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ANAEROBIC TREATMENT OF MUNICIPAL SOLID WASTE LANDFILL LEACHATE: OPERATION OF A PILOT SCALE HYBRID UASB/AF REACTOR

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ABSTRACT

Landfill disposal is a widely used technique for solid waste management. The leachate produced, owing to moisture release and rain and snow infiltration, can cause environmental hazards if it is not properly collected, treated, and disposed. An on-site pilot plant study was carried out to assess the treatability of the leachate from a developing landfill. Details of the designed reactor and data collected during a long term run are presented, showing that a young landfill leachate is amenable to anaerobic treatment of its organic fraction, but special care should be taken with the management of the inorganic compounds, especially heavy metals.

KEYWORDS

Leachate; landfill; anaerobic digestion; UASB; anaerobic filter; design; operation.

INTRODUCTION

Sanitary landfilling is the most widely employed municipal solid waste disposal technique practised in the United States (Pohland and Harper, 1986). The production and migration of leachate from a landfill into groundwater and nearby surface waters is one of the major environmental hazards associated with this method of waste disposal (Lema *et al.*, 1988). Rainwater which trickles through the refuse contacts a wide variety of organic and inorganic pollutants, making it a potential source of soil and groundwater contamination (Kennedy *et al.*, 1988). Therefore, strict regulations have been established which govern the design, construction and operation of landfills. Leachate collection systems are now included in the design of most new landfills, in an attempt to minimize hydraulic head development above the liner and prevent leachate from seeping into surrounding soils (U.S.E.P.A., 1988, 1989). Since leachate generally has a high concentration of contaminants, some type of treatment is usually necessary prior to ultimate discharge of the wastewater (Pohland *et al.*, 1985).

As a result of sequential degradation processes, well described by Pohland and Harper (1986), leachates from young landfills are generally characterized by the presence of substantial amounts of volatile fatty acids (VFA). These readily degradable volatile acids account for the bulk of the chemical oxygen demand (COD) of young leachates (Méndez *et al.*, 1989), so the ratio of biodegradable oxygen demand (BOD_5) to COD is also relatively high (Henry *et al.*, 1987).

These characteristics make leachate amenable to anaerobic treatment in high rate systems. Several studies have been carried out, using Anaerobic Filters (AF) : Henry *et al.* (1982, 1983), and Mennerich and Albers (1986); using Upflow Anaerobic Sludge Blanket Reactors (UASB): Mennerich and Albers, (1986); using contact reactors: Carter *et al.* (1984) and hybrid configurations: Kennedy *et al.*, (1988), Chang (1989), Rumpf and Ferguson, (1990).

Besides the presence of large amounts of organics, soluble metals can also be present in high concentrations. Sulfur reducing bacteria produce hydrogen sulfide from sulfate, and low oxidation reduction potentials inside anaerobic reactors tend to cause the precipitation of heavy metals as metal sulfides. Often, there is not sufficient sulfide present to complex the large quantities of iron and other metals found in young leachates. Instead, these metals tend to form insoluble carbonate species (Rumpf and Ferguson, 1990).

Mennerich and Albers (1986) experienced clogging in the bench-scale AF due to deposition of inorganic precipitates. Similar clogging problems occurred in the influent piping of the UASB reactors they operated. Rumpf and Ferguson (1990) reported a dense granular sludge bed, as well as a coating of grey precipitates on most of the interior reactor surfaces of a lab-scale UASB. Kennedy *et al.* (1988) also noted that the sludge granules in their hybrid UASB/AF became very dense and gravel-like, and experienced operational problems because of it.

In order to assess the treatability of the leachate from a young landfill, we designed and installed a pilot plant at a medium-size landfill site. The pilot plant was designed to be flexible in terms of leachate flow and composition. In addition simplicity was stressed along with maintenance capability.

The initial reactor design (Figure 1) was based on an early paper of Kennedy *et al.* (1988). It is a hybrid reactor consisting of an upflow sludge blanket at the bottom, and an anaerobic filter on top, to be used as a gas-liquid-solid separator (GLSS device).

Other features include a filter backwashing circuit, a recycle circuit, a foam breaker and sampling taps.

