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# Anaerobic Treatability of Sanitary Landfill Leachate in a Fluidized Bed Reactor

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## Abstract

The treatability of leachate from Odayeri Sanitary Landfill, located in the European part of İstanbul, in an anaerobic fluidized bed reactor (AFBR) was investigated. The experiments were performed in a pilot-scale fluidized bed reactor having an inner diameter of 10 cm, a height of 165 cm and an effective volume of 13 l. The reactor medium was a typical filter sand having an arithmetic mean diameter of 0.5 mm and a fixed bed height of 70 cm. The AFBR experiments were carried out by increasing gradually the organic loading rate (OLR) from 2.5 to 37 kg COD/m$^3$ per day in 8 operating steps. During the 240 days of operation, the feed rate ($Q_f$) and the hydraulic retention time (HRT) were 13 l/day and 1 day, respectively. The measured variables were chemical oxygen demand (COD), alkalinity, pH, volatile and suspended solids, ammonia, and gas rates. Ammonia removal efficiency appeared to be very low. However, ammonia inhibition has not occured during the study. COD removal increased from 80% to 90 % with increasing organic loading rates and the AFBR attained steady state conditions with a COD removal of 90% after 80 days. A good biogas production yield ($Y_{gas}$) was obtained; 0.50-0.52 l of biogas per g $COD_{rem}$ with a methane ($CH_4$) content of 75%. The attached biomass concentration ($X_{att}$) comprised about 90% of the total biomass concentration and showed an increase throughout the bed in the range of 3 to 38%. The mean attached biomass concentration also increased up to 70,000 mg/l in the last 2 months (for days 164-220).

**Key words:** Anaerobic treatability, Biogas production, Fluidized bed reactor, Landfill leachate, Organic loading, Process efficiency.

## Introduction

The leachate generated from a landfill site containing organic, inorganic and heavy metal compounds has a complex mixture with a foul odor. The flow rate and the composition of the sanitary landfill leachate vary depending on the site, season and age of the landfill (Knox and Jones, 1979). Leachates from young landfills can be characterized as high-strength wastewaters with 400-13,000 mg/l $BOD_5$, 10,000-60,000 mg/l COD, pH of 5-6 and several toxic/hazardous components (Ehrig, 1989). The advantages of fluidized bed processes are the accumulation of a large amount of biomass on the support media (up to 30,000 mg/l), including high organic loading rates (40-60 kg COD/m$^3$ per day), a high specific surface area (2000-3000 m$^2$/m$^3$), short retention times (1.5-3 h) and mixing characteristics (Iza, 1991; Turan and Ozturk, 1996; Buffière *et al.,* 1998; Ozturk, 1999; Turan, 2000).

Several investigators have reported on leachate treatment methods including coagulation-flocculation (Amokrane *et al.,* 1997), the electro-Fenton method (Gau and Chang, 1996), anaerobic sequencing batch reactor and anaerobic hybrid bed filter (Wu *et al.*, 1988; Inanc *et al.,* 2000; Timur *et al.,* 2000; Loukidou and Zouboulis, 2001), anaerobic fluidized bed reactor (Gulsen *et al.,* 2002) and upflow sludge blanket reactor (Ozturk *et al.,* 1999). Landfill leachate was treated in upflow hybrid (sludge-bed/fixed-bed) anaerobic reactors under methanogenic digestion with COD removal efficiencies of 81–97% (Nedwell and Reynolds, 1996). Landfill leachate from 2 young municipal landfill sites were effectively treated in anaerobic sequencing batch reactors, an anaerobic hybrid bed filter and an upflow sludge blanket reactor, at mesophilic conditions at variable influent CODs of 9000-25,000 mg/l (Timur *et al.,* 2000).

This paper presents treatability of sanitary landfill leachate in an anaerobic fluidized bed reactor (AFBR). Leachate treatment experiments were carried out by increasing gradually the organic loading rate in 8 operating steps. Bed expansion characteristics, ammonia and COD removal efficiencies, biogas production and biomass development in the reactor were evaluated.

