Domestic sewage treatment in full-scale UASBB plant at Mangueira, Recife, Pernambuco

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Abstract The anaerobic technology application for domestic sewage treatment in Pernambuco State (Brazil) is relatively recent. Some UASB reactors of less than 250 m³ were built in the Recife Metropolitan Region (RMR) in the 1990s. Mangueira (18,000 inhabitants) was the first neighborhood where the municipality built a plant with a bigger UASB reactor of 810 m³. It was intended to evaluate the performance and verify if such technology would be feasible. The objective would be the possible application of UASB reactors to the RMR, according to the new sewage master-plan under elaboration that would benefit about 3 million inhabitants.

The monitoring of the Mangueira UASB reactor over 30 months showed that satisfactory results were obtained. Three distinct operational phases occurred, in which efficiency varied from 60% up to 90% based on COD removal. The results were very dependent on the operation and maintenance, either in the plant or in the sewage collection. Significant amount of inert solids was measured inside the reactor. Despite the operational problems, the UASB was shown to be very robust and stable. Under high fluctuation of influent concentrations (150–750 mg COD/L) during the period, resulting in applied organic loading rate of 0.5 to 2.5 kg COD/m³.d, the average values of COD removal efficiency did not change significantly. An active biomass with specific methanogenic activity varying from 0.18 to 0.25 g COD/g VSS.d was measured at the end of the period.

Keywords Anaerobic technology; domestic sewage; full-scale UASB reactor; long term operation; performance

Introduction

The anaerobic technology application for domestic sewage treatment in Pernambuco State (Brazil) is relatively recent. After some initial difficulties at institutional level in accepting the advantages and recognizing the adequacy for local conditions, some full-scale UASB reactors were built in the Recife Metropolitan Region (3 million inhabitants) in the 1990s. Most of them were of small size, up to 250 m³ and serving 5,000 inhabitants of isolated housing projects (Florencio and Kato, 1998).

Mangueira (18,000 inhabitants) was the first neighborhood where the municipality built a plant with a bigger UASB reactor of 810 m³. It was intended to evaluate the performance and verify if such technology would be technically and economically feasible. The objective at long term would be the possible use of UASB reactors to upgrade the 3 existing sewage plants, as well to the new plants according to the new sewage master-plan under elaboration (PCI, 2000).

The plant in Mangueira neighborhood at Recife was built in 1997 by URB (Recife Municipal Urbanization Company). Since the start-up in July, the operation has been under the responsibility of COMPESA (Pernambuco water and sewage company). The treatment plant was designed to receive an average flowrate of 31 L/s with maximum of 51 L/s at peak hours. Due to partial implantation of the sewerage system in Mangueira, the current flowrate corresponds to the contribution of about 13,000 inhabitants (72%) (Morais et al., 1999).

At that time, the decision to build an 810 m³ reactor was a local, pioneering challenge for
the treatment of domestic sewage using anaerobic technology. Therefore, it created a certain expectation concerning its performance and its possible use as a reference, since other treatment plants were also under consideration in the new sewage master-plan. The UASB reactor conception would be the main choice for the sewage treatment in RMR.

Despite the existence of other smaller reactors that were already operating, there were no available local data on the performance. The Mangueira UASB would fulfill the requirements as a demonstration-scale reactor, due to the size and because the neighborhood was representative of many around the RMR. Consequently, a monitoring program was established in order to evaluate the operation and the performance. The objective of this work is to present the monitoring results over a 30-month period.

Methods

Wastewater treatment plant and monitoring

Mangueira Wastewater Treatment Plant (MWTP) is located in a low-income area at Recife and receives sewage from a separated sewer system. However, depending on the sewer operation, rainwater and significant amount of solid wastes can enter, influencing the characteristics of the sewage coming to the plant. Nevertheless, the wastewater composition is predominantly domestic sewage most the time with non-industrial wastewater contribution. The treatment plant units are: a grit chamber, a UASB reactor and a polishing pond. The final effluent is discharged into a River Tejipió tributary. Sludge-drying beds (Figure 1) are used to dewater the excess sludge.

The UASB reactor was designed with 8 individual cells that are operated in parallel to allow operational variation and flexibility. Each cell receives 1/8 of the total flow rate with 8 hours hydraulic retention time (HRT). The total influent flow rate is divided successively by weirs. In each cell, 9 inlet points in the bottom distribute the flow by vertical pipes (1 point/2.25 m²). The cell effluents are collected in perforated tubes connected to an external side channel in the upper part of the reactor. Then, the total effluent is discharged to the polishing pond. The biogas is collected in a fiberglass gas-solid-separator and thrown into the atmosphere without any treatment. However, in the original design a gas meter and flare were specified for burning the biogas. Each cell has 5.0 m net height, with 5 sludge sampling points in the sludge bed at 0.5, 1.0, 1.5, 2.0 and 2.5 m from the bottom. These points are also used to discharge the excess sludge into the drying beds.

