Post-treatment of anaerobic effluents in an overland flow system


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Abstract This research aimed at the investigation of an overland flow system applied to the post-treatment of anaerobic effluents. The system treated domestic sewage in Itabira City (Brazil), being composed by an anaerobic reactor and an overland flow system, the latter working as a post-treatment unit. A portion of the reactor’s effluent was directed to a group of three overland flow slopes (demonstration scale), that were operated with different application rates. During Phase 1 of the research, the overland flow system was fed under a permanent hydraulic regime (constant flows), having as inflow the effluent from an UASB reactor (full-scale, volume of 477 m³). During Phase 2, the overland system was fed under a hydraulic transient pattern (variable flows with hourly variations), having as inflow the effluent from a partitioned UASB reactor (demonstration-scale, volume of 9 m³). In general, the performance of the overland flow system as a polishing step was very good, mainly because of the low solids and organic matter concentration in the final effluent (average values of BOD from 48 to 62 mg/L; COD from 98 to 119 mg/L and SS from 17 to 57 mg/L). Regarding nutrients and coliforms, the system also reached satisfactory efficiency levels. Based on the experience obtained with this study, it is suggested that overland flow systems, working as post-treatment step of UASB reactors, can work with application rates in the range of 0.4 to 0.5 m³/m.h, which are higher than those normally applied.

Keywords Domestic sewage; low cost treatment; overland flow; post-treatment; UASB reactor

Introduction

Despite the advantages of the UASB reactors for the treatment of domestic sewage in tropical countries, they have difficulties in producing effluents that can comply with the environmental standards. Therefore, the post-treatment of UASB reactors is of great importance in order to allow compliance to usual environmental discharge standards. The main objective of the post-treatment is to complement the organic matter removal, as well as to promote the removal of components that are barely affected by the anaerobic treatment (nutrients and pathogens). Even at international level there are few consistent experiences related to this important stage of post-treatment. The existing knowledge is sufficient when each treatment unit is analysed individually, but not so much when the integrated relation of anaerobic reactors and post-treatment is investigated.

Believing that this line of an anaerobic reactor followed by a post-treatment unit can become one of the main alternatives for wastewater treatment under tropical conditions, a Federal Research Programme in this field was set up by the Brazilian Government aiming at effectively contributing to the development of this area. The programme is named PROSAB (Research Program on Basic Sanitation) and involves twelve research institutions located all around the country.

The main objective of this research work was to evaluate the applicability of an overland flow system, when utilised for polishing domestic sewage submitted to a previous treatment stage in a UASB reactor. The association of these two simple technologies can substantially contribute for the reduction of labour and energy costs of the treatment system.
Material and methods
Characteristics of the experimental units and phases
The research was undertaken in two different phases, according to the characteristics below (Araújo, 1998; Araújo et al., 1999).

Phase 1. During Phase 1, the overland flow system was fed with constant flow (permanent hydraulic regime). The inflow was a fraction of the effluent from a full-scale UASB reactor, with a volume of 477 m$^3$.

As it can be seen from Figure 1, the UASB reactor does not have a typical UASB configuration, since it is not fitted with a gas collection system and this induces the formation of a thick and dry scum layer over the whole surface of the gas compartment. During the first two years of reactor operation, it exhibited COD removal efficiencies varying from 61 to 75%, with an average of 68%. More details regarding the reactor characteristics and operational conditions are given in Brito et al. (1997), Chernicharo and Borges (1997) and Chernicharo et al. (1998).

A small percentage of the effluent from the UASB reactor was used to feed the land application system, through a pipeline that connects the reactor weir with the overland flow distribution system. Three slopes (physically identical) for wastewater overland flow constituted the post-treatment system. Each slope had a total surface area of 75 m$^2$ (25 metres long by 3 metres wide) and a grade of 4% (Figure 2). Each slope was equipped with five sampling points along its length (one every 5 metres) that allowed the monitoring of the pollutants removal profile. The last sampling point was the final collection channel of each slope.

The effluent distribution onto each slope head was achieved by using a small storage tank that fed three perforated PVC pipes. In its turn, the storage tank was directly fed by the full-scale UASB reactor. To control the flowrate to each slope, three valves were installed on the bottom of the storage tank. Those valves were adjusted twice a day in order to guarantee the right application rates to the slopes. To collect the final effluent at the end of each slope a small open channel was constructed. The final effluent was then directed to the receiving body.

A very common weed species named Brachiaria humidicola was used as vegetative cover to the slopes. This weed is known for its high resistance against flooding and a high rate of nutrient absorption (Terada et al., 1986).

The essays carried out with samples of the slope’s soil showed that the main constituents were clay and silt. The soil texture was classified as thin, with very low permeability (around $10^{-6}$ cm/s). This type of soil is considered very appropriate for the overland flow treatment system (USEPA, 1981).