## Materials and Methods

### Experimental design

A pilot-scale fluidized bed reactor with an inner diameter of 100 mm, a height of 1.65 m and an effective volume (V) of 13 l was used. The reactor was filled with a support medium of 0.5 mm diameter sand (sieve size of 30/35) to provide a fixed bed height of 70 cm. The upper settling section was 35 cm high and had a diameter of 30 cm (Figure 1). While peristaltic pumps were used for continuous leachate feeding, the combined feed and recycle flows were pumped to the reactor by a cone-shaped feed distributor (20° included-angle cone) with filled plastic balls at the bottom of the reactor.

The landfill leachate used were obtained from a municipal landfill site located in the European part of İstanbul, the Odayeri Landfill, which has been in operation since 1995 and also has characteristics of young leachate (Table 1). The leachate was collected in a 200 m$^3$ holding tank at the lowest side of the landfill and the samples were taken from the landfill once every week and diluted with tap water. The inoculum used was maintained from a yeast wastewater treatment plant. In addition, ortho-phosphoric acid was added to the feed leachate to maintain the ratio of KOI/ N/P at 500/7/1.

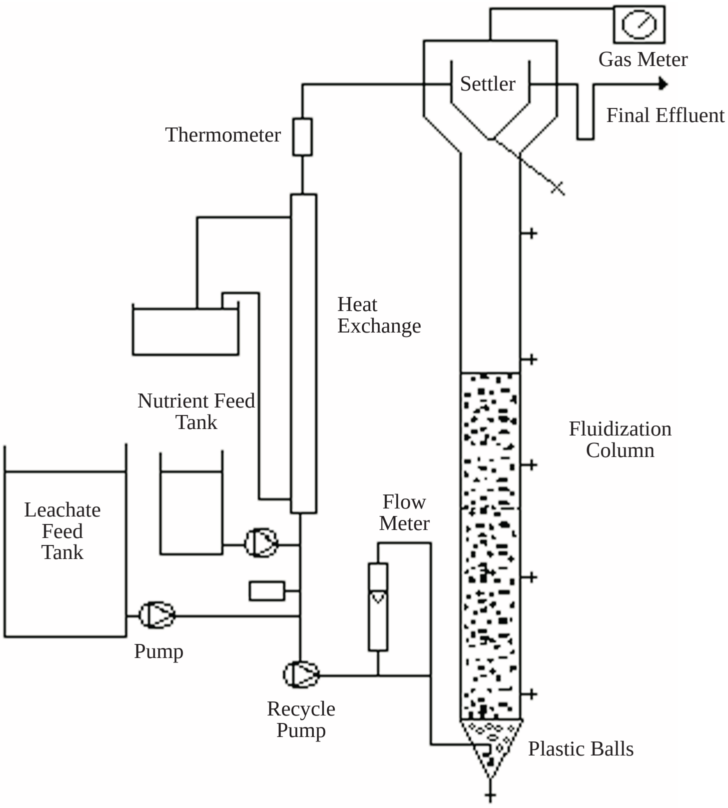

**Figure 1.** Schematic diagram of a pilot-scale anaerobic fluidized bed reactor.

**Table 1.** Characteristics of landfill leachate using in the experimental study.

| Parameter | Concentrations |
|---|---|
| pH | 7.5 - 8 |
| COD, mg/l | 10,000 - 50,000 |
| SS, mg/l | 37,500 - 46,000 |
| TDS, mg/l | 17,000 - 35,700 |
| TKN, mg/l | 1630 - 2750 |
| $NH_3$-N, mg/l | 1030 - 2350 |
| $PO_4$-P | 6.8 - 16.2 |
| Alkalinity, mg $CaCO_3$/l | 11,500 - 18,900 |

During the AFBR leachate treatment, the organic loading rate (OLR) was increased from 2.5 to 37 kg COD/$m^3$ per day while the feed rate ($Q_f$) and the hydraulic retention time (HRT) were 13 l/day and 1 day, respectively (Table 2). While the recycle pumps operated at rates of 400 l/h, the superficial velocity (U) was about 1.42 cm/s. Temperature was controlled at 35 °C in the mesophilic condition by passing the circulation water through a heat exchanger. Reactor pH was also controlled at about 7 while dynamic viscosity of the fluid was kept at 0.73 x $10^{-2}$ g /(cm/s) (at 35 °C).

