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Treatment of Sanitary Landfill Leachates in a Lab-Scale Gradual Concentric Chamber (GCC) Reactor

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Abstract Sanitary landfill leachates are a major environmental problem in South American countries where sanitary landfills are still constructed and appropriate designs for the treatment of these leachates remain problematic. The performance of a lab-scale Gradual Concentric Chamber (GCC) reactor for leachates treatment is presented in this study. Two types of sanitary landfill residuals were evaluated, one directly collected from the garbage trucks (JGL), with high organic strength (84 g COD/l) and the second one, a 6-month-generated leachate (YL) collected from the lagoon of the sanitary landfill in Quito, Ecuador, with an organic strength of 66 g COD/l. Different operational parameters, such as organic loading rate (OLR), temperature, recycling and aeration, were tested. The GCC reactor was found to be a robust technology to treat these high-strength streams with organic matter removal efficiencies higher than 65%. The best performance of the reactors (COD removal efficiencies of 75–80%) was obtained at a Hydraulic Retention Time (HRT) of around 20 h and at 35 °C, with an applied OLR up to 70 and 100 g COD/l per day. Overall, the GCC reactor concept appears worth to be further developed for the treatment of leachates in low-income countries.

Keywords Anaerobic treatment · Developing countries · Food wastes · UASB reactor

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Introduction

Sanitary landfill leachates represent an environmental problem worldwide, but mainly in low-income countries, due to the lack of affordable treatment technologies. Most of these countries use storage or recirculation of these residuals for long periods as treatment process, bringing about aging of the liquors, and making further biological remediation difficult.

In general, leachates are characterized according to the ratio of the biological oxygen demand over the chemical oxygen demand (BOD_5/COD). For young leachates (3–12 months), this ratio varies between 0.6 and 1.0, and for medium (1–5 years) and old (>5 years) leachates, from 0.3 to 0.6 and from 0.1 to 0.3, respectively [1]. Leachates generated by direct pressing in the trucks have not been well documented yet, but it has been estimated that they contribute to about 10% of the daily leachates production in the sanitary landfills, mainly in rainy seasons.

Up to now, different physico-chemical and biological options have been applied for the treatment of leachates, including coagulation–flocculation (80% COD removal) [2], ozone-activated sludge integrated system (81% COD removal) [3] and electrochemical oxidation–aerobic treatment (90% COD removal) [4]. Anaerobic processes have been also shown to be effective, with COD removal efficiencies ranging from 65% to 90% at Organic Loading Rates (OLR) of 1.3–16 kg COD/m^3/day [5–7]. However, most of these studies are still confined to multistage integrated designs and to low-strength leachates with COD less than 40 g/l [1].

The present work evaluates the one-stage biological treatment of high-strength sanitary residuals using a lab-scale gradual concentric chamber (GCC) reactor, a new and economical design with plug-flow characteristics [8]. In order to evaluate the performance of the GGC reactor, an UASB reactor was operated in parallel. The influence of different operational parameters, including the organic loading rate (OLR), hydraulic retention time (HRT), temperature, recycling and aeration, has been analyzed.

Materials and Methods

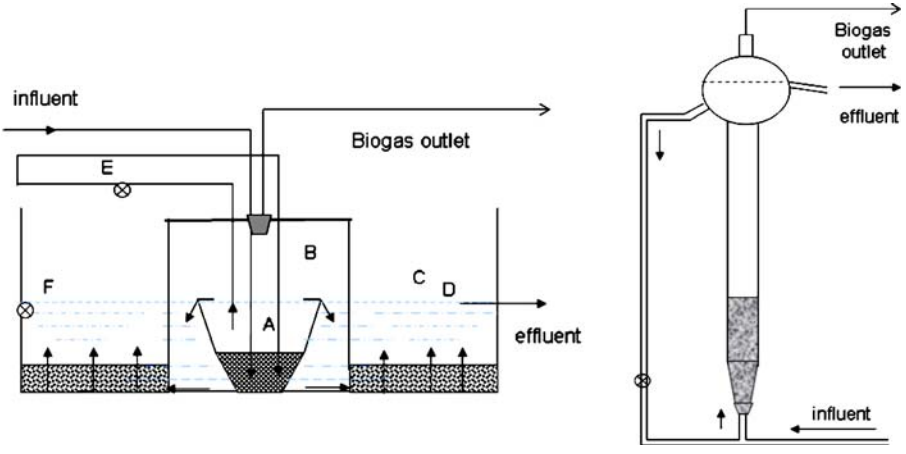
Characteristics of the leachates Two types of leachates were studied: the just generated leachates (JGL) directly taken from the bottom part of the garbage lorries (84±17 g COD/l) and a 6-month-old young leachate (YL) collected from the artificial pond of the Inga Technical Sanitary Landfill of Quito (Ecuador). This landfill has a daily domestic solid waste load and a leachate generation of nearly 1,500 tons (60% organic matter) and 100 m^3, respectively. The leachates are produced at temperatures close to 19°C with an organic strength of about 66±12 g COD/l. Leachate samples were stored in 20-l plastic carboys and refrigerated at 4°C. The physico-chemical analyses were performed in situ and within the first 2–3 days after collection. Prior to be fed into the reactors, the leachates samples were filtered by a 0.5-mm mesh net and the pH was adjusted to 7.1±0.1 with NaOH or $NaHCO_3$. Nutrient deficiencies were supplied using NH_4Cl and KH_2PO_4 to adjust the C/N/P ratio to 100/1.25/0.25.

