a packed column (Carbopak + FFAP).

Methane potential determination. At the end of the fermentation, the total methane potential was calculated by adding the quantity of methane produced to the quantity of methane calculated to be available in the VFA remaining in the flask.

Drilling

The bores were drilled with a cable-operated percussion machine. The bore diameters (24 cm) were the largest diameter possible compatible with the drilling depth (25 m). The temperature of the waste and percentage of methane (% CH_4) were regularly measured during drilling.

RESULTS

Sampling of MSW

TABLE 1 Values of the t_i, m_i and a_i Parameters, Values of the Calculated K

Families	t_i (%)	m_i (kg)	a_i ($l.kg^{-1}$)	K'
Paper	33	0.5	44.9	0.000052
Plastic material	11.7	0.1	9.3	0.007363
Glass	10.7	0.5	0	0.029000
Wood	5.8	2.0	5.5	0.089377
Metal	5.8	2.0	0	0.116000
Leaf/grass	1.0	0.01	52.4	0.000003
Food residue	9.7	0.5	51.5	0.000101
Textile/leather	1.9	0.2	8.5	0.002500
Other/fine	20.4	0.004	38.9	0.000015
			K =	0.2444

Table 1 sums up the parameter values of equation (3) (t_i, a_i, a_i, m_i) and the calculated K value. Equation (4) became :

$$\sigma^2 = 0,2444 \cdot Me \quad \text{i.e.} \quad \sigma = (0,244 \cdot Me)^{0,5}$$

For a normal distribution with a 95 % confidence level, the variation in the error due to the sample size is correct to within +/- 1.96 σ. Figure 1 shows how this error varies with the sample size.

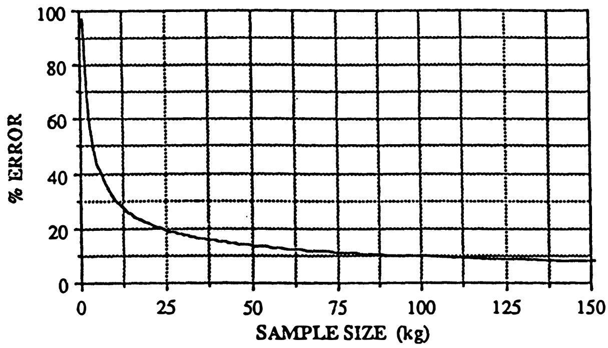

Fig. 1. Variation of the error as a function of the sample size

It can be seen that the error drops very quickly since, by increasing the sample weight from 0 to 25 kg the error reduces from 100 to 20 %. Above 25 kg, the error varies relatively slowly and even increasing the sample weight from 25 to 100 kg would only reduce it by 10 %. Above 100 kg, the error remains virtually constant, dropping only 2 % between 100 and 150 kg.

The sample weight chosen is thus a compromise between the acceptable error and both the cost and technical constraints involved in the drilling operation. Assuming that a 20 % error in the sample is acceptable, we have therefore chosen to use sample weights between 25 to 30 kg.

Sample sizes reported in the literature are relatively variable. Brunner et al (1986) have tested MSW sampling from 50 kg to several tons. The results indicated representative samples but also a high associated cost. These remarks are also applicable to Klee and Carruth (1970) who recommended a minimum size of 90 kg. On the contrary, Bogner et al (1989) worked on small samples of 2 kg but the representativeness has not be verified. Only Baubeau (1989) used 20 kg samples but also with no justification.

Size is not the only parameter to take into account for representative sample. Location is also important. Landfill sampling techniques generally require a multitude of sampling points to compensate for the heterogeneous nature of the MSW. This applies to the arbitrary grid recommended by Colin et al (1986). Baubeau et al (1989) used 2 samples per hectare and per zone with similar behaviour. Klee et al (1970) have developed a less empirical approach based on a statistical equation which calculates the sample number required as a function of the desired precision degree.

All these techniques implicitly class landfills as completely heterogeneous entities, requiring a very larger number of samples. This seems to be not compatible with the objective of this study which require samples at different depths. Then, according to the depth profile of the studied zone, the approach employed was completely different. Landfills seem to be well ordered with material of the same age in horizontal layers. Waste is disposed homogeneously in each layer. A single 25-30 kg sample will be then sufficient per MSW age. Two bore hole points were nevertheless utilized in order to compare the results and validate the approach.

