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Release and conversion of ammonia in bioreactor landfill simulators

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ABSTRACT

Bioreactor landfills are an improvement to normal sanitary landfills, because the waste is stabilised faster and the landfill gas is produced in a shorter period of time in a controlled way, thus enabling CH_4 based energy generation. However, it is still difficult to reach, within 30 years, a safe status of the landfill due to high NH_4^+ levels (up to 3 g/L) in the leachate and NH_4^+ is extremely important when defining the closure of landfill sites, due to its potential to pollute aquatic environments and the atmosphere.

The effect of environmental conditions (temperature, fresh versus old waste) on the release of NH_4^+ was assessed in experiments with bench (1 L) and pilot scale (800 L) reactors. The NH_4^+ release was compared to the release of Cl^- and BOD in the liquid phase. The different release mechanisms (physical, chemical, biological) of NH_4^+ and Cl^- release from the solid into the liquid phase are discussed. The NH_4^+ level in the liquid phase of the pilot scale reactors starts decreasing after 100 days, which contrasts real-scale observations, where the NH_4^+ level increases or remains constant. Based on the absence of oxygen in the simulators, the detectable levels of hydrazin and the presence of Anammox bacteria, it is likely that Anammox is involved in the conversion of NH_4^+ into N_2.

Nitrogen release was shown to be governed by physical and biological mechanisms and Anammox bacteria are serious candidates for the nitrogen removal process in bioreactor landfills. These results, combined with carbon removal and improved hydraulics, will accelerate the achievement of environmental sustainability in the landfilling of municipal solid waste.

1. Introduction

The application of bioreactor landfills has been the most recent development in the disposal of municipal solid waste. The advantages are: shorter waste stabilisation periods, higher biogas production and recovery, reduced leachate organic strength and higher volume recovery due to enhanced waste settlement (Pohland, 1980; Warith, 2002). In previous studies, Valencia et al. (2009a,b) showed improved stabilisation of the solid waste reaching *Final Storage Quality* (Valencia et al., 2009a) much faster in bioreactor landfills than in sanitary landfills and the biogas, pH, and BOD followed similar trends as reported by Pohland (1980) and Warith (2002) with faster responses in those simulators with improved hydraulic conditions (Valencia et al., 2009b).

An important parameter to consider the safe closure of landfill sites is the NH_4^+ content of the leachate (Barlaz et al., 2002; Burton and Watson-Craik, 1998). NH_4^+ tends to accumulate since there are no removal mechanisms under strict anaerobic conditions, especially in landfills with leachate recirculation (Onay and Pohland, 1998; Price et al., 2003). NH_4^+ can be removed from the leachate of landfills via methods such as nitrification/denitrification, precipitation and even irrigation schemes (Jokela et al., 2002; Li and Zhao, 2003; Ohlinger et al., 1998). However, these approaches are likely to produce NO_x and N_2O, which are significant pollutants for their contribution to climate change (Price et al., 2003).

Despite all efforts to reduce the levels of ammonia emissions from landfill leachate, little information is available about the origin, evolution and fate of ammonia in bioreactor landfills. Huber et al. (2004) suggested that 4% of N leaves the landfill via the leachate pathway, while 96% of N remained in the landfill body. Therefore, the objective of this study was to investigate the mechanisms involved in the ammonia release from the solid phase into the liquid phase and possible *in-situ* removal mechanisms under anaerobic conditions in bioreactor landfills.

2. Materials and methods

2.1. Pilot scale reactors

Seven bioreactor landfills were simulated using high density polyethylene sewage pipes (0.75 m^3 working volume). The simulators

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Table 1
Waste characteristics.

a. Municipal solid waste composition			b. Moisture and VS content of waste		
Component	Fresh waste	Old waste[a]	Waste	Moisture	VS
	% of weight			% of weight	
Organics	24.5[b]	24.2	Old waste	53	70
Paper/cardboard	13.4	13.2	Fresh, minus food	4	10
Plastic	6.4	6.3	Fresh + food, uncooked	19	39
Ferrous/non-ferrous	0.8	0.8	Fresh + food, cooked	45	44
Wood	3.2	3.2			
Sand, stone	42.6	43.7			
Glass	8.7	8.6			
Textile	0.4	0.01			

[a] 4 weeks old waste provided by ESSENT Milieu, Wijster, The Netherlands.
[b] Only food waste.

were filled with shredded (particle size max. 4 cm) municipal solid waste (MSW), see Table 1 for the composition. The operational features of the simulators were described elsewhere (Valencia et al., 2009a,b), but the control simulators had no gravel and were filled with 450 kg of MSW or 350 kg of MSW, but compacted with less density. The operational conditions of the two aerated reactors were changed after day 250 as intermittent forced aeration was introduced at the bottom of the reactors (240 L air week^{-1}) aiming for *in-situ* nitrogen removal. Therefore, these two simulators served as control until that day. The amount of waste added was based on the determination of the field capacity of the material collected following the methodology described by Orta de Velázquez et al. (2003).