Inoculum characteristics The inoculum used was a concentrated anaerobic granular sludge (TSS, 91 g/l; VSS, 43 g/l) from an industrial potato-processing wastewater treatment plant.

Batch tests Prior to the start-up of the reactors, batch assays were carried out to acclimatize the anaerobic biomass and to assess the leachates biodegradability. They were performed in eight 500-ml flasks (four per type of leachate) inoculated with 120 ml of anaerobic granular sludge. During the batch test, the same biomass was progressively exposed to increasing COD concentrations, by decreasing the dilution factor of the leachates, once the biogas production reached steady state. The initial temperature was 19 °C and it was also further increased to 30 and 35 °C. At 19 °C, the four JGL replicates were dosed progressively with initial COD levels (COD_i) of 1.3 and 4 g/l. Then, two out of four replicates were placed at 30 °C, while the other two stayed at 19 °C. Under these conditions, COD_i levels of 20 and 34 g/l were tested. Finally, the replicates standing at 19 and 30 °C were exposed to 30 and 35 °C, respectively, and higher COD_i levels of 40 and 84 g/l were evaluated. The same procedure was applied to YL replicates with COD_i levels of 1.1 and 3.5 g/l at 19 °C, 22 and 30 g/l at 30 °C, and 42 and 66 g/l at 35 °C. The total duration of the experiment was about 18 weeks and during this period, the daily biogas production and COD concentrations in the batch reactors were monitored.

Reactors Two GCC reactors (with around 2 l of anaerobic chamber) were used to treat the JGL (GCC_{JGL}) and the YL (GCC_{YL}), respectively. The system basically consisted of three different-sized chambers assembled to create anaerobic and aerobic conditions (Fig. 1). The anaerobic compartment was inoculated with 350 ml of the sludge previously used in the batch assays.

In order to select the suitable HRT for the start-up of the GCC reactors, a preliminary assay was carried out at 19 °C, in which the OLR was kept constant (4 g COD/l/day) and both the COD concentration in the feeding and the HRT was varied. The suitable HRT was the lower value tested at which the COD removal efficiency was relatively high (around 70%). The reactors were started-up at 19 °C and with an OLR of 2.5 g COD/l/day. The operational strategy consisted of increasing the OLR in the reactors by decreasing the dilution factor of leachates, but maintaining the HRT constant. When the COD removal was not sufficient at



a) GCC reactor b) UASB reactor

Fig. 1 Schematic diagram of the reactors. **a** GCC reactor. *A* anaerobic compartment, *B* headspace compartment, *C* aerobic compartment, *D* effluent pipeline, *E* anaerobic effluent recycling pipeline, *F* aeration pump; **b** UASB reactor. *Arrows* indicate the wastewater course a given HRT (minimum value established at 65%), a higher HRT was applied. Once the HRT could not be further increased, the temperature was increased up to 30 and 35 °C.

Finally, in order to improve the performance of the GCC reactors, three modifications were successively applied: (a) an internal recycling in the anaerobic compartment at a rate of 0.25 l/l anaerobic compartment/h; (b) aeration of the outer shallow layers of the aerobic compartment using a low-energy aerator (2 l of air/l aerobic compartment/h), and (c) pulses of air into the anaerobic compartment (90 ml of air/l of anaerobic compartment/h).