Estimation of MSW Decomposition

Age - depth relation. Two profiles of the depth were carried out on the studied zone as shown in Figure 2 for the second drill hole.

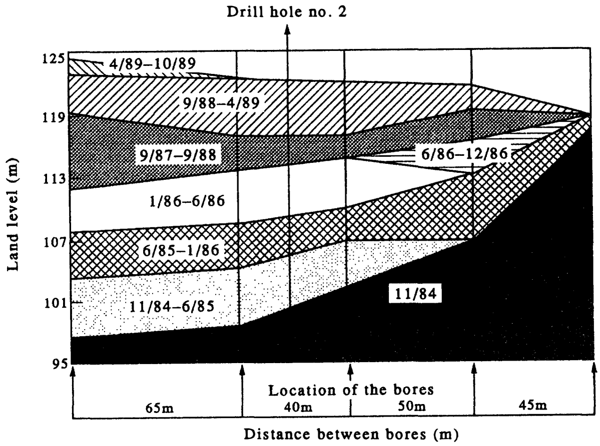

Fig. 2. Profile of the depth of the studied zone. Location of the second drill hole.

This indication of the ages of the various layers of waste was used to position the drill holes such that they pierced the largest possible number of layers with different ages.

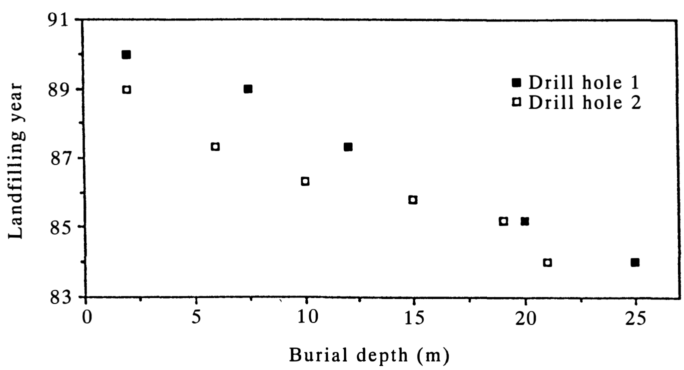

Fig. 3. Relation between the landfilling year and the burial depth

During the boring a sample was collected for each MSW age in the medium of the layer which corresponded to 11 samples. The relation between the different samples according to their depth and age is shown in Figure 3. This Figure shows that the frequency with which the household waste is placed is relatively constant over the zone studied since the curve of waste age against time is virtually a straight line. Consequently, waste with the same age will be at roughly the same depth in each of the two bores and the results will be comparable.

Variations in Physico-Chemical Parameters

The physico-chemical parameters studied were the MSW temperature and the methane percentage measured in situ. The values of these two parameters at different depths in the bore are shown in Figures 4 and 5.

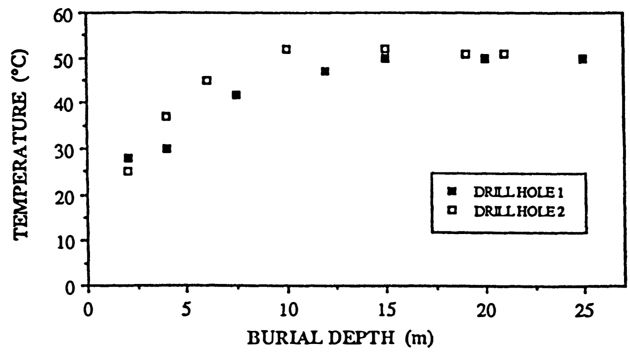

Fig. 4. Evolution of the MSW temperature as a function of the burial depth

As shown in Figure 4, the temperature inside the mass of waste varies in a similar way for both bores (Figure 4). From 2 to 10 m deep, the temperature increases from 26 to 50°C and then stabilizes for the last 15 metres. A relatively high temperature (26°C) was measured at the top layer of the landfill even though the atmospheric temperature remained at 14°C throughout the sampling procedure. Such large differences between atmospheric and internal temperature might be attributed to biological degradation of the wastes. The high temperature registered (50°C) at 10 m and below probably indicates active anaerobic biological decomposition of the MSW under thermophilic conditions.

