



Ingeniería Ambiental



ANAEROBIC CO-TREATMENT OF LEACHATES PRODUCED IN A BIODEGRADABLE URBAN SOLID WASTE COMPOSTING PLANT IN MEXICO CITY

CO-TRATAMIENTO ANAEROBIO DE LIXIVIADOS PRODUCIDOS EN UNA PLANTA DE COMPOSTEO DE DESECHOS SÓLIDOS URBANOS BIODEGRADABLES EN LA CIUDAD DE MÉXICO

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Abstract

In this work the anaerobic co-treatment of the leachates produced during urban solid biodegradable wastes composting diluted with municipal wastewater, was investigated. Leachates produced during the first 30 days of garbage composting contained 102.1 g COD L⁻¹, 20 g VFA L⁻¹, acid pH and 0.64 g NH₄⁺-N L⁻¹. Instead, leachates that remained for 3 months the composting plant after being produced contained 15.8 g COD L⁻¹, 2.35 g VFA L⁻¹, a pH near neutrality and 5.36 g NH₄⁺-N L⁻¹. An anaerobic zeolite packed filter reactor was used for the biological treatment and was operated at a constant HRT of 1.5 d. Leachates were diluted with municipal wastewater (0.4 g COD L⁻¹) to obtain feedings with organic matter concentrations ranging from 1.8 to 13.1 g COD L⁻¹ and organic loading rates from 1.2 to 8.7 g COD L⁻¹ d⁻¹. Removal efficiencies attained increased from 79.5 to 91.5% and methane productivity from 0.23 to 1.84 L CH₄ L⁻¹ d⁻¹, rendering 0.48 L CH₄ per g consumed COD, equivalent to 118 kJ L⁻¹ of fed influent.

Keywords: anaerobic filter reactor, biodegradable solid waste, compost leachate, co-treatment, methane.

Resumen

En este trabajo se investigó el co-tratamiento anaerobio de los lixiviados producidos durante el composteo de desechos sólidos urbanos biodegradables, diluidos con agua residual municipal. Los lixiviados producidos durante los primeros 30 días de composteo de la basura, contenían en promedio 102.1 g DQO L⁻¹, 20 g AGV L⁻¹, pH ácido y 0.64 g NH₄⁺-N L⁻¹. En contraste, los lixiviados que permanecieron 3 meses en la planta de composteo después de haber sido producidos, presentaron 15.8 g DQO L⁻¹, 2.35 g AGV L⁻¹, pH cercano a la neutralidad y 5.36 g NH₄⁺-N L⁻¹. Para el tratamiento biológico se utilizó un reactor de filtro empacado con zeolita que se operó a un tiempo de retención hidráulica de 1.5 d. Los lixiviados fueron diluidos con agua residual municipal (0.4 g DQO L⁻¹) para una concentración en la alimentación de 1.8 a 13.1 g DQO L⁻¹ y velocidades de carga orgánica de 1.2 a 8.7 g DQO L⁻¹ d⁻¹. Las eficiencias de remoción alcanzadas se incrementaron de 79.5 a 91.5% y la productividad de metano de 0.23 a 1.84 L CH₄ L⁻¹ d⁻¹, obteniendo 0.48 L CH₄ por g DQO consumido, equivalente a 118 kJ L⁻¹ de influente alimentado.

Palabras clave: reactor de filtro anaerobio, desechos sólidos biodegradables, lixiviado de composteo, co-tratamiento, metano.

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1 Introduction

Nowadays around 13,000 metric tons of urban solid wastes are generated in Mexico City every day, and 1,500 to 3,000 metric tons correspond to biodegradable wastes that are separated at the source (Solid Wastes Inventory of Mexico City, 2010), and are stabilized for 30-40 days in open windrow composting piles of around 300 cubic meters. The static piles are not aerated and are turned upside down to homogenize contents every other day and the stabilized waste is reused afterwards as peat substitute in parks and avenues (Solid Wastes Integrated Management Program for Mexico City, 2010).

The composting process produces liquid effluents or leachates with such a high dissolved and suspended organic matter content that cannot be classified as wastewaters (Graja and Wilderer, 2001). The amount produced depends on the inherent garbage water content and the rainwater percolated through the composting piles. It has been reported that around 27 to 53% of the initial moisture of the composting pile can be released as leachate equivalent to 0.2 to 0.4 cubic meters per cubic ton of urban solid biodegradable wastes (Krogmann and Woyzechowski, 2000). An estimation of around 120 cubic meters of these effluents can be produced every day in Mexico City, which remain untreated in unlined ponds excavated near the composting pile.

Problems on designing adequate handling procedures for these wastes arise since the generation of food and other biodegradable wastes increases constantly. In turn, waste accumulation lead to hazards for population and to the environment. In fact, it has been calculated that the biggest landfill and composting plant site in Mexico City may produce 1.2 Mtons per year of carbon dioxide due to the biodegradation process during garbage stabilization (Inventory of Green House Effect Emissions in Mexico City, 2008), the contribution of the leachates produced in this site to these emissions is unknown. Also, the main interest in the adequate treatment of the urban solid biodegradable wastes is that may render important amounts of biofuels as methane, and supplement energetic requirements in composting plants (Flores *et al.*, 2008).