Phase 2. During Phase 2, the overland flow system was fed with variable inflow (transient hydraulic regime), which followed typical diurnal variations. The inflow came from a different UASB reactor, in this case a partitioned UASB unit, with a volume of 9 m$^3$, and...
characterising a demonstration scale. The main characteristics and working principles of this partitioned reactor are presented in Chernicharo and Cardoso (1998).

During this phase of the research, a completely automated feeding system, capable of measuring, controlling and distributing the flow to each reactor compartment, was implemented. For this, a dedicated control software was developed, capable of controlling and maintaining the operational conditions previously set by the user. The automation system is composed by one electromagnetic valve for flow measurement, three acting valves for flow control and two computer boards for electrical signal reception, processing and transmission.

Experimental and operational characteristics
The overland flow system was operated as a post-treatment unit during 154 days in Phase 1 and 328 days in Phase 2. The operational parameters used along the experimental period are given in Tables 1 and 2.

Since the characteristics of the effluents from anaerobic reactors impose different degradation rates to the treatment system, in comparison with raw sewage, it was decided to use different application loading rates in each slope in order to evaluate an eventual interference on the performance of the post-treatment system. Furthermore, the application rates tested were much higher than those cited in the literature. This was meant to assess the behaviour of the overland flow system under stress conditions and eventually to reduce its land requirements. Then, each slope was operated according to the loading conditions shown in Table 2, which also presents for the sake of comparison the values suggested by USEPA (1981, 1984).

Table 1 Operational parameters of the overland flow system

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Phase 1</th>
<th>Phase 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application period</td>
<td>8 hours/day</td>
<td>8 hours/day</td>
</tr>
<tr>
<td></td>
<td>All slopes: 7:00 to 15:00 h</td>
<td>Slope 1: 4:00 to 12:00 h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slope 2: 12:00 to 20:00 h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slope 3: 20:00 to 4:00 h</td>
</tr>
<tr>
<td>Application frequency</td>
<td>5 days/week (Monday to Friday)</td>
<td>5 days/week (Monday to Friday)</td>
</tr>
</tbody>
</table>

Table 2 Loading conditions of the overland flow system during Phases 1 and 2

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Phase 1 (permanent flow)</th>
<th>Phase 2 (transient flow)</th>
<th>USEPA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Slope 1</td>
<td>Slope 2</td>
<td>Slope 3</td>
</tr>
<tr>
<td>Applied flow (m³/h)</td>
<td>1.80</td>
<td>1.20</td>
<td>0.60</td>
</tr>
<tr>
<td>Application rate (m³/m²h)</td>
<td>0.60</td>
<td>0.40</td>
<td>0.20</td>
</tr>
<tr>
<td>Hydraulic loading rate (cm/d)</td>
<td>19.2</td>
<td>12.8</td>
<td>6.4</td>
</tr>
</tbody>
</table>
Monitoring programme

The post-treatment system was monitored from June 1997 to June 2000, except during two short periods of system interruption. The monitoring programme included the evaluation of the following physical-chemical and microbiological parameters: temperature, pH and conductivity (daily); COD, BOD, TSS, VSS, N-NTK, N-NH₄, and N-NO₃ (weekly); faecal coliforms and helminth eggs (twice a month). All physical-chemical parameters were analysed according to the Standard Methods for the Examination of Water and Wastewater, 19th ed. (AWWA/APHA/WEF, 1995).

The samples for bacteriological analyses were conditioned in receptacles with ice, respecting the maximum period of 24 h for processing them. The membrane filtration technique was used for total and faecal coliform counting during Phase 1 (AWWA/APHA/WEF, 1995). In Phase 2, the Quantitray/Colilert method was used for counting total coliforms and E. coli, according to the procedures described in AWWA/APHA/WEF (1998).

The identification and enumeration of helminth eggs was carried out according to the Bailenger methodology (WHO, 1989), modified by Ayres and Mara (1996). Composite samples were taken during the 8-hour feeding period of Phase 1 and during the 24-hour feeding period of Phase 2.

Results

Organic matter (COD and BOD)

Phase 1. The results of COD and BOD are shown in Figures 5 and 6 as frequency distribution graphs. It can be seen from Figure 5 that only 20% of the results of effluent COD (effluent of the UASB reactor) were below 100 mg/L, clearly indicating the necessity for an additional treatment step. It can also be seen that around 70% of the results of the final effluent (after the overland flow system) presented a COD concentration below 100 mg/L. Although this concentration can still be considered high, there is an indication that the post-treatment system was capable of significantly complementing the COD removal. Another interesting observation is related to the similarity of the results between slopes, even though they were operated under different application rates.

