Feasibility of a pilot-scale UASB/trickling filter system for domestic sewage treatment

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Abstract This paper presents the results of pilot system comprised of one UASB reactor followed by one trickling filter (TF). The UASB reactor had a volume of 416 litres, being operated at an average hydraulic retention time (HRT) of 4 hours. The trickling filter had a useful volume of 60 litres, being operated at hydraulic and organic loading rates varying from 3.4 to 30.6 m³/m².d and 0.3 to 3.9 kgBOD/m³.d, respectively. These different operational conditions characterised eight research phases. Both reactors were fed with domestic sewage pumped directly from the main interceptor of Belo Horizonte City, Brazil. After almost 16 months of continuous monitoring, the UASB/TF system produced very good results in terms of COD and BOD removal, and also very low solids concentration in the final effluent. The average results of COD and BOD removal varied from 74 to 88% and from 80 to 94%, respectively, sufficient to maintain the COD concentration in the final effluent in the range of 60 to 120 mg/L and the BOD values systematically below 60 mg/L. The overall averages of SS in the final effluent were kept below 30 mg/L.

The UASB/TF system is a very promising alternative for the treatment of domestic sewage in Brazil and other developing countries, since the system can be designed with very short hydraulic retention times, resulting in a very compact and low cost treatment unit. Besides, the energy consumption and the labour costs are minimal.

Keywords Domestic sewage; post-treatment; trickling filter; UASB reactor

Introduction

The several favourable characteristics of anaerobic processes such as: low cost, operational simplicity and low solids production, together with the environmental conditions in Brazil, where the temperature is usually high, have contributed to highlighting the anaerobic systems for the treatment of domestic sewage, especially through UASB reactors. Nowadays, almost all alternative analyses for wastewater treatment in Brazil includes these reactors as one of the main options.

Despite these advantages, the UASB reactors have difficulties in producing effluents that can comply with the Brazilian environmental standards. Therefore, the post-treatment step is of great importance as a manner of adapting the treated effluent to the 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 which are barely affected by the anaerobic treatment (nutrients and pathogens).

The trickling filters, despite their enormous potential and series of advantages, have rarely been used in Brazil. One possible reason for this is the low diffusion of this technology within the country. For this, it becomes of great importance to increase and spread the knowledge level regarding this treatment system, contributing to increase in its use.

The trickling filters can find a large application in Brazil since the system can be designed with very short hydraulic retention times, resulting in a very compact and low cost treatment unit. Besides, the energy consumption and the labour costs are minimal.

Hence, the main objective of this research work was to evaluate the applicability of...
trickling filters for polishing domestic sewage submitted to a previous treatment stage in UASB reactors. The association of these two systems can contribute enormously to the reduction of labour and energetic costs of the treatment system. Furthermore, a new configuration of trickling filter that incorporates the settler underneath the reaction compartment was also tested. With this new configuration, the whole treatment can be achieved in one single unit, with savings in area and conferring a greater simplicity on the system.

**Material and methods**

**Feeding system**

The UASB reactor and the trickling filter (TF) were fed with wastewater taken directly from a main sewage interceptor of Belo Horizonte City, through an automated pumping system. Before feeding the reactors, the wastewaters passed through a preliminary treatment system, composed of coarse material and grit removal units, and then directed to an accumulation/distribution tank used to feed the UASB reactor. The main characteristics of the raw sewage were as follow (average values): COD$_{\text{tot}}$ = 521 mg/L, COD$_{\text{sol}}$ = 216 mg/L, BOD$_{\text{tot}}$ = 273 mg/L, BOD$_{\text{sol}}$ = 144 mg/L and SS = 122 mg/L.

After the preliminary treatment, the raw sewage was pumped into the UASB reactor through a peristaltic pump (Masterflex, two heads, 6 to 600 rpm). The effluent of the UASB reactor was directed to a splitting box, which was maintained continuously mixed in order to avoid solids sedimentation, and then pumped into the trickling filter by means of other peristaltic pump (Masterflex, one head, 6 to 600 rpm). A flowsheet of the experimental apparatus is presented in Figure 1.