Compared to landfill leachates, compost leachates handling and treatment has been rarely addressed. The biological anaerobic treatment in UASB, EGSB, or hybrid anaerobic reactors reduced significantly the amount of carbonaceous organic matter and produced

significant amounts of methane (Han and Shin, 2004; Han *et al.* 2005; Stabnikova *et al.* 2008; Liu *et al.* 2010; Rajabi and Vafajoo, 2012). The anaerobic-aerobic treatment of compost leachates in a full-scale plant has been also reported by Mokhtarani *et al.* (2012), whom utilized an anaerobic hybrid reactor packed with clay blocks as filtering media. Other mineral supports such as zeolite, have been used as filtering, packing and support material in several anaerobic reactor prototypes, to favor biomass immobilization and to improve methanogenesis through ammonium/ammonia removal by cationic interchange with Mg^{2+} , Ca^{2+} and Na^{+} , that constitute the zeolite structure (Milán *et al.*, 2001; Tada *et al.*, 2005; Fernández *et al.*, 2007; Wang *et al.*, 2011; Montalvo *et al.*, 2012).

Given the compost leachates high organic matter content, to facilitate biological treatment and guarantee reactor stability, it is advisable to dilute these effluents with municipal wastewater that generally has a low organic matter concentration as Castilla *et al.* (2009) and Mokhtarani *et al.* (2012) have proposed. The aim of this work was to study the co-treatment of compost leachates produced during urban solid biodegradable wastes stabilization diluted with municipal wastewater. An anaerobic filter reactor packed with Mexican zeolite was used to promote gas-liquid-solid-separation, anaerobic biofilm formation and enhance methane production from this waste.

2 Materials and methods

2.1 Composition of compost leachates and municipal wastewater (MWW)

Compost leachates were collected at a full-scale composting plant in Mexico City that received urban solid biodegradable wastes at a rate of 1000 to 3000 ton per day. Those collected after 30 days of being produced were considered as fresh leachates (FE) and those that were collected after 3 months of being produced were considered as depleted leachates (DE). The basis for the classification was the high organic matter and acetic acid content and low ammonium concentration found in the fresh effluents. At the contrary, the low organic matter and volatile fatty acids (VFA) contents and high ammonium concentration found in the depleted ones. Two fresh batches were collected by May 2009 (FE1) and January 2010 (FE2) and one depleted batch was collected by November 2009 (DE). MWW used for dilution was obtained

from the wastewater treatment plant located at the University campus. Collected leachates and MWW batches were characterized through total and dissolved COD content, suspended solids content, VFA content and composition, ammonium concentration and pH.

2.2 Methanogenic reactor

An anaerobic filter reactor (AFR) was selected to carry on the biological treatment and to allow solid-gas-liquid-separation. Comprised a column of 13.7 L nominal volume (Fig. 1) packed with zeolite pebbles from San Luis Potosí, Mexico, with a mean diameter of 1.6 cm. The reactor was inoculated with 260 mL of sludge from a malting factory to attain a concentration of 12.1 g SV and operated at environmental temperature of $21 \pm 4^\circ\text{C}$ and constant hydraulic retention time (HRT) of 1.5 d. Leachates were diluted with MWW at increasing total organic matter concentrations ranging from 1.8 g COD L⁻¹ for start-up (15 days) to 3.2, 7.1, 10.5 and 13.1 g COD L⁻¹ during full operation for 113 days. The criteria for increase feeding concentration was, initially to duplicate COD concentration after start-up, and afterwards step increases in 3.0 g COD L⁻¹ for each stage, to adapt the sludge to increasing organic loading rates (OLR), that varied from 1.2 to 8.7 g COD L⁻¹ d⁻¹. The performance of the AFR was followed up through influent and effluent analysis.

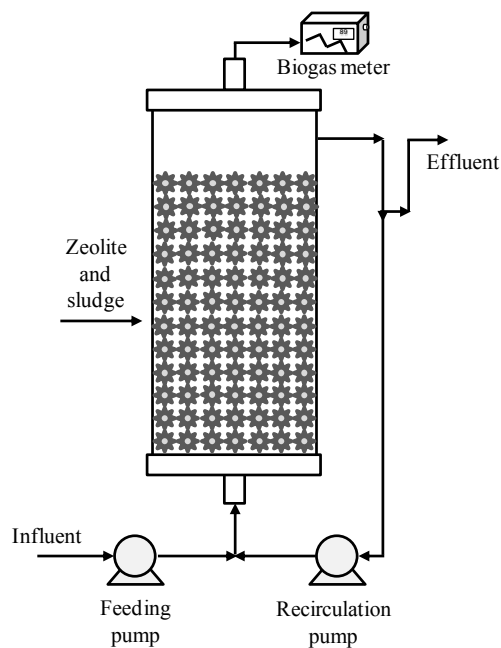


Fig. 1. Schematic diagram of the zeolite packed anaerobic filter reactor.