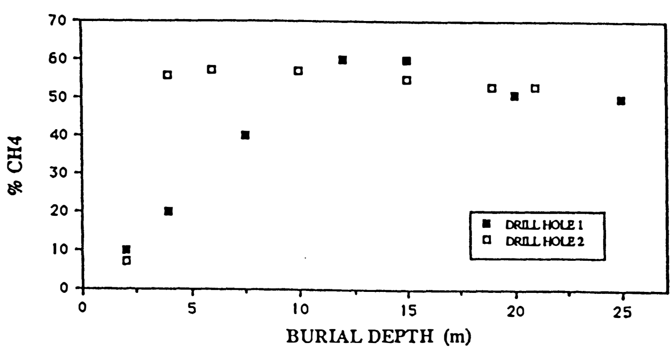

Fig. 5. Percentage of methane in the biogas as a function of the burial depth

The variation in the methane percentage (% CH_4) (Figure 5) is similar for the two bore holes. It increases from 10 to 60 % over the first 15 m and then remains stable. The methane percentage would seem to reflect the degree of decomposition reached by the waste. Figure 3 shows that the newest wastes are in the upper layers. This waste must therefore be in the hydrolysis-acidification phase, which explains the low proportion of methane observed.

Variations in Biological Parameters

The biological condition of the waste samples was represented by two parameters, the quantity of organic matter in the waste, expressed as the volatile suspended solid content (% VSS), and its degree of decomposition, expressed by the methane potential.

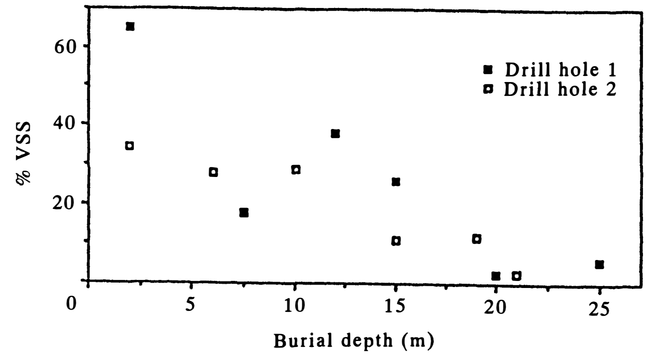

Fig. 6. Percentage of organic matter of MSW expressed in % VSS as a function of the burial depth

Figure 6 shows that the % VSS decreased similarly in both drill holes as the depth increased. Consequently, the longer the waste is buried, the greater the extent of mineralization. It is important to note that MSW at - 25 m, which was 6 years old, was completely mineralized. The organic matter content of new waste is approx 65 % of the dry matter ; this is similar to the values between 50 and 70 % published by Frerotte et al (1982).

The MSW decomposition state estimated by the methane potential is also a function of the burial depth. The older the waste, the lower the methane potential (Figure 7).

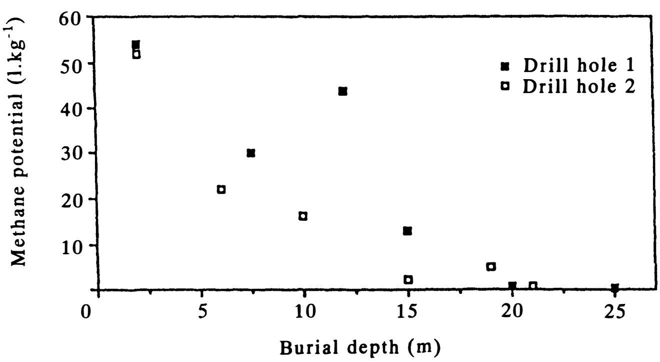

Fig. 7. Methane potential of MSW measured with the accelerated biodegradability test as a function of the burial depth

The two biological parameters studied therefore lead to the same interpretations. As would be expected, the biodegradable potential of the waste increases as its organic matter content increases (Figure 8). Consequently, a measure of the organic matter in the waste could give a fairly accurate indication of its degree of decomposition. However, this evaluation must be used carefully since large proportions of plastic material can increase the volatile suspended solid content even though plastic is very slightly biodegradable.