The experimental units were controlled by an automated system that allowed the continuous variation of the flowrate and on-line measurement of temperature, pH and turbidity. The control software allowed all feeding pumps to operate at variable speed throughout the day, in order to simulate a transient hydraulic regime. The flowrate variation was reached by varying the pump speed, according to a set curve that imposed maximum and minimum flowrates of, respectively, 62% and 50% of the average flowrate.

**Pilot units**

The main characteristics of the pilot-scale UASB reactor and TF used in the experiments are presented in Table 1, while Figures 2 and 3 illustrate the configuration of these reactors.

![Figure 1. Schematics of the experimental apparatus](https://iwaponline.com/wst/article-pdf/44/4/221/430213/221.pdf)

![Table 1. Main characteristics of the pilot reactors](https://iwaponline.com/wst/article-pdf/44/4/221/430213/221.pdf)
Packing material

The trickling filter was packed with 60 litres of blast furnace slag, size 4 to 6 cm. This is a residue material of the steel making industry, which is very abundant in Minas Gerais State. Its cost is approximately 5 to 10 times lower than the ordinary packing material usually used in Brazil, such as gneiss crushed stones (Pinto and Chernicharo, 1996). In this way, the research also contributed to the evaluation of the applicability of this waste as packing material, aiming at cost reduction and recycling of wasted material.

Working principle of the trickling filter

The effluent from the UASB reactor is pumped onto the rock bed of the trickling filter, according to the flow variation controlled by the automation system. The effluent then has a downward flow, through the reaction compartment that contains the packing material, and is finally collected on the settler compartment that is located at the bottom part of the trickling filter. In the settler, the solids released from the biofilm, or non-retained onto the packing media by filtration or adsorption, are removed from the final effluent which leaves the settler from its upper part (see Figure 3).

Process start up and operational strategy

The pilot UASB reactor had been in operation for about 4 years, hence was already adapted to the wastewater to be treated. In relation to the start up of the trickling filter, a stepwise increase in the hydraulic and organic load, as shown in Table 2 was adopted. The research project comprised the investigation of eight different operational phases, each one testing different hydraulic and organic loads in the TF. The operational characteristics of the UASB reactor were kept constant throughout the experiment, being operated at an average hydraulic retention time of 4 hours (upflow velocity of 1.4 m/h). According to the hydraulic loading rates presented in Table 2, it can be seen that the TF was operated as a low rate filter in Phase 1, as intermediate rate filter in Phase 2, and as a high rate filter in Phases 3 to 8 (Metcalf and Eddy, 1991; Jordão and Pessôa, 1995).
Process monitoring

The UASB/AF system was monitored for a period of almost 16 months, through the evaluation of the following physical-chemical parameters: temperature, pH, alkalinity, volatile acids, total and soluble COD, total and soluble BOD, suspended solids and sludge and biogas production. All analysis were carried out according to the Standard Methods for the Examination of Water and Wastewater, 20th ed. (AWWA/APHA/WEF, 1998). The frequency of analysis varied from 2 to 3 times per week, except for temperature and pH, which were monitored on-line through the automation system. Automatic samplers were used to collect 24-hour composite samples.

Results

A summary of the results obtained during the whole operational period is shown in Table 3. Figures 4 to 9 depict graphics of the results obtained during the whole operational period, in terms of COD, BOD and suspended solids.

Start-up period (Phase 1)

Although the TF performance during Phase 1 (start up period) can be considered good, the high COD concentration of the incoming wastewater (UASB effluent) contributed to a low overall efficiency of the system as a whole. During Phase 1 the UASB was capable of producing an effluent with approximately 40 mgSS/L, 71 mgBOD/L and 234 mgCOD/L, while the average concentrations in the final effluent of the TF were 15 mgSS/L, 31 mgBOD/L and 175 mgCOD/L. The applied organic loading rates stayed around 3.8 KgCOD/m3.d for the UASB reactor and 0.9 KgCOD/m3.d for the TF. The overall BOD and COD removal efficiencies were around 88% and 74%, respectively.