2.3 Analytical methods

Samples from leachates and MWW batches and from the AFR influent and effluent, were filtered using fiber glass filters of 0.45 μm pore size (Millipore, USA) for dissolved COD, ammonium and VFA content and composition determinations. Total COD, alkalinity and solids content were determined in non filtered samples. Total and dissolved COD contents were determined by closed reflux colorimetric method. Total and suspended solids (TS, TVS, TSS and VSS) were determined through gravimetric determinations. The pH was measured with a potentiometer (Hanna 255) and alkalinity content expressed as CaCO₃ concentration by potentiometric titration to pH 5.75 with H₂SO₄ 0.05 N. Alkalinity ratio was determined titrating at pH 5.75 and at pH 4.3 with H₂SO₄ 0.5 N; the quotient of both expended volumes is the ratio between produced alkalinity and titrable VFA and indicated the conversion capacity of the methanogenic process. Ammonium was determined with a selective electrode (Orion 93). VFA content and composition were determined by FID-Gas Chromatography (HP 5890) using an Altech-1000 capillary column. Biogas production rate was measured in a device with two constant volume chambers for gas accumulation, and composition was determined by TCD-Gas Chromatography (Gow Mac 580) using a Carbosphere 80/100 column. All determinations were made according to Standard Methods for the Analysis of Water and Wastewater (2005). The data set obtained from the analysis of all samples and parameters determined, were analyzed statistically obtaining the average value and the standard deviation with a confidence interval of 95%.

3 Results and discussion

3.1 Composition of compost leachates and MWW

Leachates and MWW composition is shown in Table 1. In this work it was found that depending upon the composting pile stabilization time, leachates had different COD, VFA and ammonium contents. As can be seen, fresh leachates FE1 and FE2 had high total and dissolved COD content, while the depleted batch (DE) had a fraction of the COD of fresh batches indicating that went through further natural degradation *in situ*.

Table 1. Physicochemical characterization of compost leachates and municipal wastewater utilized to feed the AFR.

Parameter (g L ⁻¹)	FE1	FE2	DE	MWW
Total COD	120.0	84.35	15.8	0.402
Dissolved COD	118.0	75.13	14.9	0.278
TS	135.0	79.7	16.2	n.d.
TVS	128.0	76.1	15.8	n.d.
TSS	15.7	5.62	1.38	0.137
VSS	13.0	4.0	0.94	0.115
Acetic acid	11.1	7.2	1.48	0.082
Propionic acid	2.8	3.3	0.19	0.016
<i>n</i> -Butyric acid	2.4	6.3	0.48	0.007
<i>n</i> -Valeric acid	0.69	4.2	0.29	0.002
Ammonium (g NH ₄ ⁺ -N L ⁻¹)	0.55	0.74	5.36	0.049
pH	4.50	4.83	6.55	8.10

FE: Fresh leachate. DE: Depleted leachate. MWW: Municipal wastewater

The total COD concentration contained in fresh batches, was found to be within the range reported by Liu *et al.* (2010), Rajabi and Vafajoo (2012) and Mokhtarani *et al.* (2012) from 42 to 109 g COD L⁻¹. Coincident findings may arise from the fact that these authors investigated compost leachates produced in full scale composting plants in China and Iran, similar in capacity to those found in Mexico City.

On the other hand, TS values found were higher than those reported before by Rajabi and Vafajoo (2012) and Maleki *et al.* (2009). TSS and VSS concentration were lower as compared to previously reported values of 15.9 to 33.6 g TSS L⁻¹ by Liu *et al.* (2010) and Rajabi and Vafajoo (2012), while Mokhtarani *et al.* (2012) found a range between 2.9 to 17 g TSS L⁻¹. In this work, the VSS content in the FE samples represented 82.8 and 70.4% of the TSS, indicating high organic matter content. Leachates suspended solids content probably depends on the composting pile stabilization stage; as the wastes are stabilized the suspended solids released to the leachates diminishes, and probably also the natural organic matter degradation in the leachate may produce the dissolution of suspended solids.

The acid pH in fresh leachates was due to the VFA content found of 17.0 g L⁻¹ for FE1 and 21.0 g L⁻¹ for FE2, that are several times higher than those reported by Stabnikova *et al.* (2008) and Shin *et al.* (2001). Brinton (1988) reported that the highest degradation and VFA production in the composting process was observed during the first 200 hours, and that these compounds are responsible for the typical rejectable odor of these wastes. Regarding VFA composition, acetic acid represented 65.6% and 34.2% for FE1 and

FE2 respectively, indicating that these batches were collected during a still active fermentation stage of the composting process (Brinton, 1988; Han and Shin, 2004). It is also noticeable that acetic acid, which is the main methane precursor, predominated above other VFA in fresh leachates batches collected; as can be seen in Table 1, indicating the freshness of the leachate accumulated near the composting pile. Also propionic, butyric and valeric acids were found in lesser concentration, and varied between both batches and did not show a pattern related to the leachate time of production.

