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Effect of leachate injection modes on municipal solid waste degradation in anaerobic bioreactor

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ABSTRACT

Three pilots simulated landfill bioreactors were used to investigate the effect of leachate injection modes on anaerobic digestion and biogas production from municipal solid waste. The technical modes used to increase waste moisture consisted of an initial saturation of the waste by flushing with leachate followed by a quick drainage, or weekly leachate injections with two different rates. The results confirmed that increasing moisture content is a key parameter to boost the biological reactions. Weekly leachate injection with high flow rate led to better results than the initial saturation of the waste in terms of biogas production kinetics. Water percolation was found to be an important factor to accelerate the degradation of solid waste. However, a modelling of the collected data by Gompertz model clearly showed that the intrinsic biogas potential determined on the initial solid waste was not reached with any of the progressive leachate injection modes.

1. Introduction

The "sanitary" landfill technique, as it is practiced today, has been used for the disposal of municipal solid waste (MSW) in industrialized countries. The principle is based on a strict containment of the waste and a control of liquid (leachate) and gas (biogas) emissions in order to reduce the environmental risks. Due to the initial low water content of the refuse at the placement inside the landfill, this containment emphasizes the progressive drying of the refuse and the decrease of the biological activity. The stabilization of the waste is therefore obtained only through its low humidity. This situation can cause environmental threats over the long-term if the conditions of containment degrade in time.

In order to accelerate the achievement of a more stable state, the landfill site can be designed and operated in a different manner to install favourable conditions for biodegradation. The bioreactor approach mostly consists in controlling moisture through the recirculation of the leachate generated or by other means. Increasing the moisture content and flux through the landfill creates favourable environment for microbiological processes and organic matter decomposition. The idea was expressed more than 30 years ago (Pohland and Kang, 1975; Leckie et al., 1979; Ham and Booker, 1982) but, until recently, the "dry tomb" concept (strict containment) was usually preferred and promoted by the regulations in industrialized countries. The idea of accelerating biodegradation reappeared a few years ago for the development of landfill sustainability. Hence, several studies were recently published to evaluate the effect of leachate recycling (Bayard et al., 2005; Sponza and Agdag, 2004; Jianguo et al., 2007; Francois et al., 2007). Obviously, increasing the waste moisture content results in accelerating the biodegradation, improving methane production and enhancing the MSW stabilization compared to conventional landfills (Pohland and Kang, 1975; Otieno, 1994). Moreover, the studies of Gurijala and Sulfita (1993) suggest that moisture content close to the field capacity of waste (approx. 50% w/w), may be optimal for unsorted domestic waste. It results in faster methanisation and 3–4-fold higher methane yields during the observation time than at a moisture content of 20–30%.

However, recirculation of leachate into fresh waste also can lead to the inhibition of methanogenesis due to volatile fatty acids (VFAs) or ammonia nitrogen accumulation (Ledakowicz and Kaczarek, 2002; Burton and Watson-Craik, 1998; Price et al., 2003). Townsend et al. (1996) indicated that a landfill in Florida, where leachate recycling was applied, had a lower methane production than the control areas, with no leachate recirculation. Mehta et al. (2002) research on a Californian landfill was consistent with Townsend's investigations. Moreover, the high recirculation rates found by different authors (Sponza and Agdag, 2004; San and Onay, 2001; Chugh et al., 1998) make the full-scale experiment not an effective way relative to lab test (Yuen, 2001). High recirculation rates may cause some operational problems, such as ponding, flooding or clogging, especially in areas with increased precipitation (San and Onay, 2001; Reinhart, 1996; Reinhart and Al-Yousfi, 1996).

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Therefore, leachate injection regimes must be properly adjusted since moisture content close to the field capacity of waste is considered as an optimal value for leachate recirculation. The objective of this research was to identify the effect of various leachate injection modes on waste degradation, using pilot-scale simulated landfill reactors filled with crushed residual MSW.

2. Methods

2.1. Municipal solid waste (MSW)

The municipal solid waste used for this research was collected from a sanitary landfill site located in the south-east of France. Before waste was used in the pilot reactors, some preliminary procedures were carried out.

After the disposal of the refuse in landfill, aerobic reactions are involved within the surface waste. Aguilar et al. (1999) showed relationships between the landfilling practice (especially the air exposure time of the surface refuse layer) and the fraction of oxidized substrates at the landfill closure. Therefore, our waste was spread out in a layer of 50 cm on a concrete platform for 15 days to simulate the passive aerobic phase of landfilling operations during which the most easily biodegradable organic matter in the waste was biodegraded. Thereby, the risk of inhibition due to VFAs accumulation in the early stage of anaerobic digestion was reduced (Barlaz et al., 1989). Next, the waste was crushed and sieved down to approximately 150 mm.