Carbonaceous material removal

Although the UASB reactor had presented very high efficiencies in terms of total BOD and total COD removal, above 70% in almost all phases, it was observed that the trickling filter was capable of promoting an additional removal of carbonaceous material. The overall efficiency of the UASB/TF system was pushed to around 80 to 94% for the majority of the operational period. These high efficiency removals were obtained despite the large variations of COD and BOD concentration in the raw sewage (influent UASB).

Higher efficiency removals and better effluent quality were obtained in Phases 2 to 6, when the trickling filter was operated with hydraulic and organic loading rates varying from 6.8 to 17.1 m3/m2.d, 1.0 to 2.7 kgCOD/m3.d and 0.7 to 1.4 kgBOD/m3.d. Under these loading conditions, the TF was able to produce a very high quality final effluent, with aver-
age COD and BOD concentrations around 90 mgCOD/L and 30 mgBOD/L, respectively (see Table 3 and Figures 4 and 6). It is also interesting to notice that during these Phases (2 to 6) the UASB/TF system was able to comply with the discharge standard of Minas Gerais State in more than 70% of the COD results (see Figure 5). For BOD results, the compliance level was near 100% (see Figure 7).

Lower efficiencies and effluent qualities were noticed during Phases 7 and 8, when the TF was exposed to very high hydraulic and organic loading rates (20.4 and 30.6 m³/m².d, 3.7 and 5.6 kgCOD/m³.d and 2.0 and 3.9 kgBOD/m³.d). However, during these phases the UASB/TF system was still capable of producing a final effluent with relatively low concentrations of COD (average of 113 mgCOD/l) and BOD (averages below 60 mgBOD/L). The overall system efficiency stayed around 80% in terms of COD and BOD removal.

Suspended solids
Also in relation to the suspended solids, although its concentration in the effluent of the UASB reactor was systematically low (average results of Phases 1 to 8 varying from 28 and 68 mg/L), a complementary polishing was observed in the trickling filter. The average concentrations in the final effluent varied from 10 to 30 mg/L in most phases, staying in accordance with most of the very restrictive international discharge standards (see Table 3 and Figure 8).

Again, a better effluent quality was obtained in Phases 2 to 6, when the trickling filter was operated with hydraulic and organic loading rates varying from 6.8 to 17.1 m³/m².d, 1.0 to 2.7 kgCOD/m³.d and 0.7 to 1.4 kgBOD/m³.d. Under these loading conditions, the TF was able to produce a very high quality final effluent, with average SS concentrations below 30 mgSS/L (see Table 3 and Figure 8). It is also interesting to notice the excellent

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behaviour of the internal settler compartment tested during this research. Although very low hydraulic retention times were imposed to the settler (varying from 0.53 h in Phase 2 to 0.26 h in Phase 4), no negative effects were observed in the final effluent, which presented solids concentration of 11, 26 and 18 mgSS/L, for Phases 2, 3 and 4, respectively. In relation to the compliance with the discharge standard of Minas Gerais State, 100% of the results of suspended solids during Phases 2 to 6 were below the limit of 60 mgSS/L (see Figure 9).

Slightly higher concentrations of suspended solids in the final effluent were observed during Phases 7 and 8, when the TF and the settler compartment were exposed to very high hydraulic loading rates (20.4 to 30.6 m3/m2.d). However, during these phases the TF was already operating with a larger volume external settler, which certainly contributed to keep the solids concentration at low levels, usually below 60 mgSS/L. The average concentrations during these phases were 36 and 39 mgSS/L, respectively.