Fresh leachates attained an ammonium concentration less than 1.0 g NH₄⁺-N L⁻¹ that is comparable to values reported by Krogmann and Woyczehowski (2000), Liu *et al.* (2010) and Zhou *et al.* (2010), ranging from 0.23 a 0.82 g NH₄⁺-N L⁻¹.

In contrast with FE batches, DE presented a characteristic dark brown color, that was not removed during treatment, COD and VFA concentration of 15.8 and 2.35 g L⁻¹, suspended solids content of 1.38 g TSS L⁻¹ and 0.94 g VSS L⁻¹, while ammonium concentration was as high as 5.6 g NH₄⁺-N L⁻¹, consequently pH was near neutrality. Krogmann and Woyczehowski (2000) found that compost leachates produced in a 200 hours period had acid pH and low ammonium concentration, and that pH increased along with ammonium content during composting time; the highest ammonium concentration was found in food wastes leachates after of 7 weeks. Brinton (1988) found out that VFA diminished at a rate of 1000 ppm each 10 days in relation to the leachate age. All DE characteristics can be attributed to the elapsed time before its collection.

The differences found between the data reported by other authors and those found in this work, are probably due to urban biodegradable wastes composition in different countries, handling procedures in the composting facilities, the time elapsed between leachates formation and collection and the season of the year when samples were collected.

In comparison, MWW presented alkaline pH and low total and dissolved COD content, suspended solids, VFA and ammonium concentration (Table 1), that are typical of these effluents (Cervantes *et al.*, 2011).

3.2 Methanogenic AFR performance

For performance evaluation, the AFR was fed with COD increasing concentrations in five stages (Figure 2). Operation parameters, removal efficiency and methane productivity corresponding to these stages are shown in Table 2.

The reactor was started-up with the mixture of FE1 and MWW at a concentration of 1.8 g COD L⁻¹, attaining 79.5% removal efficiency that increased to 88.0% when the organic matter concentration in the feeding was increased to 3.2 g COD L⁻¹ in stage I (day 16 to 36). Alkalinity ratio increased from 0.82 during start-up to 0.84 in stage I and produced alkalinity as bicarbonate increased slightly, while

methane productivity duplicated from 0.23 to 0.46 L CH₄ L⁻¹ d⁻¹. In this stages, ammonium concentration fed was 70 mg NH₄⁺-N L⁻¹ while 146 mg NH₄⁺-N L⁻¹ during start-up and 175 mg NH₄⁺-N L⁻¹ in stage I were found in the effluent, indicating that around 76 to 105 mg L⁻¹ were formed.

During stage II (day 37 to 50), 7.1 g COD L⁻¹ were fed, removal efficiency attained 91.5 % and methane productivity increased to 1.0 L L⁻¹ d⁻¹, while alkalinity ratio diminished to 0.75, indicating that the reactor was slightly affected by the increase in loading rate. Additionally, ammonium concentration in the effluent increased to 223 mg NH₄⁺-N L⁻¹ along with an increase in organic matter of 0.49 g COD L⁻¹.

In stage III (day 51 to 98), the concentration fed was increased to 10.5 g COD L⁻¹, organic matter in the effluent increased to 2.0 g L⁻¹ and removal efficiency diminished to 81.2%. The amount of organic matter found was probably due to the saturation of the AFR by the solids retained during operation that were discharged in this stage. Produced alkalinity increased slightly but alkalinity ratio remained in 0.74, while no effect on methane productivity was noticed which increased to 1.3 L L⁻¹ d⁻¹ (Table 2). At the end of stage III (day 83), the mixture of DE and MWW was fed and yielded a mean ammonium concentration of 675 mg NH₄⁺-N L⁻¹ while 703 mg NH₄⁺-N L⁻¹ were determined in the effluent, indicating no ammonium removal by zeolite.

