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Detailed internal characterisation of two Finnish landfills by waste sampling

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Abstract

The aim of this study was to characterise the internal structure and composition of landfilled waste at two Finnish landfills to provide information for active and post-landfill operations. The two sites, Ämmässuo and Kujala, have been in operation for 17 and 48 years, respectively. Waste was sampled (total 68 samples) and analysed for total solids (TS), volatile solids (VS), total Kjeldahl nitrogen (TKN), biological methane potential (BMP) and leaching of organic material (determined as chemical oxygen demand, COD) and ammonium nitrogen (NH_4–N). The results showed high vertical and horizontal variability, which indicated that both the waste composition and state of degradation varied greatly in both landfills. Ämmässuo was characterised by 2- to 4-fold higher BMP, NH_4–N and COD leaching than Kujala. Moreover, the ratio of VS to TS was higher at Ämmässuo, while TS content was lower. The highest mean BMPs (68 and 44 m^3/t TS), TKN content (4.6 and 5.2 kg/t dry weight) and VS/TS ratio (65% and 59%) were observed in the middle and top layers; and the lowest mean BMP (21 and 8 m^3/t TS), TKN content (2.4 kg/t dry weight, in both landfills) and VS/TS ratio (55% and 16% in Ämmässuo and Kujala, respectively) in the bottom layers. In conclusion, waste sampling is a feasible way of characterising the landfill body, despite the high variation observed and the fact that the minimum number and size of samples cannot easily be generalized to other landfills due to different methods of waste management and different landfilling histories.

1. Introduction

Landfilling has continued to be a major method for municipal solid waste (MSW) disposal during recent years (Eurostat, 2005; US EPA, 2005a). In the European Union (EU), solid waste management and landfilling are undergoing major changes following the EC Landfill Directive (1999/31/EC). The requirement that landfills must have a bottom liner means that a large number of landfills in the EU will be closed by 2007 (EC, 1999). The EU directive also phases out the quantity of organic waste that can be landfilled; therefore, waste minimisation and pre-treatment before landfilling are encouraged, which in turn affects the composition of landfilled waste. From the 1990s, Finnish MSW has been increasingly segregated at source into bio-waste, glass, metals, paper and cardboard and residual fraction. The residual fraction as such or after mechanical removal of materials for recycled fuel or other uses, the residual fraction has commonly been landfilled.

Operational and closed landfills are potential sources of environmental pollution, such as polluted leachates (e.g., ammonia and dissolved constituents; Ehrig, 1989) and greenhouse gases (e.g., methane; IPCC, 2001). When landfills are closed, they are typically sealed by cover layers such as geomembrane composites and/or soils to minimise leachate generation and gas formation or emissions. The landfill gas can be collected and used for energy production, flared, or alternatively methane can be oxidised biologically into carbon dioxide. It has been estimated that waste degradation and emissions from waste in landfills will continue for decades or even centuries after closure (e.g., Stegmann, 1989). However landfills can also be operated as bioreactors in order to enhance biodegradation and

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stabilisation with a higher level of control for liquids and gases. A typical bioreactor landfill operation would apply leachate recirculation to adjust the moisture and improve the contact between different substrates and micro-organisms, and thus stimulate anaerobic degradation (e.g., Reinhart and Al Youshi, 1996; Reinhart and Townsend, 1998; Morris et al., 2003). Recently, landfill aeration to enhance biodegradation of waste has also been studied (Heyer et al., 2005).

Because in many cases the composition, volume and placement of landfilled wastes were not well documented, the internal composition and structure of landfilled wastes and their emission potential remain unknown. In the landfill, wastes undergo various biological, physical, and chemical processes at different rates. These processes, together with the heterogeneous nature of the landfilled waste, may result in different conditions in different parts of the landfill. All of these factors can cause uncertainty when planning post-landfill and/or bioreactor operations. In practice, the content of the landfill is mainly dependent on the specific waste management practices of communities contributing waste to a particular site. The major fractions (Table 1) of discarded MSW are paper and cardboard, kitchen biowaste, plastics and garden waste (Golder Associates, 1999; YTV, 2004; US EPA, 2005b), and major portions of the methane potential can be attributed to cellulose and hemicellulose (Barlaz et al., 1989; Baldwin et al., 1998). The emission (and energy) potential of different MSW fractions vary greatly; e.g., the source segregated residual fraction of MSW (termed “grey waste” in Finland) and biowaste may have a biological methane potential (BMP) of 46 m^3/t total solids (TS) (grey waste) and 410 m^3/t TS (biowaste) and contain 2.1 kg NH_4–N/t TS (grey waste) and 3.6 kg NH_4–N/t TS (biowaste) of leachable nitrogen (Jokela et al., 2002). Furthermore, in addition to waste, landfills often contain soil of variable properties, which is used as daily cover.