The start-up of each individual cell occurred at different times and it was completed only after three months due to non-availability of seeding sludge. Three cells started up without any seed (cells 2, 7 and 8). Two cells were inoculated with anaerobic sludge from a conventional sewage sludge digester (cells 5 and 6). Two cells were seeded with industrial sludge.
anaerobic sludges, from brewery (cell 1) and yeast factory (cell 3) wastewater plants, and 
the last one was inoculated with aerobic activated sludge from an extended aeration reactor 
treating domestic wastewater (cell 4).

While the MWTP operation was under COMPESA responsibility, the university 
(UFPE) carried out the monitoring. Due to institutional reasons, the monitoring program 
could only begin after six months of the cells’ inoculation. The original monitoring pro-
gram intended to analyze weekly samples from four points of the plant (raw influent, and 
grit chamber, UASB, and final lagoon effluents). However, due to operational problems, 
the frequency was variable, and the original 12-month monitoring period was extended to 
more than 18 months (30 months in total). Because the monitoring program (day 0) could 
start only six months after reactor start-up, no significant difference was found in COD 
removal among cells, regardless of the cell inoculum. Therefore, the COD removal effi-
ciency was determined only with the sample collected at the final reactor effluent.

Analytical methods and anaerobic activity test assay
The pH was determined immediately after sampling. The physico-chemical analyses were 
conducted as recommended by Standard Methods (APHA, 1992). Prior to the determina-
tion of volatile suspended solids (VSS), samples were centrifuged at 4,000 g for 15 min-
utes. COD removal efficiency is based on the difference between the influent and effluent 
total COD, or influent total COD and effluent soluble COD (0.45 µm membrane filtration).

The maximum specific activity tests were performed in 0.6 litre glass serum bottles 
sealed with 5 mm rubber septum kept in place by a screw cap. Each serum bottle contained 
0.5 g VSS/l of methanogenic sludge from the lowest sampling port at 0.5 m from the bottom 
of the reactor, 2 g COD/l of acetate and 500 ml of macro- and micronutrients as described 
elsewhere (Florencio et al., 1993). Inoculation was done in a temperature-controlled room at 
30 ± 2°C. Methane production was monitored during the assay by using a sodium hydroxide 
solution displacement system. The strength of the solution (3% w/w) was sufficient to 
remove the carbon dioxide from the biogas. All experiments were conducted in duplicate.

Results and discussion
Mangueira wastewater treatment plant was monitored by UFPE from the beginning until 
the present. During this period the reactor was run continually, but several operational 
phases occurred and greatly influenced the performance of the treatment plant. An evalua-
tion of the monitoring results is presented, based on a local context. Some important opera-
tional aspects are presented in order to obtain design and operational parameters for new 
wastewater treatment plants based on the UASB concept.

The COD removal results are illustrated in Figure 2. The operation can be divided into 
three distinct phases, that reflects the actual MWTP operation. In phase I (days 0 to 200) the 
average COD removal efficiency was around 70%; in phase II (days 200 to 500) the COD 
removal was stable and higher than 80%; and in phase III (days 500–900) COD removal 
ranged from 60 to 90%. Table 1 summarizes the average operational results and reactor per-
formance. The influent and effluent pH values in all phases were very stable averaging 7.2. 
The bicarbonate alkalinity present in the wastewater was sufficient to prevent pH changes 
in the reactor. Although air temperature varied from 22 to 35°C, the wastewater tempera-
ture was always at 30°C throughout the monitoring period.

In phase I, the long time to achieve high COD removal efficiency can be attributed to the 
adaptation period needed for a proper biomass development. The average influent total 
COD was 290 mg/l, resulting in a low applied organic load. In this phase, during field 
inspection fluvial water connected to the sewers was observed. Consequently, the resulting 
low COD values are certainly correlated with the sewerage operation. Since most of the
streets in the neighborhood are predominantly unpaved, diluted wastewater and sand are expected to reach the WWTP, as confirmed during the monitoring period. Because of the inefficiency of the grit chamber, a significant amount of inert solids accumulated inside the UASB reactor.