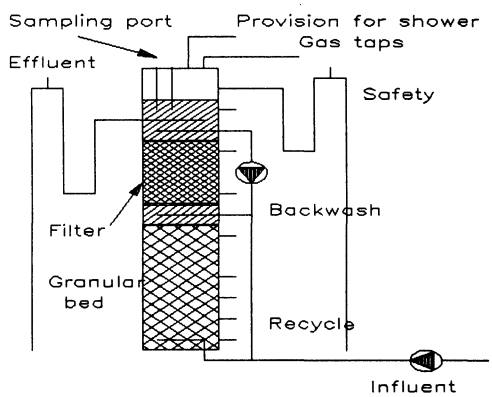

Fig. 1. Initial design of the pilot reactor.

Site Description

The Connecticut Valley Sanitary Waste Disposal facility is an 80 Ha landfill located in Chicopee, Massachusetts, USA . It receives more than 300 t/day of municipal solid waste (MSW), 7% of which is municipal sewage sludge. Leachate production varies widely from 0 to 390 m^3/d but averages 52 m^3/d.

The newer phases are lined with a standard composite liner as is common practice, and leachate is collected in a perforated pipe network which underlies the landfill. The operation of these sections started at the beginning of 1988.

Currently, leachate is collected in a leachate well prior to discharge to the municipal sewer system (Figure 2).

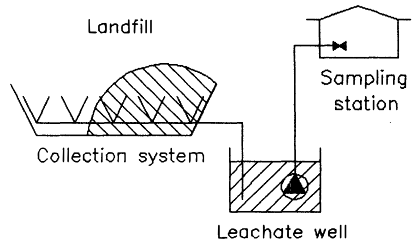

Fig. 2. Landfill collection system.

MATERIAL AND METHODS

Setup Description

The pilot plant was conceived as a highly flexible setup, where different configurations could be tested. It is composed of a pretreatment section, the anaerobic reactor and ancillary equipment, and an effluent collection and disposal section (Figure 3).

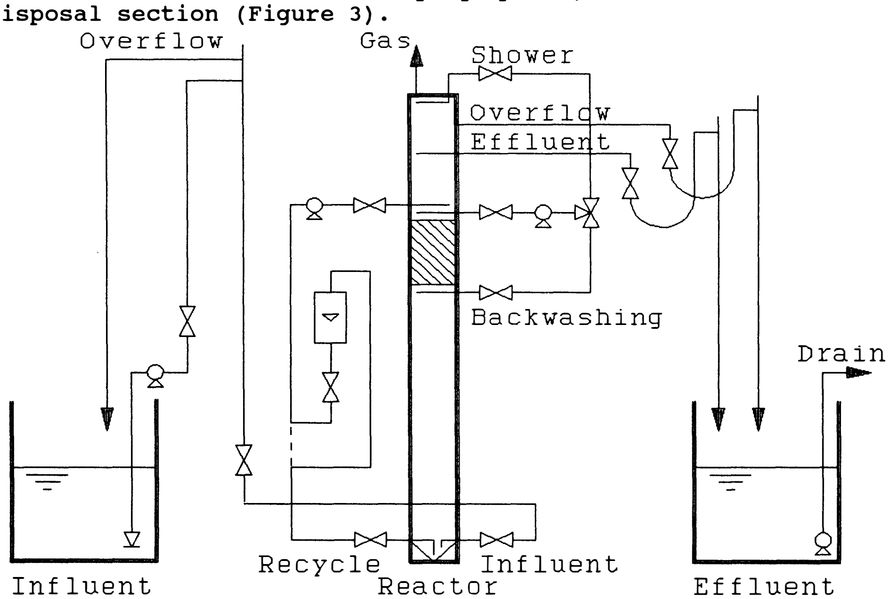

Fig. 3. Final piping schematics

Predesign

With a target goal of hydraulic retention times ($\bar{t}$) lower than one day and the site space limitations, a 30 L reactor and a 200 L pretreatment tank were designed. Several fail-safe devices and overflow containers were included in order to prevent spills, loss of biomass and overheating, since the reactor was usually unattended during operation.

Design

Pretreatment section. The leachate is usually not treated directly in the anaerobic reactor. Some kind of equalization is usually performed. For this task we will use the big leachate well, where residence time is long enough to smooth any short-term hydraulic and/or organic loading peaks. Long-term peaks will need a large equalization lagoon.

The initial pretreatment setup was a 200 L container, which was filled up on a weekly basis. When the flowrate was stepped-up and the hydraulic residence time was reduced to less than 2 days, a small tank fitted with a level controlled valve was built to provide a continuous supply of influent.