The start-up parameters of the UASB reactor (2.5 l effective volume) were selected according to Nuri and Sponza [7] and the operational strategy was the same as described for the GCC reactor.

Overall, the experiment lasted 165 days and influent and effluent samples were taken periodically for physico-chemical and microbiological analyses.

Analytical techniques pH values were measured with a C532 pH meter (Consort) and the other physico-chemical (solids content, COD, BOD_5, NH_4^+-N, Kjeldahl-N, PO_4^{3-}-P, SO_4^{2-}-S and humic, and fulvic acids) and microbiological (total and fecal coliforms) parameters were determined according to standard methods [9]. Biogas production was followed by liquid displacement.

Results and Discussion

Characteristics of the Leachates

Table 1 shows the physico-chemical and microbiological characteristics of the leachates used in this study. JGL and YL owned differences based on its origin. Similar to other studies [10], the pH value of JGL was lower (5.5±0.5) than that of YL (6.4±0.4) and its total organic matter content was higher (84±17 g/l) than in YL (66±12 g/l). The observed high organic strength is characteristic of leachates from low-income countries, due to the high organic matter content (40–85%) of their solid wastes [11]. However, the soluble organic concentrations were similar for both types of leachates, 68±11 and 62±10 g/l, respectively. The solids content was also higher in the JGL (around 60 g/l) than in the YL (around 40 g/l). Moreover, elevated dissolved solids concentrations were observed in both leachates (around 80% of total solids), probably due to the lack of household waste classification, which results in an increase of inorganic compounds content, such as nitrates and sulfates. The presence of heavy metals was not of concern, since their concentrations (data not shown) remained below the reported tolerance limit values [12], and the presence of total and fecal coliforms in JGL and YL was negligible. The latter is in accordance with Cameron and McDonald [13], who reported that the concentrations of total and fecal coliforms in nearly 1-year-old sanitary landfill leachates were not significant.

Batch Tests

Figure 2 shows the results of the acclimatization of the anaerobic biomass to biodegrade JGL leachates at different temperatures. At 19 °C and initial COD (COD_i) levels below 34 g/l, the biogas production rate was very low regardless of temperature (Fig. 2a), ranging from 16 to 24% of the theoretical value (assuming 0.5 l of biogas produced per g COD removed). As a result, the COD removal efficiency remained below 25% (Fig. 2b). At 30°C, the biogas

Table 1 Characteristics of the two types of leachates used in this work before and after treatment.

Parameter	Before treatment (n=16)		After treatment (n=3)	
	JGL	YL	JGL	YL
pH	5.5±0.6	6.4±0.4	7.9±0.3	7.7±0.1
TS (g/l)	62±10	41±12	44±3	20±2
TSS (g/l)	12±2	7±1	6±2	2±1
VSS (g/l)	10±1	4.5±0.6	3.0±0.9	1.0±0.3
tCOD (g/l)	84±17	66±12	16±2	17±1
sCOD (g/l)	68±11	62±10	13±1	14 ±1
BOD_5 (g/l)	61±8	46±5	9±1	9±1
BOD_5 /COD	0.7±0.1	0.7±0.1	0.6±0.1	0.5±0.0
N- NH_4^+ (mg/l)	86±65	338±36	58±11	167±14
Kjeldahl-N (mg/l)	702±98	4,500±213	487±55	2,950±106
PO_4^{3-} –P (mg/l)	7±4	67±11	6±2	52±9
SO_4^{2-} S (mg/l)	99±28	38±4	17±2	3±1
Humic acids (mg/l)	36±10[a]	528±35[a]	264±18	375±12
Fulvic acids (mg/l)	320±30[a]	772±58[a]	232±32	678±46
Total coliforms (MPN per 100 ml)	<3[a]	<3[a]	<3	<3
Fecal coliforms (MPN per 100 ml)	<2[a]	<2[a]	<2	<2

JGL leachates directly collected from the garbage trucks, *YL* young leachates (6-month-generated leachates)

[a] n=4

production and COD elimination did not surpass 40%, even at higher COD_i concentrations of 84 g/l. However, the biogas production rates increased at 35°C, i.e., 55% and 80% at COD_i of 40 and 84 g/l, respectively, and consequently the COD removal. The experiments with YL showed similar results in terms of initial COD and temperature influence (data not shown), but the biogas production rates were 50% lower, approximately, than those achieved with JGL. Furthermore, the acclimatization of the anaerobic biomass to the degradation of YL took longer (around 3 months) than for JGL (around 1 month). The poor biodegradability of YL compared to JGL could be a result of the high ammonium and Kjeldahl nitrogen content in these samples (Table 1). Calli et al. [14] observed a change in methanogens activity at increasing ammonium levels (up to 700 mg/l), demonstrating that although the reactors performance was not completely inhibited, the biogas production decreased.