### Sampling and analysis

The reactor pH and temperature were controlled using a WTW pH 330 Model pH meter and a Julabo LC4 F Mode temperature controller, respectively. A Ritter TG 05 gas meter was employed for biogas production measurements. The influent and effluent COD, temperature, pH, alkalinity, ammonia, suspended solids and total volatile acids concentrations were determined in accordance with Standard Methods (1999). The expanded bed sample (bioparticles and leachate) was collected at 2 heights (30 and 75 cm from base) via the sampling ports of the column. These samples were dried at 105 °C for 24 h in a ceramic evaporating dish and then muffled at 550 °C for 1 h. The difference between these weights represents the total biomass concentration ($X_{tot}$), measured volatile solids. The effluent volatile solids concentration ($X_{sus}$) in the leachate was also measured. The attached biomass concentration ($X_{att}$) was calculated as the difference between the total biomass concentration and the suspended biomass concentration in the bed sample.

## Results and Discussion

### Bed expansion characteristics

Biological fluidized bed reactors have 2 types of bed expansion; the first is due to an increase in the superficial velocity and the second is due to the microbial growth in the bed. The Richardson-Zaki correlation (Richardson and Zaki, 1954) is widely used to describe the expansion characteristics of fluidized beds and is given as

$$U/U_i = \varepsilon^n \tag{1}$$

The minimum fluidization velocity ($U_{mf}$) and the bed expansion ratio ($E_b$) can be calculated as follows:

$$U_{mf} > U_i \varepsilon_s \tag{2}$$

$$E_b = (L - L_s)/L_s = (\varepsilon - \varepsilon_s)/(1 - \varepsilon) \tag{3}$$

where U is the superficial (upflow) velocity, $U_i = 0.91 U_o \psi^{-0.400}$, the intercept velocity, $U_o$ is the ter-

**Table 2.** Treatment performance and operating data of the AFBR.

| Time from start-up (day) | OLR kgCOD/$m^3$ per day) | Feed rate (l/day) | HRT (day) | COD (mg/l) Inf. | COD (mg/l) Eff. | COD E(%) | $Q_{gas}$ (l/day) | $Y_{gas}$ (l/g$COD_{rem}$) |
|---|---|---|---|---|---|---|---|---|
| 0-30 | 2.5 | 13 | 1 | 2520 | 430 | 83 | 13,8 | 0.508 |
| 31-55 | 4.5 | 13 | 1 | 4490 | 535 | 88 | 26 | 0.506 |
| 56-80 | 8 | 13 | 1 | 8130 | 825 | 90 | 49 | 0.516 |
| 81-106 | 12 | 13 | 1 | 12,010 | 1210 | 90 | 73 | 0.520 |
| 107-128 | 18 | 13 | 1 | 18,015 | 2000 | 89 | 108 | 0.518 |
| 129-163 | 27 | 13 | 1 | 27,025 | 3050 | 89 | 163 | 0.523 |
| 164-220 | 37 | 13 | 1 | 37,010 | 6750 | 82 | 203 | 0.516 |
| 221-240 | 20 | 13 | 1 | 20,020 | 2150 | 89 | 120 | 0.516 |

minal settling velocity, $\psi$ is the particle sphericity, n is the bed expansion coefficient and $\varepsilon$ and $\varepsilon_s$ are the fluidized bed and fixed bed porosities, respectively (Turan, 1986, 1992).

The minimum fluidization velocity was calculated using Eq. (2) and the data given by Turan (1992) as $U_{mf} > U_i \varepsilon_s^n$= 8.1 cm/s x 0.468 $^{3.4}$ = 0.61 cm/s. Since the recycle pump was operated at a flow rate of 400 l/h, the upflow (superficial) velocity was 1.42 cm/s. Using Eq.(1), the expanded bed porosity was obtained as $\varepsilon = (1.42/\ 8.1)^{1/3.4} = 0.6$. Initial or non-biological bed expansion ratio can be calculated from Eq. (3) as $E_b$ (%) = (0.6-0.468)/(1-0.6) × 100 = 33%. In addition, expansion indices for biological fluidized beds were considerably larger than that for a bed containing uniform clean spherical particles (Ro and Neethling, 1994). In this study, we used the term fluidized bed reactor, since the term expanded bed is generally used for bed expansions of less than 20% (Denac and Dunn, 1988).