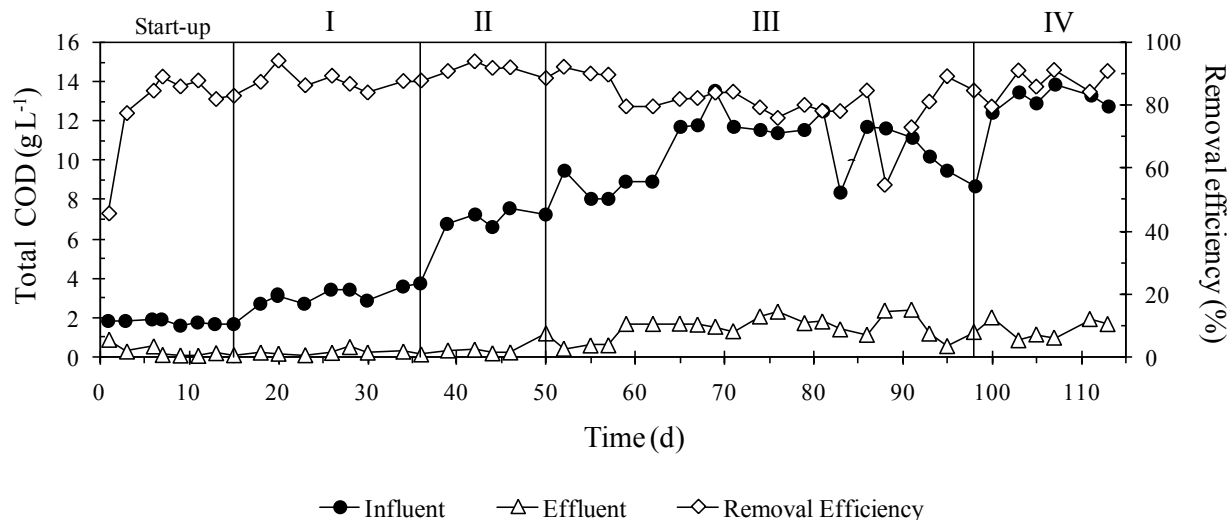


Fig. 2. Total COD fed and removal efficiency pattern of the AFR.

Table 2. AFR performance and methane productivity based in total COD.

Stage (d)	Batch	Influent COD (g L ⁻¹)	OLR (g L ⁻¹ d ⁻¹)	Removal efficiency (%)	Alkalinity (g CaCO ₃ L ⁻¹)	Alkalinity ratio	Methane productivity (L CH ₄ L ⁻¹ d ⁻¹)	Effluent COD (g L ⁻¹)
Start-up	1-15	1.8 ± 0.13	1.21 ± 0.09	79.5 ± 14.1	1.2 ± 0.92	0.82 ± 0.08	0.23 ± 0.04	0.37 ± 0.26
I	16-36	3.2 ± 0.41	2.16 ± 0.28	88.0 ± 2.9	1.3 ± 0.13	0.84 ± 0.04	0.46 ± 0.06	0.39 ± 0.09
II	37-50	7.1 ± 0.49	4.72 ± 0.53	91.5 ± 1.9	2.1 ± 0.15	0.75 ± 0.04	1.04 ± 0.09	0.49 ± 0.15
III	51-98	10.5 ± 2.02	7.0 ± 1.09	81.2 ± 7.9	2.6 ± 0.36	0.74 ± 0.07	1.36 ± 0.22	2.02 ± 0.99
IV	99-113	13.1 ± 0.52	8.73 ± 0.34	87.2 ± 4.7	2.6 ± 0.24	0.79 ± 0.08	1.84 ± 0.15	1.67 ± 0.57

At the beginning of stage IV (day 99 to 106) the mixture of DE and MWW was still being fed and COD concentration was increased to 13.1 g L^{-1} . Removal efficiency increased to 87.2% and alkalinity ratio to 0.79; organic matter in the effluent diminished slightly while methane productivity increased to $1.8 \text{ L L}^{-1} \text{ d}^{-1}$. A mean ammonium concentration of $911 \text{ mg NH}_4^+ \text{ N L}^{-1}$ was fed during the first 7 days of this stage which diminished gradually to 415 mg L^{-1} , for an ammonium removal attributed to zeolite of 54.4%, improving methane productivity, as other authors has reported before (Milán *et al.*, 2001; Tada *et al.*, 2005; Wang *et al.*, 2011).

Also zeolite has been reported as a suitable support for microorganisms immobilization (Fernández *et al.*, 2007; Weiß *et al.*, 2011). In this investigation, the biomass immobilized on the packing of the AFR probably hindered a rapid ionic interchange that would lead to ammonium diminution since the moment when a high concentration was fed.

At the end of stage IV (day 107), the feeding with FE2 reduced the ammonium concentration to $93 \text{ mg NH}_4^+ \text{ N L}^{-1}$ and in the effluent 127 mg L^{-1} were found and ammonium removal by zeolite was not detectable. COD removal efficiency and alkalinity ratio increase was observed, although a high organic matter concentration was still being detected in the effluent.

Liu *et al.* (2010) found that ammonium produced during anaerobic treatment, from 350 to $900 \text{ mg NH}_4^+ \text{ N L}^{-1}$ helped to buffer the system when high COD concentrations were fed. No buffering was found in the AFR when ammonium concentrations similar to those reported by Liu *et al.* (2010) were fed, due to the zeolite ammonium removal.

As can be seen in Figure 3a, the highest removal efficiency attained in the AFR was around 90% at an organic loading rate of $4.7 \text{ g COD L}^{-1} \text{ d}^{-1}$. After 80 days of operation (stage III), an important amount

of organic matter was detected in the effluent and consequently removal efficiency diminished, probably due to the saturation of the filtering packing media by the solids retained in the reactor, that were dragged out at this time. Also the dragging of small solid particles by biogas production was observed which may contribute to the organic matter amount detected in the effluent.

Along with the increase in organic loading rate, methane productivity increased from 0.46 to $1.84 \text{ L L}^{-1} \text{ d}^{-1}$, as can be seen in Figure 3b. The high methane productivity equivalent to production rates of 6.0 to $25.2 \text{ L CH}_4 \text{ d}^{-1}$, indicated the biodegradability of the diluted leachate rendering 0.48 L CH_4 produced per g consumed COD (at 0.77 atm and 21°C in Mexico City), that is higher than the theoretical value. The high methane productivity is in agreement with the results obtained by Milán *et al.* (2001) and Weiß *et al.* (2011), who found that zeolite may enhance methane production by ammonium removal and by providing essential micronutrients for methanogenic archaea. Interestingly, the energetic capacity estimated for a methane production rate of 25.2 L d^{-1} is of 717 kJ d^{-1} equivalent to 118 kJ L^{-1} of influent fed, indicating the suitability of compost leachates to obtain an alternative energy source.