Reactors Performance

The results of the preliminary experiment carried out to select the HRT to be applied during the start-up of the reactors demonstrated that a HRT of 10 h was the minimum value bringing about a satisfactory COD removal efficiency of around 70% (data not shown). This HRT is a bit low compared with other studies dealing with anaerobic treatment of leachates [7, 15, 16].

Table 2 shows the performance of GCC reactors. During phase 1 (HRT of 10 h, 19°C), the OLR could be increased from 3 to 19 g COD/l/day in the GCC_{JGL} and from 3 to 10 g COD/l/day in the GCC_{YL}, resulting in a decrease in the removal efficiencies from 73% and 71% to 67% and 63%, respectively. In phase 2, the HRT was increased to 15 and 16 h in the GCC_{JGL} and GCC_{YL}, respectively, while keeping constant the temperature at 19°C. This

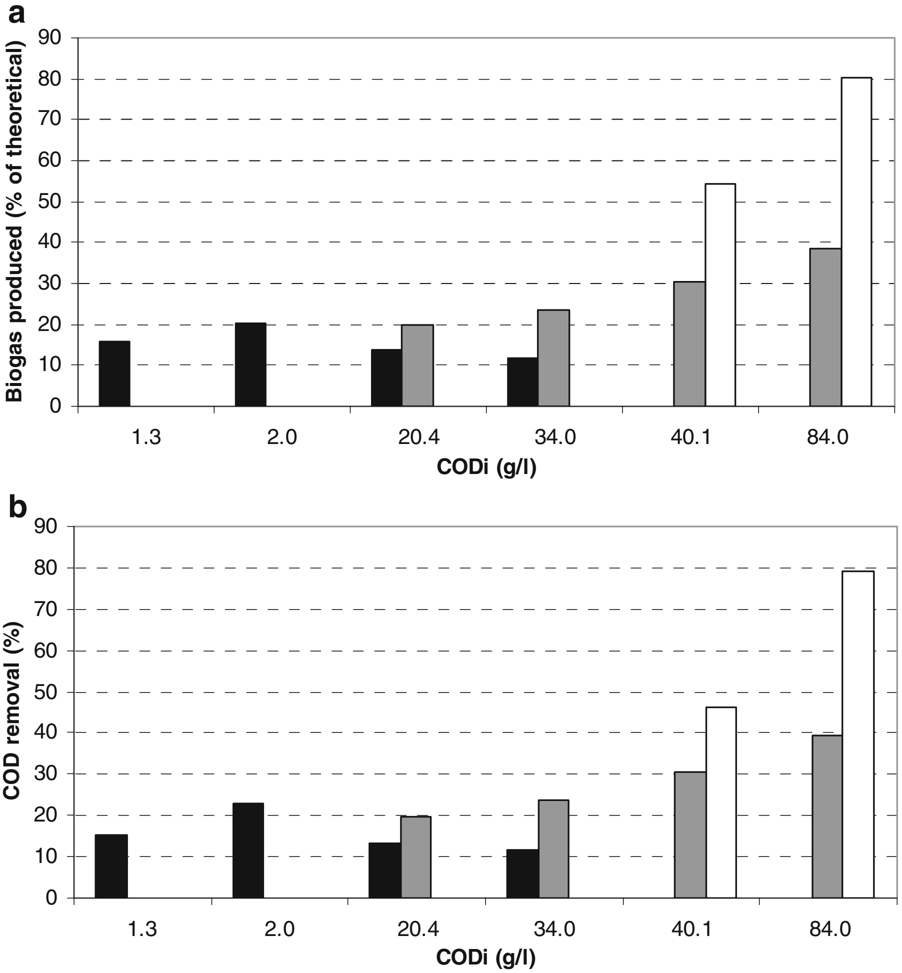


Fig. 2 Biogas production (**a**) and COD removal (**b**) during the acclimatization experiments with JGL. *black bars* 19°C, *gray bars* 30°C, and *white bars* 35°C. Theoretical biogas production was calculated assuming 0.5 l of biogas produced per gram COD removed