Reactor section. The anaerobic reactor is the main component of the plant. Careful design and operation are key factors in order to obtain valid information for scaling-up and future operation of a full scale system. Some of the more important design aspects are explained hereafter.

Reactor section: Anaerobic Filter. The physical design of the filter can be based on randomly packed material (biorings, Raschig rings, Koro-Z) or oriented packing like Muntek (TM). A simple design based on roughened plastic pipes was built, since it could permit us to extract some sections of the filter for biomass analysis and quantification.

A filter cleaning circuit, using a backwash stream able to scour the filter packing, was also provided to avoid clogging due to chemical precipitation and biomass accumulation.

Reactor section: Recirculation. A dedicated pump was used for recycling purposes, withdrawing liquid from the quiescent area above the filter, and injecting it at the distributor area. Although one of the easiest ways to provide both filter backwashing and foam breaking is to use the recycle stream, we included a dedicated pump, manually switched, for such tasks.

Reactor section: Overflow system. The overflow system should be designed to collect the effluent from the reactor while providing a quiescent zone for settling of biomass. To avoid high liquid velocity near the outlet, a multiple weir was used.

The overpressure inside the reactor (gauge) should be controllable to match levels with the biogas measurement and monitoring equipment. Another liquid gauge is used for safety, to avoid reactor floods (due to effluent pipe clogging or pump malfunction) or excessive underpressure (vacuum).

For total biogas measurement, we used a wet tip gasmeter due to the reproducibility of the measurement and its minimal maintenance needs. Gas sampling bulbs were also connected to provide gas samples for further analysis at the laboratory.

Reactor section: Reactor heating. In pilot plant systems, several heating strategies can be used:
1) direct heating of the liquid, (the reactor or the influent or recycle streams) by steam injection or electrical heater, or
2) indirect heating, by wall tracing or use of an intermediate heating fluid.

It is very important to avoid the formation of local hot points, which may contribute to the destruction of the biomass. To keep the reactor at 37 °C, we used a tape heater controlled by an electronic thermostat, and insulated with a thick close-cell polyurethane cover. This system will prevent the formation of hot points, since the reactor wall is used to spread the heat along the liquid-reactor interface. To avoid any overheating, a temperature sensing device is inserted into the reactor.

Effluent section. The effluent overflows from the reactor to a waste container where a sump pump is level-actuated to evacuate the treated leachate back to the leachate well. All reactor and pretreatment overflow pipes are connected to the waste tank, which is placed below all feed and recycle pumps. In case of a malfunction, the spill/overflow is safely collected and drained.

Analytical Methods

Analyses were carried out following the Standard Methods (APHA, AWWA, WPCF, 1985). Routine analyses included pH, total and soluble COD, total and bicarbonate alkalinity, VFA, and gas composition. To estimate bicarbonate alkalinity and VFA, the methods described by O´Brien and Donlan (1977) and Jenkins *et al.* (1983) were used simultaneously. Gas composition was analyzed by gas chromatography using a Gow Mac Series 550 instrument.

Heavy metals were analyzed by atomic absorption spectrometry, using a Perkin Elmer instrument model 3030B, after acid digestion with nitric acid (Bacon, 1988).

LEACHATE CHARACTERIZATION

The main problem of leachate treatment in anaerobic reactors is its variability. There are many factors affecting the quantity and quality of leachate:

(When) Seasonal weather variations: storms, rainfall, droughts.
(How) Landfilling technique, phase sequencing, piling and compaction method.
(What) Waste composition, presence of sludge, fly-ash, *etc.*

The newer sections of the Chicopee landfill are fully lined and leachates are collected and properly disposed to the Chicopee Municipal Wastewater Plant through a leachate well.

Flow

Daily data from a flow totalizer are available since January 1989. Pumping time data are available since the beginning of the operation (January 1988). It can be seen on Figure 4 that the maximum daily peak flow is around 380 m^3/d and no flow occurs during times of little or no precipitation.