The results obtained in this work are similar to those presented by Han and Shin (2004) and by Han *et al.* (2005) that operated UASB reactors at pilot scale treating urban food waste leachates at HRT from 3.8 to 0.18 days and attained COD removal efficiencies between 56-96%, with methane productivities of 0.4 a $4.1 \text{ L L}^{-1} \text{ d}^{-1}$. Also are similar to those found by Liu *et al.* (2010), whom reported that the treatment of compost leachates in an expanded granular sludge bed (EGSB) reactor at HRT of 31 hours, attained removal efficiencies from 90 to 97% and methane productivities from 0.7 to $7.1 \text{ m}^3 \text{ m}^{-3} \text{ d}^{-1}$, at dissolved COD concentrations of 4.0 to 38.0 g L^{-1} .

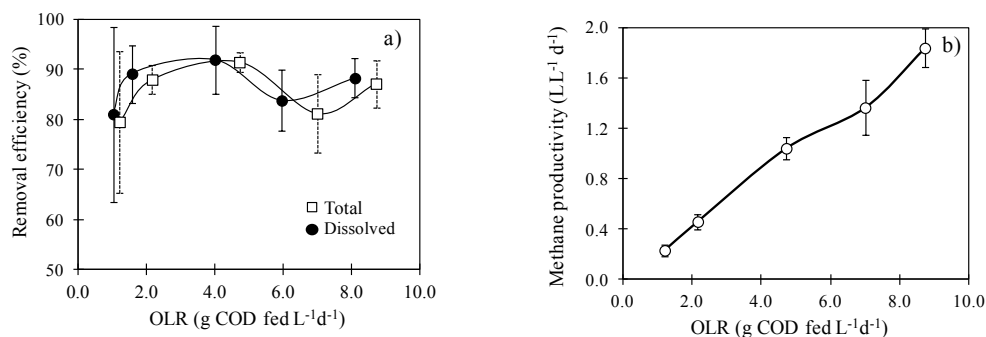


Fig. 3. Removal efficiency pattern (a) and methane productivity (b) vs. organic loading rates applied to the AFR.

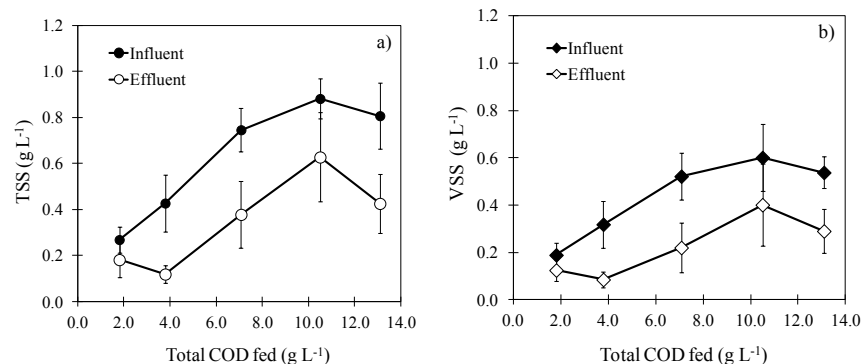


Fig. 4. Total (a) and volatile (b) suspended solids removal pattern during the AFR operation.

In contrast the hybrid anaerobic system (HASL) proposed by Stabnikova *et al.* (2008) attained COD removal efficiencies higher than 90% at HRT of 2.1 d and 8.7 g COD L⁻¹ d⁻¹, although the estimated methane produced from biogas was 2.1 L CH₄ d⁻¹ in the methanogenic section of the system. A full scale plant reported by Mokhtarani *et al.* (2012) consisting of hybrid anaerobic reactors and an aerobic posttreatment, attained a COD removal efficiency of 91% at 4.5 kg COD m⁻³ d⁻¹, although no methane productivity was reported.

These findings indicate that anaerobic digestion is the suitable treatment for liquid effluents formed during the composting of urban biodegradable wastes to produce a biofuel such as methane.

3.3 Suspended solids removal efficiency

TSS influent concentration increased gradually from 0.27 to 0.81 g L⁻¹ along with the total COD being fed (Figure 4a), and removal efficiencies increased from 34.5% to 69.0% during start-up and stage I and decreased to 50.2% and 29.2% during stage II and III with a slight recovery to 47.0% in stage IV. As can be seen in Figure 4b, VSS presented a similar increasing concentration pattern in the feeding from 0.19 to 0.54 g L⁻¹. Removal efficiency increased after start-up to 70.7% and decreased in stage III to 31.3%, due to solids output found in the effluent. A slight recovery to 45.9% during the last stage was found.