Waste sampling was performed according to the French standard procedure XP X30-408 (AFNOR, 2007) known as MODECOM™ procedure. The fraction of easily biodegradable materials was determined at 30% wM (wet mass) (paper – 21.2%, cardboards – 5.7%, putrescible waste – 3.1%). Other potentially biodegradable materials, namely fine particles (<20 mm), textiles, sanitary textiles, composite materials and unclassified combustible materials, altogether represented 40% wM. The content in kitchen waste was low and the proportion of fine relatively high because of the aerobic preparation. Inert components such glass, plastic and metal composed the remaining 30% wM.

Another consequence of this initial aerobic phase was the low moisture content of the waste, around 26.5% wM. The main characteristics of the waste sample are given in Table 2. The procedures on solid waste characterization are detailed by Bayard et al. (2009).

Table 1
Recirculation rates of leachate in some previous work.

Lab-scale cells	Reference	Recirculation rate (L t_{DM}^{-1} day^{-1})
Three pilots, from 24 to 29 kg	Sponza and Agdag (2004)	621 1750
Six pilots, 10 kg each	Bayard et al. (2005)	4.3 34.3
Six columns, from 28 to 65 kg	Francois et al. (2007)	38.6
Four pilots, 28 tons each	Jianguo et al. (2007)	6.9 10.1 20.4

2.2. Experimental set-up

Three 1.2 m^3 simulated landfill pilot reactors were constructed and equipped as shown in Fig. 1 and Table 3. The reactors were made of high density polyethylene with an internal diameter of 960 mm and a height of 1300 mm. A 100 mm-thick gravel layer (gravel particle size <10 mm) was placed for leachate drainage at the bottom of the reactors. The drainage layer was covered with a geotextile Bidim^{TM} in order to avoid the migration of solid particles with leachate and prevent clogging of the drainage system. Each reactor was uniformly filled with waste to reach an initial apparent density of 0.5 t m^{-3} (see Table 3). A 100 mm-thick gravel layer (gravel particle size <10 mm) was then placed at the top surface of the waste mass and the reactors were sealed and flushed for 60 min with nitrogen to ensure anaerobic conditions. The pilots were then incubated in an insulated box at 35 ± 2 °C which is considered as the optimal mesophilic temperature range. The box was heating by a fan heater unit equipped with a ventilation device to ensure a regular distribution of the heat. Leachate was injected through the upper gravel layer, using a perforated tubular ring placed at the top of the gravel layer.

An aluminium tube was initially placed in the centre of the pilots to allow moisture determinations at different heights using a neutron probe and the monitoring of the settlement by magnetic measurements (data not shown here).

The operational parameters for the three pilots are reported in Table 3.

2.3. Experimental protocol

At time 0 of the study, pilot A1 was saturated with leachate by introducing 390 L of leachate from bottom to top. After a contact time of 12 h, leachate was drained by gravity and a volume of 204 L was recovered. Leachate was then allowed to drain for several weeks and no leachate was injected into this pilot over 200 days of incubation. Pilots A2 and A3 were injected weekly with 17.0 and 4.25 L of leachate, respectively (corresponding to 8 and 2 L day^{-1} t_{DM}^{-1}, see Table 4). These values are low compared to the ones used in previous work (see Table 1) but are more realistic with real landfill cases.

The leachate used was taken from the same landfill site as the waste itself. It was collected from an old landfill and preserved at 4 °C in a cold room. It showed a stable and high pH, a low concentration of Total Volatile Fatty Acids (TVFA) and a low BOD_5/COD ratio (see Table 5).

2.4. Bioreactor monitoring

The three bioreactors were monitored over a period of 200 days. The volumes of leachate released from each reactor were monitored every week. Gas production was monitored continuously with a drum-type Ritter® gas flow meter, model TG05. Gas volumes were corrected to dry gas at 0 °C and 1 atm. Gas composition was determined using an Agilent™ micro-gas chromatograph equipped with a thermal conductivity detector and a Poraplot U column for CO_2 and H_2S separation and a Molsieve column for O_2, N_2, and CH_4.

Table 2
Characteristics of the waste sample used in the pilot bioreactors.

Dry matter (% wM)	Water retention capacity (% wM)	Volatile solids (% DM)	Chemical oxygen demand (gO_2 kg_{DM}^{-1})	Total organic carbon (g kg_{DM}^{-1})	Biogas potential (Nm^3 t_{DM}^{-1})	Methane potential (Nm^3 t_{DM}^{-1})
73.5	48.4	69.5	1023	356	221	114