Table 1
Composition of MSW (wet weight) after source segregation of recyclable materials in Finland, US and Australia

Waste	Finland (%)[a]	US (%)[b]	Australia (%)[c]
Paper and paper/cardboard	20	26.3	9.9
Glass	4	6.2	6.8
Metals	4	7.3	7.1
Plastics	13.6	15.4	7.3
Rubber and leather	–	3.5	–
Textiles	4	5.5	–
Kitchen biowaste	38 (including garden waste)	16.4	38.1
Garden waste	–	7.6	17.8
Wood	3	7.5	6.4
Inorganic Wastes	–	2.2	–
Diapers	7	–	–
Other combustible	3	–	–
Other	3.4	2	6.6

[a] YTV (2004).
[b] US EPA (2005b).
[c] Golder Associates (1999).

In order to evaluate the range of conditions prevailing in existing landfills, this study examined gas, pore water and leachate quality at two Finnish landfills. Due to the large size and heterogeneity of most landfills, and for economic reasons, internal landfill sampling must be carefully coordinated with available information about waste age and composition. Sampling before or in conjunction with the construction of gas recovery wells or leachate recirculation, especially at sites with limited existing information, may have economic benefits to optimise the gas extraction or liquid recirculation methods. Landfills have been previously sampled to estimate the rate of degradation of MSW and its different waste components (e.g., Hartz and Ham, 1983; Bogner, 1990; Gurijala and Suflita, 1993; Baldwin et al., 1998; Jokela et al., 2002; Gardner et al., 2003) while – to our knowledge – only a few studies have been published on vertical profiles of pH, temperature, moisture, organics, cellulose, lignin, or BMP (Bookter and Ham, 1982; Jones et al., 1983; Attal et al., 1992; Ham et al., 1993; Wang et al., 1994; Townsend et al., 1996; Chen et al., 2004; Östman et al., 2006) and even fewer studies (Ettala et al., 1988; Ham et al., 1993; Östman et al., 2006) on landfill nitrogen content. These earlier studies showed MSW landfills to be heterogeneous with respect to the stages of degradation and conditions within the landfill body with wastes in the top layers usually less degraded than in the deeper layers.

The aim of this study was to evaluate the feasibility of sampling landfill bodies (and analysing the samples) in order to characterise their properties and thus provide information for post-landfill monitoring and operation. The specific objectives were (1) to analytically characterise the composition, TS, volatile solids (VS), total Kjeldahl nitrogen (TKN), pH, BMP and NH_4–N as well as organic material (determined as chemical oxygen demand, COD) leaching in two Finnish MSW landfills; and (2) to characterise their vertical and horizontal distribution.

2. Materials and methods

2.1. Sampling sites and sampling

The samples were taken from the MSW landfills of Ämmässuo (Espoo, Finland, 17 yr in operation) and Kujala (Lahti, Finland, 48 yr in operation) (Table 2). The sampling was done during the installations of vertical gas collection wells (borehole ∅ 1.2 m, Ämmässuo) or leachate observation tubes (borehole ∅ 90 mm, Kujala). The sampling procedures were planned to obtain depth profiles at different locations using a 50–100 m grid (Fig. 1). For both landfills the mean values and standard deviations of the measured variables were calculated for different layers, which were normalized according to age (Table 3) using, as far as possible, a statistically significant number of samples from each layer (Table 4).

In the Ämmässuo landfill (the largest landfill in Scandinavia, established in 1987 in metropolitan Helsinki), the