In spite of the high organic matter removal efficiencies found, the suspended solids removal was not as high as expected in the anaerobic filter as reported before by Castilla *et al.* (2009), that attained 80% removal. As explained before, two operational drawbacks may have been responsible for the variable solids removal efficiency found: the saturation of

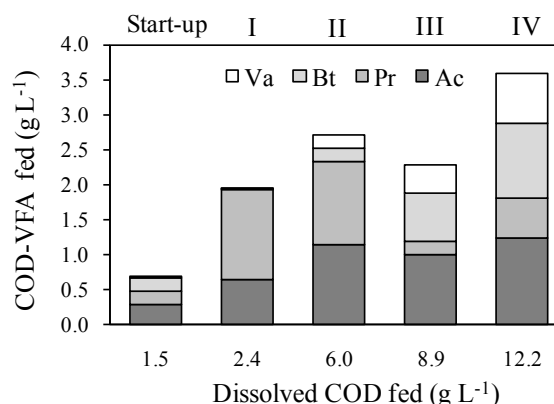


Fig. 5. VFA composition in the AFR fed at different stages: acetic acid (Ac); propionic acid (Pr); butyric acid (Bt); valeric acid (Va).

the filter and solids dragging to the effluent due to biogas production during stages III and IV, as shown in Table 2. Also, TSS fed contained an important biodegradable fraction and after being retained and degraded in the filter, probably contributed in some extent to the biogas production, which may explain the high methane yield obtained.

3.4 VFA conversion

The VFA content in the fed varied according to the increase in dissolved COD (Table 3 and Figure 5) and represented from 45 to 79% in the stages fed with fresh leachates and diminished to 25% when the DE batch was fed. VFA varied in the feeding in the proportion shown in Figure 5, being acetic, propionic and butyric acids the predominant compounds while valeric acid was found in a smaller concentration. During stages I and II, no VFA were detected in the effluent, and attained 0.1 and 0.2 g COD L⁻¹ during stages III and

Table 3. COD-VFA content based in dissolved COD.

Stage (d)	Influent		Effluent		Removal Efficiency (%)	
	COD (g L ⁻¹)	COD-VFA (g L ⁻¹)	COD (g L ⁻¹)	COD-VFA (g L ⁻¹)		
Start-up	1-15	1.5±0.17	0.7±0.04	0.3±0.28	0.3±0.06	81.0±17.5
I	16-36	2.4±0.22	1.9±0.19	0.2±0.13	0.01±0.0	89.1±5.7
II	37-50	6.0±0.23	2.7±0.32	0.4±0.41	0.0±0.0	91.9±6.7
III	51-98	8.9±0.64	2.2±0.10	1.4±0.59	0.1±0.03	83.8±6.1
IV	99-113	12.2±0.31	3.6±0.32	1.4±0.49	0.2±0.05	88.3±3.9

IV (Table 3), which along with the stability found in produced alkalinity, indicated that the AFR could tolerate higher loading rates without acidification.

It is important to notice that fresh leachates with high acetic acid content are suitable for the anaerobic treatment because acetic acid is the main methane precursor.

Conclusions

Compost leachate characterization showed that the composting pile maturation stage and the time elapsed since leachates were produced had an important effect on the type and concentration of organic matter content, such as COD, VFA, ammonium and pH.

The AFR used for the co-treatment of compost leachates diluted with municipal wastewater, represented a feasible strategy for COD removal and its conversion to methane. The biodegradability of the mixture used in the anaerobic treatment was demonstrated since the methane production from the consumed COD was higher than the theoretical yield value. High ammonium concentration present in depleted leachates was removed in 50% by zeolite, improving removal efficiency and methane productivity. Nevertheless, it is advisable to carry out fresh leachates treatment, because of the nature of leachates, the organic matter content is highly biodegradable and can be recovered as an alternative energy source, avoiding emissions to the atmosphere.

Suspended solids removal efficiency has to be optimized and a nitrogen removal posttreatment has to be implemented to obtain a high quality effluent.

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References

- Brinton, W.F. (1988). Volatile organic acids in compost production and odorant aspects. *Compost Science and Utilization* 6, 75-82.
- Castilla, P., Aguilar, L., Escamilla, M., Silva, B., Milán, Z., Monroy, O., Meraz, M. (2009). Biological degradation of a mixture of municipal wastewater and organic garbage leachate in expanded bed anaerobic reactors and a zeolite filter. *Water Science and Technology* 59, 723-728.
- Cervantes-Zepeda, A.I., Cruz-Colín, M.R., Aguilar-Corona, R., Castilla-Hernández, P. and Meraz-Rodríguez, M. (2011). Physicochemical and microbial characterization of the treated wastewater in a pilot scale UASB reactor. *Revista Mexicana de Ingeniería Química* 10, 67-77.
- Fernández, N., Montalvo, S., Fernández-Polanco, F., Guerrero, L., Cortés, I., Borja, R., Sánchez, E. and Travieso, L. (2007). Real evidence about zeolite as microorganisms immobilizer in anaerobic fluidized bed reactors. *Process Biochemistry* 42, 721-728.
- Flores, R., Muñoz-Ledo, R., Flores, B.B. and Cano, K.I. (2008). Power generation from biomass estimation for projects of the clean development mechanism program. *Revista Mexicana de Ingeniería Química* 7, 35-39.
- Graja, S. and Wilderer, P.A. (2001). Characterization and treatment of the liquid effluents from the