In phase II, an apparent steady state was reached since COD removal efficiency was

![Figure 2](https://iwaponline.com/wst/article-pdf/44/4/71/430121/71.pdf) Performance of UASB reactor and Mangueira Wastewater Treatment Plant

<table>
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<tr>
<th>Parameter</th>
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<th>Phase II 200-500 days</th>
<th>Phase III 500-950 days</th>
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(a): 100 (total CODin – total CODeff) / total CODin; (b): 100 (total CODin – sol CODeff) / total CODin; (c): 100 (total CODin – sol CODeff) / total CODin; (d): total CODin / HRT; (e): based on daily flowrate measurement; N = number of samples.
constant and above 80%, indicating the presence of an active biomass. Additionally during this phase, the sewerage network was operated properly which resulted in a small amount of rough material and grit in the treatment plant, and in a more concentrated wastewater with total COD around 550 mg/l. The MWTP operation and maintenance were also improved with more frequent grit removal, pipe cleansing, as well as the scum layer removal from the upper part of the UASB reactor.

The applied organic load in phase III was at the same level as in the second phase. Although the average COD removal was high and averaged 78%, it fluctuated between 65 to 90%, probably due to the great amount of inert solids present in the sludge bed, as detected in the sludge profile. In this phase, the operation and maintenance service also deteriorated.

Figure 3 shows the sludge bed profiles determined for each individual cell at day 880. The maximum concentration of total solids in the sludge bed ranged to 100 to 126 g/l at 0.5 m from the bottom, with 96% of suspended solids. However, the sludge bed was very dynamic among cells, and the maximum sludge concentration did not always occur at the bottom. Hydraulic load and possibly due mainly to the gas production, resulted in a sludge bed profile where a less dense layer was formed between the height 1 to 2 m in most of the cells. This type of profile seems to be quite different from that of sludge beds with granular sludges in UASB reactors.

The relationship between volatile suspended solids and total solids in the sludge bed was 32%, regardless of the sludge sampling point and sludge concentration, as presented in Figure 4. Those values are lower than the 60–70% usually found in UASB reactors, indicating a high amount of accumulated inert solids in the sludge bed. In contrast, in the effluent most of the solids are dissolved, and the volatile suspended solids represent only 6% of the total solids.

The high amount of accumulated inert solids in the sludge bed might be attributed to the low performance of the grit chamber due to the deficient operation and also the wastewater characteristics, typical of low-income areas. However, the UASB effluent suspended
solids were low in all phases indicating a good solid–liquid separation that is confirmed by the low settleable solids in the effluent.

As is shown in Figure 5, a linear relationship exists between total effluent COD and soluble effluent COD plus effluent VSS measured as COD. Therefore, volatile suspended solids in the effluent were assumed to be as loss of biomass washed out from the reactor. Therefore, COD removal efficiency can be best represented by using effluent soluble COD.

Figure 6 shows that the COD removal efficiency was basically independent of the organic load applied, indicating the reactor was underloaded. This means that since the beginning of monitoring, an active biomass developed inside the reactor. The specific methanogenic activity determined at day 880 ranged from 0.180 to 0.215 CH4-COD/gVSS.d, confirming an active biomass. The calculated sludge production yield based on sludge accumulated in the reactor and volatile suspended solid washed out in the effluent was 0.12 g VSS/g COD removed.
Conclusions
The Mangueira domestic sewage plant with a UASB achieved very good results during a monitoring period of over 30 months. Reactor performance was shown to be very stable and robust, regardless of the operating problems that occurred and the fluctuations in the influent characteristics. At organic loading rates ranging from 0.5 up to 2.5 kg total CODin / m³.d, COD removal efficiency achieved values from 60 to 90%. During the monitoring phases when operation was conducted on a regular basis, average efficiency most of the time was 80% or higher. The partial construction of the sewerage system and the operation characteristics resulted in an applied hydraulic retention time between 8.8 to 9.7 h. Despite the accumulation of a significant amount of inert solids inside the reactor, an active biomass developed achieving values of 0.180 to 0.215 g COD/g VSS.d in methanogenic activity tests.

The results show that the anaerobic technology with UASB reactor types can be feasible in the treatment of domestic sewage for the local conditions. Important operational parameters for local context refer to the regular maintenance, cleansing and removal of the grit, scum layer in the reactor and also in the sewerage system. The grit chambers project should be re-evaluated with new designs due to the local influent characteristics. In the case of bigger plants with a UASB reactor, the operation can be a bottleneck if adequate attention is not given to better operational procedures and trained personnel.

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