### Evaluation of nitrogen content

The leachate samples were taken from the landfill once every week and high strength leachate was diluted with dechlorinated tap water to obtain the proposed COD concentrations to detect the reactor performance at different organic loading rates. The total suspended solids (TSS) and the total dissolved solids (TDS) values showed an increase with increasing organic loading rates (OLRs). High organic loads of leachate indicated high concentrations of ammonia in the feeding of the reactor. Influent and effluent ammonia ($NH_3$-N) concentrations also varied between 145 and 1275 mg/l and 140 and 1340 mg/l, respectively. Although ammonia removal efficiency appeared to be very low, ammonia inhibition did not occur during the operation. Similarly, total Kjehdahl nitrogen (TKN) showed little difference between influent and effluent, varying between 175 and 1400 mg/l and 165 and 1380 mg/l. The influent pH also varied between 7.6 and 8 values (Figure 2).

### COD removal efficiency

The influent chemical oxygen demands (CODs) were 2500, 4500, 8000, 12,000, 18,000, 27,000, 37,000 and 20,000 mg/l while the OLRs were 2.5; 4.5; 8; 12; 18; 27; 37 and 20 kg COD/m$^3$ per day, respectively, during the study (Figures 3 and 4). On the other hand, the COD removal efficiency in each step showed a decrease at the beginning but arrived at a stable condition in approximately 3 weeks. In addition, the effluent COD values varied as 430, 535, 825, 1210, 2000, 3050, 6750 ve 2150 mg/l during the 240 days of operation (Figure 4). As shown in Figure 4, the COD removal of between 83 and 88% showed little variation as the OLR was increased within the range 2.5 to 4.5 kg COD/ m$^3$ per day. Then the COD removal remained at 89-90% while the OLRs were