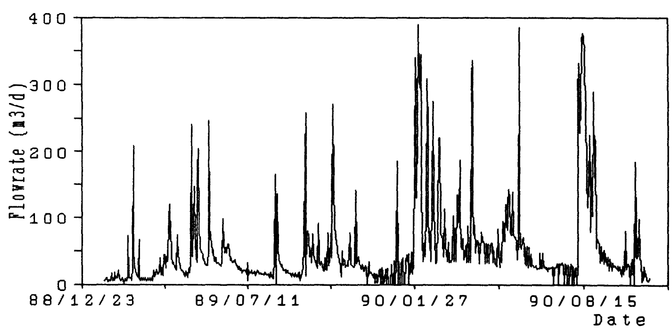

Fig. 4. Leachate flowrate at the landfill

Composition. Seasonal variations

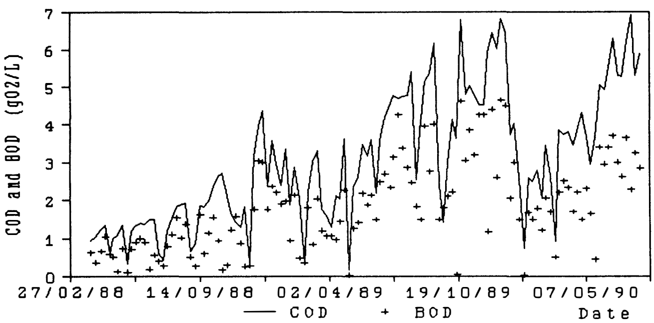

Fig. 5. Organic concentration of leachate

Weekly analyses of BOD_5 and COD, using EPA approved methods, are available since the beginning of the landfill operation (January 1988) and are plotted on figure 5. The BOD_5/COD ratio averages 0.6, typical for a young landfill leachate. A more detailed analysis was performed on a monthly basis, following trace metals and organics. A summary of these analyses is presented in Table I.

TABLE 1. Leachate characteristics

Parameter	Minimum	Average	Median	Maximum	Units
pH	6.1	6.70	6.3	7.8	-
BOD_5	33	1786	1760	4500	mg/L
COD	176	3168	3150	6440	mg/L
Oil/Grease	BDL	1.31	1	10	mg/L
Sb	BDL	0.37	0.2	2	mg/L
As	BDL	2.14	1	18	mg/L
Be	BDL	0.002	BDL	0.01	mg/L
Cd	BDL	0.035	0.02	0.31	mg/L
Cr	BDL	0.02	0.02	0.05	mg/L
Pb	BDL	0.14	0.1	0.3	mg/L
Hg	BDL	0.0045	0.002	0.03	mg/L
Se	BDL	2.49	1	11	mg/L
Ag	BDL	0.013	0.01	0.03	mg/L
Cu	BDL	0.04	0.02	0.3	mg/L
Ni	0.05	0.14	0.13	0.32	mg/L
Zn	0.03	0.18	0.08	0.77	mg/L
Ta	BDL	0.14	0.1	0.3	mg/L
Cr(VI)	BDL	0.04	BDL	0.51	mg/L
Phenol	BDL	0.57	0.55	1.35	mg/L
CN	BDL	0.05	BDL	1.4	mg/L

BDL = Below Detection Limits

Due to leachate variability and the sampling technique ("grab sample"), values reported serve only as indicators and no formal mass balance can be performed. The difference between average and median values indicates the variability of leachate composition and the existence of pollution spikes, which shift the averages towards higher values. During this study, due to the same effects, influent and effluent values are weekly and daily grab sample values, respectively: the removal efficiency calculation is based on such values.

Biotreatability

In order to assess the seasonal impact on leachate characteristics, assays of anaerobic treatability (Biochemical Methane Potential -BMP- and Anaerobic Toxicity Assay -ATA-) (Owen et *al.*, 1979) were performed during Fall 1989 and Spring 1990. Results showed that this leachate is easily treated, and it does not show any toxic effect to anaerobic bacteria, as is indicative of a young landfill leachate.

REACTOR OPERATION

Inoculum

The reactor was inoculated with anaerobic granular sludge fed on lactose from a previous experiment at our laboratory. The amount used was 6 L with a total solids concentration of 99.9 g/kg. The volatile to total solids (VS/TS) ratio was 0.37.

Start-up

Due to the long term storage of the seed sludge, a slow start-up was scheduled, in order to avoid any overload during the lag phase. The reactor was batch fed during 45 days and then switched to continuous flow. This period was also used to evaluate the behavior of feed and recycle pumps as well as the heating system.

Pseudo-steady state operation

The system was then installed at the landfill site and feed rate was increased step by step, when a pseudo-steady state was reached. Many full scale systems operate at hydraulic retention times of more than 1.5 - 2 days. We operated our system at $\bar{t}$=1 d for more than one month to evaluate the long term stability since, due to leachate variability, a shorter period would not be enough to get a good estimation of the system performance.