- anaerobic digestion of biogenic solid waste. *Water Science and Technology* 43, 265-274.
- Green House Effect Emissions Inventory of Mexico City (2008). Secretariat of the Environment-Mexico City Government. Available in: http://www.sma.df.gob.mx/inventario_emisiones/index.php?op=gei [Accessed: September 6, 2012].
- Han, S.K., Kim, S.H., Shin, H.S. (2005). UASB treatment of wastewater with VFA and alcohol generated during hydrogen fermentation of food waste. *Process Biochemistry* 40, 2897-2905.
- Han, S.K. and Shin, H.S. (2004). Performance of an innovative two-stage process converting food waste to hydrogen and methane. *Air & Waste Management Association* 54, 242-249.
- Krogmann, U. and Woyczehowski, H. (2000). Selected characteristics of leachate, condensate and leachate released during composting of biogenic waste. *Waste Management and Research* 18, 235-248.
- Liu, J., Zhong, J., Wang, Y., Liu, Q., Qian, G., Zhong, L., Guo, R., Zhang, P. and Xu, Z.P. (2010) Effective bio-treatment of fresh leachate from pretreated municipal solid waste in an expanded granular sludge bed bioreactor. *Bioresource Technology* 101, 1447-1452.
- Maleki, A., Zazouli, M.A., Izanloo, H. and Rezaee, R. (2009). Composting plant leachate treatment by coagulation-flocculation process. *American-Eurasian Journal of Agricultural & Environmental Sciences* 5, 638-643.
- Milán, Z., Sánchez, E., Weiland, P., Borja, R., Martín, A. and Ilangovan, K. (2001). Influence of natural zeolite concentration on the anaerobic digestion of piggery wastes. *Bioresource Technology* 80, 37-43.
- Mokhtarani, N., Bayatfard, A. and Mokhtarani, B. (2012). Full scale performance of compost's leachate treatment by biological anaerobic reactors. *Waste Management and Research* 30, 524-529.
- Montalvo, S., Guerrero, L., Borja, R., Sánchez, E., Milán, Z., Cortés, I., de la Rubia, M.A. (2012). Application of natural zeolites in anaerobic digestion processes: A review. *Applied Clay Science* 58, 125-133.
- Rajabi, S. and Vafajoo, L. (2012). Investigating the treatability of a compost leachate in a hybrid anaerobic reactor: An experimental study. *World Academy of Science, Engineering and Technology* 61, 1175-1177.
- Shin, H.S., Han, S.K., Song, Y.C. and Lee, C.Y. (2001). Performance of UASB reactor treating leachate from acidogenic fermenter in the two-phase anaerobic digestion of food waste. *Water Research* 35, 3441-3447.
- Solid Wastes Integrated Management Program for Mexico City (2010). Official Government Journal of Mexico City No. 925. Available in: http://www.semarnat.gob.mx/temas/residuos/solidos/Documents/pepgir/PPGIR_%20Distrito%20Federal.pdf [Accessed: November 11, 2012].
- Solid Wastes Inventory of Mexico City (2010). Secretariat of the Environment-Mexico City Government. Available in: http://www.sma.df.gob.mx/sma/links/download/biblioteca/inventario_residuos_solidos_2010.pdf [Accessed: January 10, 2013].
- Stabnikova, O., Liu X-Y. and Wang, J-Y. (2008). Anaerobic digestion of food waste in a hybrid anaerobic solid-liquid system with leachate recirculation in an acidogenic reactor. *Biochemical Engineering Journal* 41, 198-201.
- Standard Methods for the Examination of Water and Wastewater (2005). Edited by the American Public Health Association/American Water Works Association/Water Environment Federation, 21th ed., Washington DC, USA.
- Tada, C., Yang, Y., Hanaoka, T., Sonoda, A., Ooi, K., Sawuayama, S. (2005). Effect of natural zeolite on methane production for anaerobic digestion of ammonium rich organic sludge. *Bioresource Technology* 96, 459-464.
- Wang, Q., Yang, Y., Yu, C., Huang, H., Kim, M., Feng, C. and Zhang, Z. (2011). Study on a fixed zeolite bioreactor for anaerobic digestion of ammonium-rich swine wastes. *Bioresource Technology* 102, 7064-7068.
- Wei, S., Zankel, A., Lebuhn, M., Petrak, S., Somitsch, W. and Guebitz, G.M. (2011). Investigation of microorganisms colonising activated zeolites during anaerobic biogas

production from grass silage. *Bioresource Technology* 102, 4353-4359.

Zhou, C., Wang, R. and Zhang, Y. (2010). Fertilizer efficiency and environmental risk of irrigating Impatiens with composting leachate in decentralized solid waste management. *Waste Management* 30, 1000-1005.