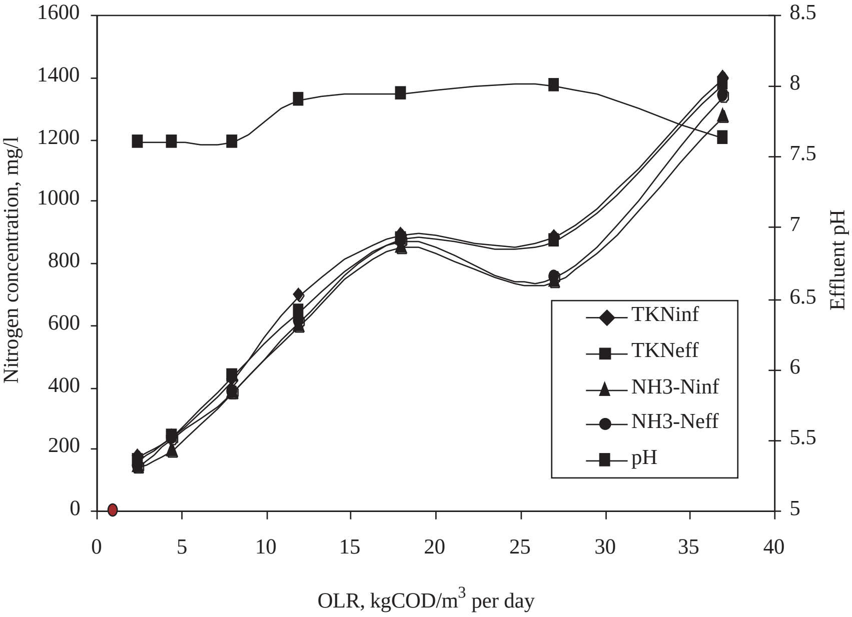

**Figure 2.** Ammonia nitrogen, TKN and pH versus organic loading.

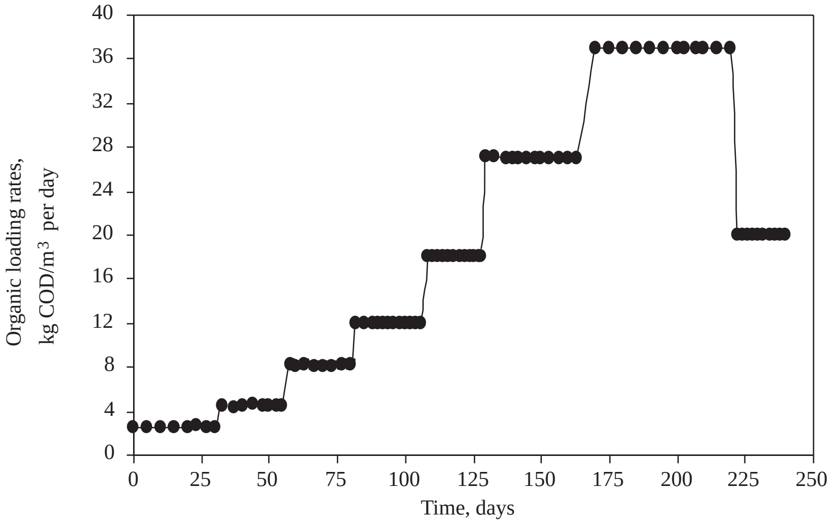

**Figure 3.** Variation of organic loading rates versus operation time.

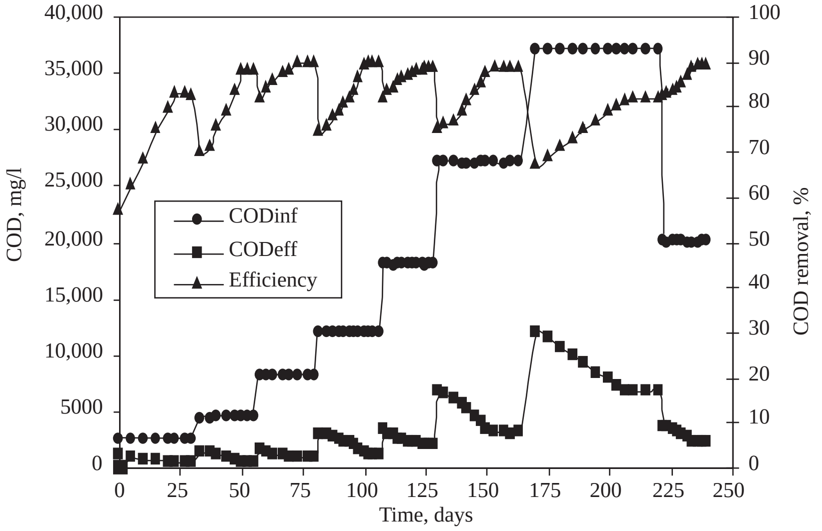

**Figure 4.** Variation of COD removal related to influent COD values.

between 8 and 27 kg COD/m$^3$ per day. Although the COD removal decreased to 82% at an OLR of 37 kg COD/m$^3$ per day, increasing loading rates did not hinder the COD removal efficiency of the AFBR. Consequently, the AFBR system attained steady state conditions on approximately day 80 and effective organic loading range was 4 to 30 kg COD/ m$^3$ per day.

### Biogas production

The AFBR system was operated in a closed cycle and biogas production appeared in 10 days. Biogas production increased continuously as 13.8; 26; 49; 73; 108; 163 and 203 l/day during the operation while the loading increased in the range of 2.5 to 37 kg COD/m$^3$ per day. However, this production decreased to 120 l/day when OLR was reduced to 20 kg COD/ m$^3$ per day. The relationship between the biogas production rate ($Q_{gas}$) and the removed COD per day ($B_r$, kg $COD_{rem}$/day) is presented in Figure 5. The average biogas production yield ($Y_{gas}$) was 0.515 l of gas/g COD $_{rem}$. As seen in Figure 6, at high OLRs, the performance of anaerobic fluidized bed reactor is particularly sensitive to gas effervescence effects (Diez Blanco *et al.,* 1995; Buffière *et al.,*1998). The fractions of $CH_4$ and $CO_2$ in the gases within the reactor were maintained at an effective level of about 75% and 25%, respectively. Thus, methane yield was found at about 0.39 l of $CH_4$/g $COD_{rem.}$

### Biomass development

The expanded bed sample (bioparticles and leachate) was collected at 2 heights (30 and 75 cm from base) via the sampling ports of the column. These samples were dried at 105 °C for 24 h in a ceramic evaporating dish and then muffled at 550 °C for 1 h. The difference of these weights per reactor volume would yield the total biomass concentration ($X_{tot}$), measured volatile solids in the bed sample. Increased organic loading generally caused an increased biofilm attachment on the support media of the AFBR.