In relation to BOD, it can be observed from Figure 6 that only around 25% of the results from the effluent of the UASB reactor presented values below 60 mg/L, which is the discharge standard adopted by many environmental agencies in Brazil. Again, the post-treatment unit was capable of complementing the BOD removal in the system, increasing the percentage of results that comply with the Brazilian standards to around 70%. Again, the similarity of BOD distribution in all slopes must be highlighted, indicating that the slopes worked very similarly.

Regarding the average COD and BOD results obtained in the treatment system, it can be seen from Table 3 that the concentrations in the effluent from the UASB reactor are still high, indicating the need for post-treatment. It can also be noticed that the three slopes reached average results below 60 mg/L. The removal efficiencies in the overland flow
system are around 50%, which can be considered a satisfactory value, considering that the post-treatment unit receives organic matter of lower biodegradability.

**Phase 2.** The average COD and BOD results from Phase 2 are shown in Table 4. The overall removal efficiencies were in the range of 80%. However, it should be noted that during most of Phase 2 the UASB reactor showed low removal efficiencies, due to a low detention time that was being investigated (5.5 h only). The final effluent quality was only slightly worse than that obtained in Phase 1.

Suspended solids

Figure 7 shows that, during Phase 1, approximately 50% of the samples from the UASB effluent presented suspended solids concentrations above 60 mg/L, which is the discharge standard adopted by some environmental agencies in Brazil. Again, the post-treatment unit was capable of complementing the solids removal in the system, increasing the percentage of results that comply with the discharge standards to above 90%. Also here, the similarity of results between slopes can be observed, even though they were operated under different application rates.

The average concentration of total suspended solids in the effluent of the UASB reactor was 67 mg/L in Phase 1 and 143 in Phase 2. The final effluent SS concentrations varied from 17 to 21 mg/L in Phase 1 and had average values of 57 mg/L in Phase 2. The results show the very good capacity of the post-treatment system to retain solids, being capable of producing a well clarified effluent (Phase 2 had the described problems with the UASB reactor, which were reflected in the final effluent quality). The analysis of the operational results from Phase 1 indicated very little influence of the application rates in the quality of the final effluent. This was also noticed during the rainy season.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Average concentrations (mg/L)</th>
<th>Average removal efficiencies (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Effluent</td>
<td>Effluent</td>
</tr>
<tr>
<td>COD</td>
<td>205</td>
<td>98</td>
</tr>
<tr>
<td>BOD</td>
<td>104</td>
<td>51</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Average concentrations (mg/L)</th>
<th>Average removal efficiencies (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Influent</td>
<td>Effluent</td>
</tr>
<tr>
<td>COD</td>
<td>592</td>
<td>323</td>
</tr>
<tr>
<td>BOD</td>
<td>376</td>
<td>195</td>
</tr>
</tbody>
</table>

Figure 7 Frequency distribution of TSS results (Phase 1)
Nitrogen
The overland flow system was also capable of reducing the TKN and N-NH$_4^+$ concentration in the final effluent. During Phase 1, the average TKN removal efficiency was around 46% for slopes 1 and 2, while for slope 3 the average removal was slightly higher (around 54%). The average removal efficiency N-NH$_4^+$ was around 47% for slopes 1 and 2, while for slope 3 the average removal was again higher (around 59%). This was possibly due to the lower application rate in slope 3, which caused the increase of the wastewater detention time and favoured the accomplishment of bacterial nitrification. For Phase 2, the average TKN and N-NH$_4^+$ removal efficiencies were 43% and 33%, respectively. The final effluent ammonia concentration was still high, in the range of 14 to 18 mg N-NH$_4^+$ /L in Phase 1 and with an average value of 26 mg N-NH$_4^+$ /L in Phase 2.

Helminth eggs
The results of enumeration and identification of helminth eggs are shown in Table 5 (Zerbini et al., 1999). The concentrations of helminth eggs in Phase 1 stayed below those obtained for Phase 2, with arithmetic average concentrations of 47.3 and 14.0 eggs/L, for the raw sewage and the UASB effluent, respectively. Eggs of nematodes (Hookworm, Ascaris lumbricoides, Enterobius vermicularis, Trichuris trichiura) and of cestodes (Hymenolepis sp and Taenia sp) were found, with a major prevalence of Ascaris and Hookworm. These results indicated removal efficiencies around 70% in the UASB reactor (Phase 1). No nematode or cestode eggs were found in the final effluent of the slopes. It should be mentioned, however, that counting “zero” does not guarantee that the final effluent is completely free of helminth eggs, since none of the enumeration methods can guarantee a recovery of 100% of the eggs eventually present in the processed sample.