Performance

Figure 6 is a plot of the organic loading rate B_V and specific gas production rate (also expressed in g CH_4-COD/L·d), and as can be seen, there is a general increase in specific gas production, although a high variability exists.

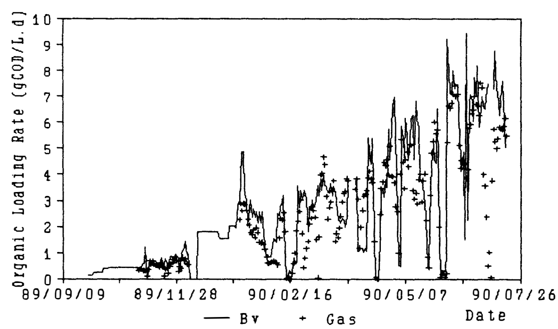

Fig. 6. Organic loading rate and specific gas production rate

The leachate well from which the influent was taken has a very low capacity and the equalization effect is therefore somewhat minimal. A plot of COD-based removal efficiency *vs.* the organic loading rate applied shows an almost constant efficiency, around 90%. Lower values occurred during the start-up period (low B_V values), and due to malfunction of the recycle pump, and/or bed compaction, which caused a severe channelling effect through the bed. A slight reduction on efficiency can be observed at the end of the experiment, when lower hydraulic retention times were applied ($\bar{t}$=18 h).

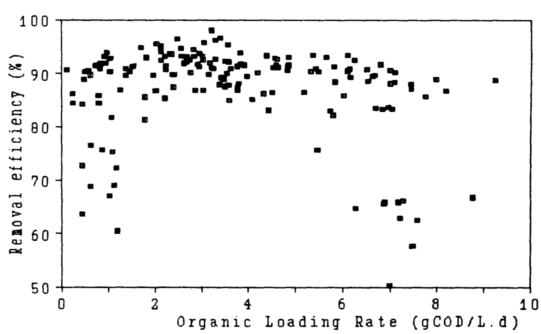

Fig. 7. Removal efficiency *vs.* organic loading rate plot

SLUDGE EVOLUTION

After the initial washout of fines, the sludge bed profile showed a typical UASB granular sludge profile: a large bed of granular sludge, a fairly narrow blanket of suspended biomass, and an almost flat profile up to the top of the reactor.

After several months of operation, the sludge bed /liquid interface slowly decreased due to precipitation and accumulation of heavy metal salts over and between the granules. The mineralization of the sludge, represented by the IS/TS ratio (IS= inert solids), was gradually augmenting, producing an increase in the number of reactor failures due to bed compaction and channeling.

At the end of the experiment, samples of the sludge were collected for their analysis and characterization (Keenan *et al.*, 1991). Very dense, gritty sludge was found at the bottom of the reactor, whereas at the top, hollow granules were found. The hollow granules seem to be produced by a massive deposition of metal salt precipitates over the fresh granules, causing the biomass inside the shell to become endogenous and produce some gas, which cannot be released and, thus, increase the buoyancy of the particle.

A serum-flask assay was carried out with several sludge samples to evaluate the methanogenic specific activity, and compare their temporal changes. Due to the long storing time, the original sludge had a lag phase of about 2 weeks. Once activated, the specific activity of the sludge remained almost constant, in spite of the heavy mineralization. Even the floating granules showed some activity of the biomass attached to the outer side of the precipitate shell.

CONCLUSIONS

* A young landfill leachate, due to its composition, is amenable to anaerobic treatment of its organic fraction. It is possible to achieve high treatment efficiencies operating at short hydraulic retention times.

* A long term operation requires a previous pretreatment step, where heavy metals are removed, in order to reduce the sludge mineralization. The specific methanogenic activity of the sludge is not affected, but the mineralization increases its effective density and causes bed compaction effects and channelling, reducing the treatment efficiency.

* On-site studies are necessary to correctly assess the treatability of the effluent. The high variability of quantity and quality of leachate imposes longer experimental periods, in order to evaluate the behavior of the plant.

* A very flexible set-up is required during the pilot-plant step to study different treatment strategies. This flexibility concept should be also stressed on the full-scale plant design, due to the very long term changes of the leachate during the operating life, and after the closure of the landfill.

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