change did not affect significantly the performance of the GCC_{YL}, since the OLR could be slightly increased to 11 g COD/l/day with COD removal efficiencies of 64-67%. In contrast, the OLR in the GCC_{JGL} could be raised to 25 g COD/l/day with removal efficiencies ranging from 63 to 70%. In phase 3, the HRT was raised to 19 and 21 h in the GCC_{JGL} and GCC_{YL}, respectively, which allowed increasing the OLR up to 30 and 15 g COD/l/day, respectively, resulting in average COD removal efficiencies of 65%. During phases 4 and 5, the temperature was increased to 30 and 35 °C, respectively, which allowed increasing of the OLR up to 90 and 105 g COD/l/day in the GCC_{JGL} and up to 26 and 53 g COD/l/day in the GCC_{YL}, while the removal efficiencies remained at around 65%. In the case of JGL, the increase of temperature to 35 °C allowed the treatment of raw JGL, i.e., without dilution. In general, the higher the OLR applied, the lower the COD removal efficiency. In addition, GCC reactors attained faster the steady-state conditions compared to the batch experiments (data not shown), which clearly indicates the positive effect of the previous acclimatization and adaptation exerted on the biomass, thus avoiding long start-up periods in the reactors [17].

Table 3 shows the performance of UASB reactor. Similar to GCC reactors, five phases of performance can be identified. Since in this case the COD removal efficiencies were higher than those obtained in the GCC reactors, the operational parameters were modified when the COD removal efficiencies were close to 70%. The UASB reactor treating JGL showed similar results as the GCC_{JGL} during phases 1, 2, and 3. In contrast, the UASB reactor treating YL showed better performance than the GCC_{YL}, since the maximum OLR applied in each phase was higher than in the GCC_{YL}. However, an opposite behavior was observed during phases 4 and 5 when the temperature was increased, since a poorer performance of the UASB treating JGL was obtained compared to GCC_{JGL}, while the operation of the UASB treating YL was similar to GCC_{YL}. Similar to GCC reactors, the higher the OLR applied, the lower the COD removal efficiency, with average values between 70% and 78%. These values correlate with those found by Kennedy and Lentz

Table 2 GCC reactors performance treating JGL and YL.

T (ºC)	HRT (h)	OLR (g/l per day)	COD_i (g/l)	Removal (%)
Just generated leachates (JGL)				
19	10	2.5	1.0	73
		3.2	1.4	72
		4.4	2.0	72
		5.4	2.3	72
		6.6	2.8	71
		7.2	3.1	71
		7.9	3.4	70
		10	4.4	70
		13	5.5	70
		15	6.6	68
		19	8.0	67
	15	13	8	70
		14	9	70
		16	10	69
		19	12	68
		22	14	66
		26	16	63
	19	20	16	67
		25	20	65
		30	24	64
30	19	30	24	67
		44	35	66
		90	72	63
35	19	90	72	69
		105	84	69
35	19	105	84	73[a]
				78[b]
				81[c]

Table 2 (continued)

T (ºC)	HRT (h)	OLR (g/l per day)	$\mathrm{COD_i}$ (g/l)	Removal (%)
Young leachates (YL)				
19	10	2.5	1.0	71
		3.2	1.4	70
		4.5	2.0	68
		5.4	2.3	68
		6.6	2.8	67
		7.3	3.1	67
		8.0	3.4	66
		10.0	4.4	63
	16	6.2	4.4	67
		7.8	5.5	66
		9.4	6.6	66
		11.0	8.0	64
	21	9	8	68
		10	9	68
		11	10	66
		13	12	65
		15	14	63
30	21	15	14	66
		18	16	64
		22	20	63
		26	24	60
35	21	26	24	66
		44	40	64
		53	48	64
35	21	53	48	67[a]
		64	58	70[a]
		72	66	70[a]
				74[b]
				75[c]

[a] Recycling in the anaerobic compartment

[b] Aeration in the anaerobic compartment

[c] Air pulses in the anaerobic compartment

[18], who achieved a COD removal efficiency of 77% in a UASB reactor treating leachates at OLR of 20 g COD/l/day (HRT of 24 h). Overall, the better performance of GCC reactors at lower HRT could be explained by the wider area of the anaerobic GCC reactors compartment, promoting a higher contact between the substrate and the standing sludge.