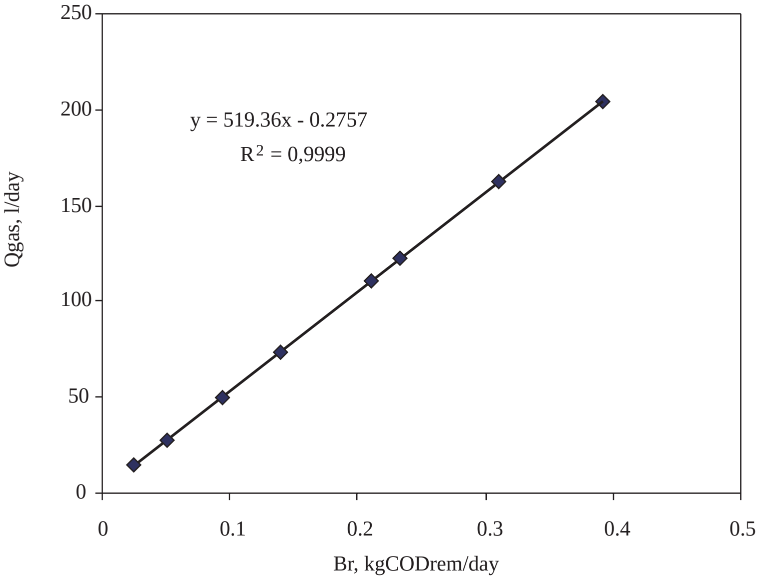

**Figure 5.** Relationship between biogas production and removed COD.

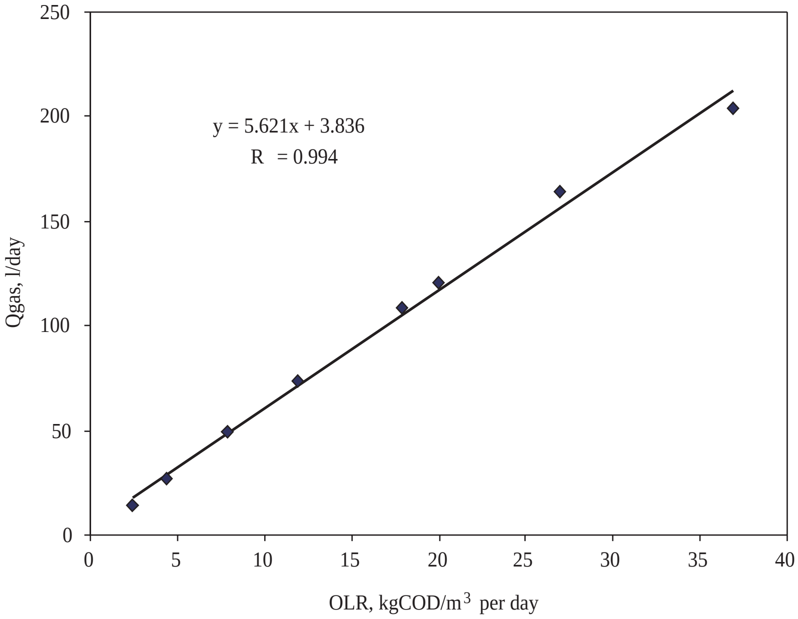

**Figure 6.** Relationship between biogas production and organic loading.

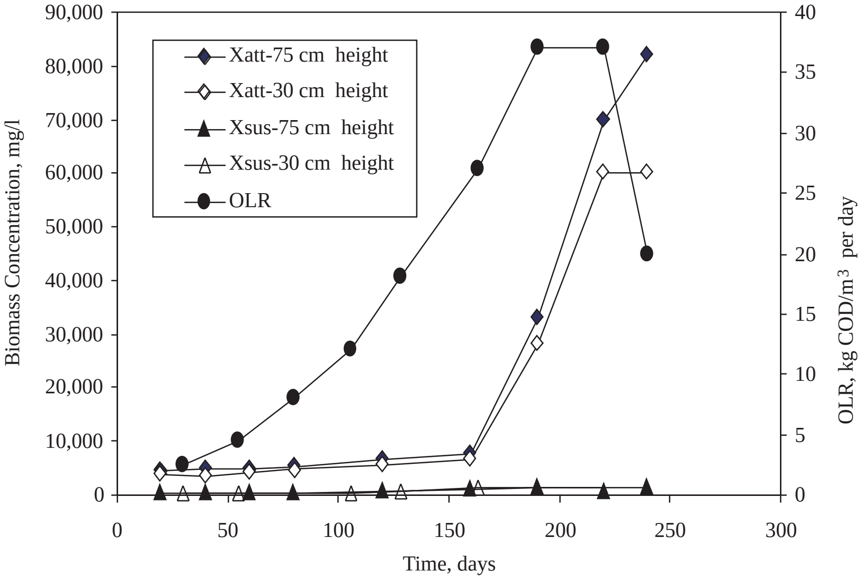

**Figure 7.** Variation of attached and suspended biomass concentrations during the AFBR treatment.

The attached biomass concentration ($X_{att}$) varied in the range of 4035 to 7105 mg/l in days 25 to 163, but then increased very sharply to 70,000 mg/l in the last 2 months (days 164 to 220), for the the organic loading of 37 kg COD/m$^3$ per day (Figure 7). On the other hand, the COD removal efficiency decreased from 90% to 82%. When organic loading decreased 20 kg COD/m$^3$ per day, the attached biomass concentration remained constant at about 70,000 mg/l. This is attributed to the fact that the COD removal performance of the AFBR is limited by the concomitant stabilization of both organic loading and biomass development.

The biofilm thickness on the support particle and the porosity differ throughout the bed and lighter bioparticles move to the upper part (Ro and Neethling, 1994). As a result, the attached biomass concentrations in the upper part of the column were found to be higher than those in the lower part. This difference varied between 3% and 38 % during the operation (Figure 7). In addition, the attached biomass concentration contained more than 90 % of the total biomass. The suspended biomass concentration ($X_{sus}$) showed an increase between 190 and 1480 mg/l. This increase in the suspended solid concentration is evidence of biomass detachment from support media of the reactor (Stronach *et al.*, 1987; Turan, 2000).

## Conclusions

The AFBR treatment of young landfill leachate was studied with the salient points summarized below.

Initial or non-biological bed expansion ratio was 33%, while the upflow (superficial) velocity was 1.42 cm/s and the expanded bed porosity was 0.6.