In relation to Phase 2, the removal efficiencies in the treatment system were kept very high, being 82% in the UASB reactor and 99% in the slopes. The presence of helminth eggs in the slopes’ effluent was observed in 5 samples, within the 27 that were analysed during the 328 days of system operation. In those 5 samples, the average concentration was 1.0 egg/L, with maximum and minimum concentrations of 2.0 and 0.5 eggs/L, respectively.

It is important to mention that, although excellent results of egg’s removal from the liquid effluent were obtained, the risks to public health still remain because the eggs are retained on soil and on vegetation, across a certain extension of the slopes.

Faecal coliforms
The results of faecal coliforms (Phase 1) and E. coli (Phase 2) are shown in Figures 8 and 9. For Phase 1, the raw sewage countings varied from $3.4 \times 10^6$ to $1.1 \times 10^8$ FC/100 mL, with a geometric mean of $2.5 \times 10^7$ FC/100 mL. The effluent from the UASB reactor presented countings ranging from $2.9 \times 10^5$ to $4.2 \times 10^7$, with a geometric mean of $3.8 \times 10^6$ FC/100ml, representing an average removal efficiency in the UASB reactor of about 1 log-unit. The countings of faecal coliforms in the final effluent of the three slopes also

Table 5 Average results of enumeration and identification of helminth eggs

<table>
<thead>
<tr>
<th>Phase</th>
<th>Sampling point</th>
<th>A. lumbricoides</th>
<th>Hookworm</th>
<th>E. vermicularis</th>
<th>T. trichiura</th>
<th>Hymenolepis sp</th>
<th>Taenia sp</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Raw sewage</td>
<td>36.4</td>
<td>8.7</td>
<td>0.2</td>
<td>1.2</td>
<td>0.8</td>
<td>-</td>
<td>47.3</td>
</tr>
<tr>
<td>1</td>
<td>Eff. UASB</td>
<td>11.0</td>
<td>2.2</td>
<td>0.3</td>
<td>0.1</td>
<td>0.3</td>
<td>0.1</td>
<td>14.0</td>
</tr>
<tr>
<td></td>
<td>Eff. slopes</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Raw sewage</td>
<td>105.4</td>
<td>9.8</td>
<td>-</td>
<td>1.5</td>
<td>4.0</td>
<td>-</td>
<td>-</td>
<td>120.7</td>
</tr>
<tr>
<td>2</td>
<td>Eff. UASB</td>
<td>17.8</td>
<td>2.6</td>
<td>-</td>
<td>0.1</td>
<td>0.8</td>
<td>-</td>
<td>21.3</td>
</tr>
<tr>
<td></td>
<td>Eff. slopes</td>
<td>-</td>
<td>0.2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.2</td>
</tr>
</tbody>
</table>
presented great variations \((1.0 \times 10^3\) to \(4.8 \times 10^6\) FC/100 mL\), with average values of \(2.4 \times 10^5\), \(8.4 \times 10^4\) and \(1.4 \times 10^5\) FC/100ml for slopes 1, 2 and 3, respectively. Although slightly better results were obtained for slope 2, the differences in relation to the values obtained in the other two slopes were not statistically significant, as demonstrated by the analysis of variance. The results indicate a 2 to 3 log-units removal for the overall system \((UASB/overland flow system)\). The bacteriological quality of the final effluent was unsatisfactory for use in unrestricted irrigation, not complying with the value of 1000 FC/100 mL (WHO, 1989).

Conclusions
In general, the overland flow system worked satisfactorily as a polishing step for the UASB reactor, being capable of producing a final effluent with low concentrations of suspended solids, organic matter and helminth eggs. In terms of nitrogen and faecal coliforms, the required removal efficiency should be higher in order to comply with most existing standards, but the performance of the system was still acceptable.

The post-treatment system presented a very good performance when operated with higher application rates than those reported in the literature. Considering an average influent BOD concentration of 105 mg/L, it can be verified that the system operated with loading rates up to 202 kg DBO/ha.d, similar to those used in the stabilisation ponds (100 to 350 kgDBO/ha.d). Thus, the land requirements for overland flow systems applied to the post-treatment of UASB reactors can be similar or even smaller than those used for the post-treatment with stabilisation ponds.

The results obtained in the present study indicated an excellent removal of helminth eggs in the UASB/overland flow system. No eggs were observed in the final effluent during Phase 1 and an average of 0.2 egg/L was found in Phase 2. In relation to faecal coliforms, the removal was only satisfactory, with the whole system removing 2 to 3 log-units.

Based on the experience obtained through this study, it can be concluded that the post-treatment with overland flow process can be designed with less conservative application rates, in the range of 0.4 to 0.5 m³/m²/h. However, the transient flow regime and the high concentrations of solids and organic matter in the anaerobic effluent seem to interfere with the final effluent quality. For these situations, the length of the slope should be kept above 35 metres.

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