In general, greater HRT favors the reactors performance in terms of OLR applied and COD removal efficiency. However, Carrhá [19], who deeply studied UASB reactor robustness, indicated that there is also an upper limit of HRT, at which the settleability of the anaerobic sludge deteriorates, affecting negatively the biomass–substrate uptake. Similar to other studies [20], 35 °C contributed to higher COD removal efficiencies compared to those at 30 °C in both types of reactors and regardless of the kind of leachates.

Table 3 Summary of UASB performance treating JGL and YL.

T (ºC)	HRT (h)	OLR (g/l per day)	COD_i (g/l)	Removal (%)
Just generated leachates (JGL)				
19	13	3	1	78
		20	11	69
	19	13	11	73
		22	18	70
	27	16	18	74
		26	29	70
30	27	26	29	74
		39	43	71
35	27	39	43	76
		69	72	72
Young leachates (YL)				
19	14	2	1	78
		16	10	67
	23	11	10	73
		18	16	68
	29	13	16	73
		21	26	69
30	29	21	26	72
		31	39	70
35	29	31	39	74
		52	65	69

However, the maximum OLR to be applied in each reactor is very much dependent on the characteristics of the leachates.

Effect of Modifications

The internal recycling in the anaerobic compartment, the aeration in the aerobic compartment and the short air pulses into the anaerobic cube enhanced the COD removal efficiencies up to 73, 78, and 81%, respectively, in the GCC_{JGL} (Table 2). In the GCC_{YL}, the internal recycling allowed the direct treatment of raw YL (without dilution) with even higher removal efficiency (70%), and the other two modifications increased this efficiency to around 75% (Table 2).

Barber and Stuckey [21] stated that although recycle tends to lower the efficiencies in some reactors, it can be beneficial when reactors face low pH, high levels of toxic material or high loading rates. In this study, the positive effect of recycle could be attributed to the change of the relatively still conditions persisting at the bottom of the anaerobic compartment in the GCC reactors. The improvement on COD removal provided by the aeration in the aerobic compartment was lower than that found in GCC reactors treating sewage [22], where the simple recirculation of the shallow layer promoted 20% higher COD removal efficiencies. This fact could be attributed to the poor oxygen transfer capacity of the aerator, thus resulting insufficient to remove the still high organic matter present in the anaerobic effluent [23]. Although up to now, the positive effect of aeration in anaerobic reactors still remains unclear [24], some studies have already shown its successful application for sulfide removal in full-scale anaerobic digesters [25].

Effluent Characteristics

Table 1 shows the characteristics of the effluent of the GCC reactors during the last phase of the experiment. It can be observed that the high organic strength of the tested leachates was strongly decreased after their treatment in the GCC reactors. Despite the difference in the initial COD concentrations between both kinds of leachates (Table 1), the residual COD levels in the effluent were similar (around 16 g/l). Higher residual solids were obtained in the effluent of the GCC_{JGL} (44±3 g/l) than in the effluent of the GCC_{YL} (20±2 g/l), which is correlated with the solids content in the raw leachates (Table 1). The ammonium levels in the effluent of the GCC_{JGL} and GCC_{YL} were around 58±11 and 167±14 mg/l, respectively, which are lower than those present in the raw leachates (Table 1). This decrease in the ammonium concentrations is probably a result of the aeration prevailing in the upper layers of the aerobic compartment, because prior to aeration, the ammonium concentrations were higher, ca. 115±36 mg/l in GCC_{JGL} and 420±90 mg/l in GCC_{YL}. However, much higher ammonium levels were expected in the final effluents since the Kjeldahl nitrogen was decreased by around 30% in both GCC reactors. According to Xia et al. [26], adsorption of ammonium takes place when the content of solids is high, as it occurs at the bottom of the aerobic compartment. In addition, the effect of aeration–non aeration conditions promotes nutrient removal [27].

Finally, phosphate concentrations were not strongly affected during the treatment, since similar levels were measured in the final effluent as those detected in the raw leachates. The concentrations of humic and fulvic acids in the treated effluents were low and their contribution to recalcitrant COD was not of concern. Similar to raw leachates, the presence of total and fecal coliforms was negligible.