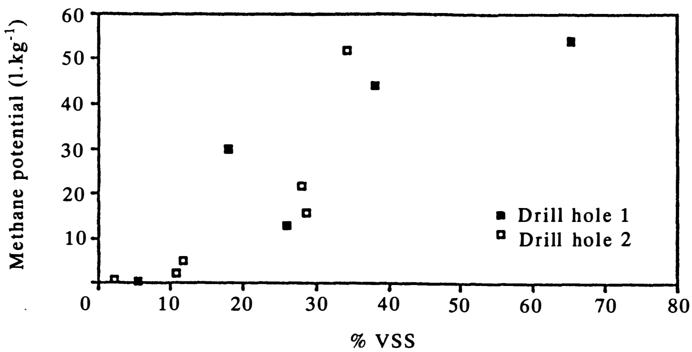

Fig. 8. Relation between the percentage of organic matter of the MSW and the methane potential for the two drill holes

Although the methane potential value of fresh MSW found here (45 $l.kg^{-1}$)is much lower than the theorical value reported by Frerotte et al (1982) (105 $l.kg^{-1}$), it is nonetheless comparable to the results reported by Baubeau (1989) 25 $l.kg^{-1}$)and by Ham et al (1979)(62.5 $l.kg^{-1}$).Some authors have considered separately the different MSW fractions according to their biodegradability properties. For example, Mouton et al (1985) measured the methane potential for the 45 % easily biodegradable fraction at 30 to 50 $l.kg^{-1}$. For Findikakis et al (1988), the MP varied from 90 to 0.8 $l.kg^{-1}$ depending on the biodegradability of the organic matter.

Considering that 6 year-old wastes are almost completely mineralized, one can reasonably assume that this landfill will generate biogas for approximately 12 years. Landfill life reported in the literature varies a lot. Gas generation was reported by Mouton et al (1985) and Bogner et al (1989) during 20-25 years and 20 years respectively. For Findikakis et al (1988), theoretical landfill life expectancy is about 12 years but he assumes that maximum gas productivity occurs after 5 years.

The general conditions under which MSW are placed exert a significant role in the overall decomposition rate of a landfill. Two factors could probably explain the relatively rapid mineralization at the Villeparisis site. First, pumping of the biogas would prevent stagnation of some gases which inhibit the methanogenic population such as, for example, sulphur compounds which are present in relatively large proportions in the biogas (about 5 ppm). Second, the water level in the bores was at -9 m. Wastes are, therefore, completely submerged and this considerably enhances biological activity. Consequently, all aspects of the site environment would appear to have a major effect on the biological activity and, consequently, on the life expectancy of the landfill. This must never be ignored when investigating a site.

The stratification of the wastes demonstrated in this study could considerably simplify the procedure used in the diagnosis of the energetic potential of the site. Since the degree of decomposition of all the wastes in the site can be estimated "at a first approximation" based upon :

- the dates at which the site was opened and closed,
- the environmental conditions which, mainly, affect the quantity of water retained within the mass of waste,
- the operating conditions (placement technique, biogas pumping and leachate treatment).

The accelerated biodegradability test on representative waste samples, taken at relatively shallow depth, would then allow a complete diagnosis of the site by comparison between the various data obtained.
Consequently, long and costly deep-drilling would no longer be necessary ; the energetic value of the site could be determined relatively cheaply and quickly.

CONCLUSION

All the physical and biological parameters studied on Municipal Solid Waste (MSW), at different depths in the landfill, lead to similar conclusions.

- Fresh MSW close to the surface is only slightly decomposed while the older MSW, buried deeper, is more highly decomposed.
- The biological activity close to the surface is of a different type since it tends to be mesophilic hydrolysis-acidification while thermophilic methanogenic activity occurs in the older wastes.
- The biological parameters, i.e. the methane potential and the % VSS, relate directly to the depth. The measurement of the VSS content could be used as a first quick test to estimate the degree of decomposition of the waste before an accelerated biodegradability test.

The results also indicate that the sampling technique used makes an adequate allowance for the heterogeneous nature of the site. Moreover, the possibility of changing the sample size allows for the technique to be adapted to different sites.

This original technical approach, therefore, showed that a landfill site, although at first view completely heterogeneous, in fact possesses a relatively regular structure consisting of a number of strata, each layer containing homogeneous wastes of different ages.

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