Buffered tap water (124 L, 0.1 M $NaHCO_3^-$) was added to stimulate leaching. The leachate was recycled 3 times per week ($\pm$60 L week^{-1}) in order to maintain a dynamic leachate flow and at least 45% moisture content (field capacity) on a wet weight basis (Vroon et al., 1999). Buffer (0.3 M $NaHCO_3^-$) was added to the leachate prior to recycling during a period of 6 weeks (day 50–100) to reduce the negative impact of the VFA on the pH. The internal temperature of the simulators was within the range of 30 $\pm$ 4 °C.

2.2. Laboratory scale (1 L)

Specific questions arising from the pilot scale reactors were studied at smaller scale. Six laboratory-scale landfill bioreactors were assembled using 1 L capacity plastic containers (diameter 160 mm, height 210 mm) for all series. Each reactor had three sample ports: for leachate sampling, for leachate recirculation and for gas exhaust. The sampling was carried out with a plastic syringe. About 350 mL of demineralised and deoxygenated water was used to initiate leachate formation. The water was slowly poured into the bioreactor and as soon as the leachate had reached the bottom about 10 mL was withdrawn with a 30 mL plastic syringe. Leachate was recirculated (30 mL) at the top of the reactor and 10 mL samples were withdrawn for analysis. About 30 mL of the leachate was recirculated to the reactor prior to the collection of the sample.

About 30 kg of shredded municipal solid waste, comparable to the composition of normal Dutch solid waste, from ESSENT Milieu (a Dutch solid waste handling company) was used, packed in 1 kg units and stored at 5 °C, ready for use. The C/N ratio was 16, a little bit below the optimal range for the AD process (20–30); the initial moisture content was 20% (wet weight basis) and VS content 44.9%.

The fresh waste was prepared manually, following ESSENT Milieu waste composition (Table 1a). The fresh waste was used with or without food waste; the food waste was either cooked or uncooked. Each reactor contained about 300 mg of waste. The moisture and volatile solids (VS) content of the wastes are shown in Table 1b. Experiments were carried out at 5 °C, 20 °C and 30 °C in controlled temperature rooms.

2.3. Analytical methods

Leachate samples were analysed immediately or stored in the freezer and were analysed for pH and temperature with portable meters WTW pH 340 and LF 340. BOD was analysed according to Standard Methods (APHA, 2005). NH_4^+ was analysed according to NEN (1983). Chloride – used for comparison because it is a very easily released ion – was analysed using an Ion Chromatography system DIONEX ICS-1000 attached with an automated sample injector DIONEX ASI-100. All liquid samples were filtered with glass fibre filters GF 52 (Schleicher & Schuell). Hydrazine was measured using detector tubes (MSA, range 0.1–5 ppm) and a thumb-pump sampler (100 cc sample volume/stroke). Samples for the Anammox bacteria determination were taken from the 4 cores extracted (0.60 cm length), these cores were extracted from the bottom and the middle part of each simulator. Anammox identification in the residue was carried out using fluorescent in situ hybridisation (FISH) techniques employing the following probes: Pla46 for planctomycetales, AMX820 covering all Anammox organisms, specially *Kuenenia* sp. and *Brocadia* sp. and DHI820 for *Anammoxoglobus* sp. Probes and hybridisation procedures are described by Schmid et al. (2003) and Kartal et al. (2007).

3. Results

3.1. Ammonia in the pilot plants

The process parameters of the 800 L bioreactor landfill simulators are shown in Fig. 1. Due to the accumulation of hydrolytic products the pH decreased in the first months of operation, but

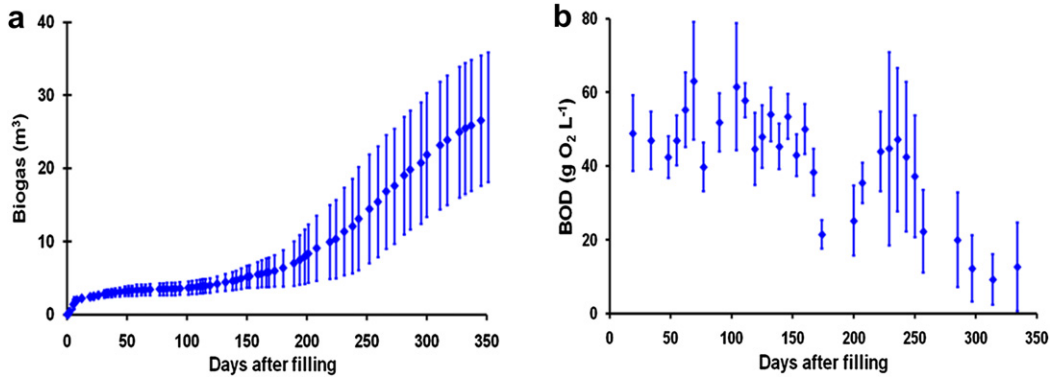

Fig. 1. a) Cumulative biogas production from the bioreactor landfill and b) BOD in the leachate.