**Settler compartment**

The proposed settler configuration, located at the bottom part of the trickling filter, worked very favourably during Phases 1 to 4, when this unit was exposed to superficial application
rates and hydraulic retention times varying from 3.4 to 13.7 m$^3$/m$^2$.d and 63 to 16 minutes, respectively (see Table 2). Although the settler volume was very small (only 10.5 litres), compared with the reaction compartment of the TF (60 litres), the results of suspended solids in the final effluent were usually below 20 mgSS/L.

Effects of loading rates on the performance of trickling filter

Figures 10 and 11 depict the effect of organic loading rate on the quality of the final effluent and on efficiency removal of the trickling filter. Although a good correlation was not reached in both cases, it can be seen that there is a clear deterioration of the effluent quality and removal efficiencies when the organic loading rate increases beyond 3 or 4 kgCOD/m$^3$.d. For lower loading rates (up to 3 kgCOD/m$^3$.d), the trickling filter was capable of maintaining the effluent COD concentration below 100 mgCOD/L, and usually below or very close to the guideline of Minas Gerais State (90 mgCOD/L).

Also in terms of COD removal efficiencies, the results were very satisfactory when the trickling filter operated with lower loading rates (up to 3 kgCOD/m$^3$.d). For this, the average efficiencies ranged from 30 to 50%, which can be considered very good for a post-treatment system. Even better results were obtained for BOD, when the average removal efficiencies stayed between 50 and 65%, when the TF was operated with loading rates up to 1.4 kgBOD/m$^3$.d. For this loading rate, the TF also exhibited a very good quality effluent in terms of BOD concentration, with average results always below 35 mgBOD/L.

For suspended solids, the effect of hydraulic loading rate on final effluent quality is shown in Figure 12. Again, a deterioration of the effluent quality when the hydraulic loading rate increases can be observed, although reasonably good average results were obtained even when the loading rate was as high as 30 m$^3$/m$^2$.d. From these results, it seems that the filter and the settler compartment can accommodate loading rates up to 20 m$^3$/m$^2$.d, keeping the suspended solids concentration in the final effluent below 30 mg/L.

Conclusion

The results obtained in this research demonstrate that trickling filters can promote an important additional COD and BOD removal in effluents of UASB reactors. Very good
results were obtained during Phases 2 to 6, when the filter was operated with hydraulic and organic loading rates varying from 6.8 to 17.1 m$^3$/m$^2$.d, 1.0 to 2.7 kgCOD/m$^3$.d and 0.7 to 1.4 kgBOD/m$^3$.d. Under these loading conditions, the TF was able to produce a very high quality final effluent, with average COD, BOD and SS concentrations around 90 mgCOD/L, 30 mgBOD/L and 25 mgSS/L, respectively. During Phases 2 to 6 the UASB/TF system was able to comply with the discharge standard of Minas Gerais State in more than 70% of the COD results and approximately 100% of the COD and SS results. Lower efficiencies were obtained during Phases 7 and 8, due to the very high hydraulic and organic loads imposed on the filter. From the data presented here, it can be assumed that trickling filters as post-treatment unit of UASB reactors can be reasonably operated at organic loading rates up to 3 kgCOD/m$^3$.d (up to 1.5 kgBOD/m$^3$.d) and hydraulic loading rates up to 20 m$^3$/m$^2$.d.

The new settler configuration, located at the bottom part of the trickling filter, worked very favourably, being able to produce a highly clarified effluent, even when operated at extreme hydraulic retention times. With this new configuration, the whole treatment can be reached in one single unit, with savings in area and conferring a higher simplicity to the system.

Although the research is still on course, the results obtained so far demonstrate the feasibility of the UASB/TF system for the treatment of domestic sewage in tropical countries, at ambient temperatures, even in less favourable situations when the effluent of the UASB reactor presented very low concentrations in terms of COD, BOD and SS. The UASB/TF system can become a very promising alternative for the treatment of domestic sewage in Brazil and other developing countries, since the system can be designed for very short hydraulic retention times, resulting in a very compact and low cost treatment unit. Besides, the energy consumption and the labour costs are minimal.

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