Conclusions

1. The effect of previous acclimatization of the anaerobic biomass to leachates biodegradation had a positive effect on reactors performance avoiding long start-up periods.
2. The operational conditions of GCC reactors should be adjusted according to the specific characteristics of the leachates to be treated. Yet, this study shows that OLR up to 100 g COD/l per day could be applied at 35 °C and a HRT of around 20 h, resulting in relatively high COD removal efficiencies of 70–80%.
3. Although the objective of the present study was not to present a design meeting the standard goals for leachates discharges, the novel and economically design GCC reactor appears a useful high-rate biological step to be applied in low-income countries. Yet, a post-treatment step, such as the possibility of integrating a second GCC reactor, would be required to meet the COD discharge limits for leachates.

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References

1. Alvarez-Vazquez, H., Jefferson, B., & Judd, S. (2004). *Journal of Chemical Technology and Biotechnology, 79*, 1043–1049.
2. Tatsi, A. A., Zouboulis, A. I., Matis, K. A., & Samaras, P. (2003). *Chemosphere, 53*, 737–744.
3. Geenens, D., Bixio, B., & Thoeye, C. (2001). *Water Science and Technology, 44*, 359–365.
4. Li, T., Li, X., Chen, J., Zhang, G., & Wang, H. (2007). *Water Environment Research, 79*, 514–520.
5. Kettunen, R. H., & Rintala, J. A. (1998). *Water Research, 32*, 537–546.
6. Inanç, B., Çalli, B., & Saatçi, A. (2000). *Water Science and Technology, 41*, 223–230.
7. Nuri, O., & Sponza, D. T. (2005). *Process Biochemistry, 40*, 895–902.
8. Mendoza, L., Carballa, M., Sitorus, B., Pieters, J. & Verstraete, W. (2009). *Electronic Journal of Biotechnology, 12*(2), issue April 15. http://www.ejbiotechnology.info/content/vol12/issue2/full/8/.
9. APHA-AWWA-WPCF. (2000). *Standard methods for the examination of water and wastewater* (20th ed.). Washington, DC: American Public Health Association.
10. Sponza, D. T., & Nuri, O. A. (2004). *Process Biochemistry, 39*, 2157–2165.
11. Tchobanoglous, G., Theisen, H., & Vigil, S. A. (1993). *Integrated solid waste management: engineering principles and management issues*. Toronto: McGraw-Hill.
12. Nies, D. H. (2009). *Applied Microbiology and Biotechnology, 51*, 730–750.
13. Cameron, R. D., & McDonald, E. C. (1977). *Journal of the Water Pollution Control Federation, 49*, 2504–2511.
14. Calli, B., Mertoglu, B., Inanc, B., & Yenigun, O. (2005). *Enzyme and Microbial Technology, 37*, 448–455.
15. Iza, J., Keenan, P. J., & Switzenbaum, M. S. (1992). *Water Science and Technology, 25*, 255–264.
16. Timur, H., Ozturk, I., Altimbas, M., Arikan, O., & Tuyluoglu, B. S. (2000). *Water Science and Technology, 42*, 287–292.
17. Akram, A., & Stuckey, D. C. (2008). *Environmental Technology, 29*, 1053–1065.
18. Kennedy, K. J., & Lentz, E. M. (2000). *Water Research, 34*, 3640–3656.
19. Carrhá, R. (2004). Ph.D thesis, Wageningen University, Netherlands.
20. Garcia, H., Rico, J. L., & Garcia, P. A. (1996). *Bioresource Technology, 58*, 273–277.
21. Barber, W., & Stuckey, D. (1999). *Water Research, 33*, 1599–1578.
22. Mendoza, L., Carballa, M., Zhang, L., & Verstraete, W. (2008). *Water Science and Technology, 57*, 1155–1160.
23. Guangzhi, S., Yaqian, Z., & Stephen, A. (2005). *Journal of Biotechnology, 115*, 189–197.
24. Kato, M. T., Field, J. A., & Lettinga, G. (1997). *Brazilian Journal of Chemical Engineering, 14*, 395–407.
25. Jenicek, P., Keclik, F., Maca, J., & Bindzar, J. (2008). *Water Science and Technology, 58*, 1491–1496.
26. Xia, X. H., Yang, Z. F., Huang, F. H., Zhang, X. Q., Yu, H., & Rong, X. (2004). *Chemosphere, 57*, 1017–1029.
27. Ujang, Z., Salim, M. R., & Khor, S. L. (2002). *Water Science and Technology, 46*, 193–200.