Total suspended solids showed an increase with increasing OLRs. High organic loads of leachate indicated high concentrations of ammonia in the feeding of the reactor. Although the ammonia removal efficiency was very low, ammonia inhibition did not occur.

COD removal efficiency increased up to 90% with increasing OLRs. In addition, the COD removal decreased to 82% at an OLR of 37 kg COD/ m$^3$ per day. The AFBR system attained steady state conditions on approximately day 80 and effective organic loading range was 4 to 30 kg COD/ m$^3$ per day.

Biogas production also increased with increasing the loading, and decreased with decreasing loading. An average biogas production yield ($Y_{gas}$) of 0.515 l of gas/g $COD_{rem}$ was obtained.

The attached biomass concentration was low up to day 163. Then it increased very sharply to 70,000 mg/l in the last 2 months, while the COD removal decreased. The COD removal performance of the AFBR is limited by the concomitant stabilization of both organic loading and biomass development.

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## Nomenclature

| | |
|---|---|
| $B_r$ | COD removal rate (kg $COD_{rem}$/day). |
| COD | chemical oxygen demand (mg/l) |
| E COD | removal efficiency (%) |
| $E_b$ | bed expansion ratio (%) |
| HRT | hydraulic retention time (day) |
| n | bed expansion coefficient |
| OLR | organic loading rate (kg COD/$m^3$ per day) |
| $Q_f$ | leachate feed rate (l/day) |
| $Q_{gas}$ | biogas production rate (l/day) |
| U | superficial (upflow) velocity (m/s) |
| $U_o$ | terminal settling velocity (m/s) |
| $U_{mf}$ | minimum fluidization velocity (m/s) |
| V | effective volume of the reactor ($m^3$) |
| X | biomass concentration (mg/l) |
| $Y_{gas}$ | biogas production yield (l of biogas/ $gCOD_{rem}$) |
| $\varepsilon$ | bed porosity |

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