Performance of constructed wetland systems treating anerobic effluents

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Abstract The purpose of this present paper is to verify the performance of three wetland systems operated with effluents from a UASB reactor, with respect nutrient removal (nitrogen and phosphorus), pathogenic organisms and remaining carbonaceous material, monitored over a three-year period. The experiment was carried out and monitored at PROSAB (Programa de Saneamento Básico) in Campina Grande, Paraíba. The removal efficiency of the carbonaceous material expressed in DQO ranged from 70 to 86%, but concerning the total suspended solids, the efficiency ranged from 50 to 71%. The removal efficiency in terms of nitrogen and phosphorus of both vegetated systems was about 65.5 to 86%, respectively, during the first year of operation. Under the operational conditions of the experiment, the removal of phosphorus in a wetland system containing washed sand as the substratum decreased, as its operation period increased. The vegetated wetland has been the most efficient in removing faecal coliforms (roughly 4 log units) as compared to the non-vegetated one (about 3 log units), when both were operated with the same hydraulic load (2.3 cm. per day). Thus, the effluent produced over the three-year period ranged from 800 to 1,800 UFC/100 mL in the analyzed samples.

Keywords Constructed wetlands; nutrient removal; performance; UASB effluent

Introduction

The increasing water demand in urban regions and the scarcity of high quality fresh water, especially in arid regions, highlight the need to develop wastewater treatment technology that allows the reuse of effluents. The use of a UASB reactor for anaerobic sewage treatment in tropical regions today is a consolidated practice (van Haandel and Lettinga, 1994; Chernicharo, 1997). Under appropriate operational conditions (HRT of 4 to 6 hours), this reactor will remove the organic and suspended solids loads with an efficiency of 70–80%. However in many cases the produced effluent will require a post treatment step to produce a final effluent quality that is compatible with the standards set by the environmental control authorities (Sousa et al., 2001; Sousa and Foresti, 2001). Constructed wetlands have been applied for the treatment of low strength waste waters and polluted surface waters as well as domestic sewage and industrial wastes (Denny, 1997; Herbel, 1999). Wetland systems offer significant environmental benefits. They reduce global heating, enhance environmental carbon fixation, so that atmospheric CO₂ is reduced and conserve biodiversity (Denny, 1997). This paper has as its objective to evaluate the performance of three wetland systems operated with the effluent from a UAB reactor treating municipal sewage. The evaluated parameters are the removal efficiency of nutrients (nitrogen and phosphorus), pathogenic organisms and residual organic material and suspended solids. The behavior of the wetlands was evaluated over a three-year period.

Material and methods

The experimental investigation was part of the Research Program of basic sanitation
(PROSAB) set up by the Brazilian government. The research was carried at in Campina Grande-Brazil. The experimental system was constructed at pilot scale and was composed of two units: (1) a UASB reactor and (2) three wetland systems. Table 1 gives the main constructive details of the treatment units. The medium in the wetland systems was washed sand with an average diameter of 2.88 mm. Wetlands 2 and 3 were planted with macrophytes (Juncus spp) with a density of 25 plants per m². No plants were grown on Wetland 1.

The treatment plant was operated with a constant influent flow. Appropriate flows were fed to the wetlands by means of dosing pumps and flowed sub-superficially through the Wetland units. A hydraulic load of 2.3 cm.d⁻¹ was applied to Wetland 1 and 3, Wetland 2 received 3.3 cm.d⁻¹. The performance of the wetlands was evaluated over a period of 36 months. The analyzed parameters were: temperature, pH, COD, NH₄⁺, TKN, Total P, Faecal Coliforms and Streptococcus. With the exception of the first one, all parameters were determined by methods in accordance with Standard Methods (APHA, 1998). The differences of the treatment efficiencies of the three Wetland Systems over the three-year operational period were statistically analyzed (ANOVA).

Results and discussion
In Table 2 it can be noted that the applied organic load varied between 6.64 and 9.93 gCOD.m⁻².d⁻¹ the nitrogen load was between 1.38 and 1.98 gTKN.m⁻².d⁻¹ and the phosphorus load ranged from 0.17 to 0.25 gP.m⁻².d⁻¹. Higher loads have been applied by Batchelor and Loots (1997) and Sousa et al. (2001). It is important to note that the effects of evaporation and precipitation were not considered.

Organic matter removal
Table 3 shows the average experimental results obtained in the Wetlands 1, 2 and 3 (W1, W2 and W3) over the operational period of 3 years. It can be noted that the removal efficiency of carbonaceous material expressed in COD varied between 70 and 86%. With respect to the total suspended solids concentration, a removal efficiency of 50 to 71% was observed. The average COD and TSS concentrations of the final effluents of the wetland systems during the first year of operation did not exhibit significant differences between the three units (p >0.05), although the values of the Wetland 1 (without vegetation) were slightly smaller than those in the wetland with plants and the same hydraulic load (2.3 cm.d⁻¹). However, from the first year onwards, there was a significant difference between the COD values in these two wetland systems. It is concluded that in the first year the macrophytes did not influence the organic material removal.

Nitrogen removal
With respect to nitrogen, it can be seen in Figure 1 that significant removal took place in the units with macrophytes but much less in the unit without plants. The removal efficiency for nitrogen was very high during the first year, but decreased in the subsequent years. A
variance analysis (5% significance level) showed that there was a significant difference ($p < 0.05$) between the three wetland systems. From the data it is clear that the presence of the macrophytes had a fundamental role in the process of nitrogen removal. An evaluation of the monthly averages of the experimental data showed that the removal efficiency was not linear with time, it oscillated during the period of monitoring. The oscillations may be attributable to the cyclic nature of macrophyte growth. In the aging phase the plants no longer absorb nutrients as they did in the growth phase (Sousa et al., 2001).

Phosphorus removal

Figure 2 shows the behavior of the UASB reactor effluent and of the three-wetland systems over the thirty-six-month monitoring period. As shown in the picture, over the first six-month monitoring, the effluent produced by the wetland systems contained a low concentration of phosphorus, less than 0.4 mgP L$^{-1}$ for wetland 3 and about 0.6 P L$^{-1}$ for wetland 2.

Phosphorus removal occurs due to chemical precipitation and adsorption in the medium as well as absorption by plants and biofilms that tend to develop in the medium and the roots of the macrophytes. During the experimental period pH in the systems ranged from 7.0 to 7.5, a range that favors chemical precipitation of calcium phosphates (Metcalf and Eddy, 1991). As in the case of nitrogen, the phosphorus removal efficiency was not constant over
the experimental period. The very high removal efficiency during the first year (82 to 90% in W2 and W3, respectively) was reduced substantially in the following years and at the end of the operational period the final phosphorus concentration sometimes was greater than in the anaerobic effluent. This may be attributed to saturation of the soil with little soluble phosphate salts. Thus, the phosphorus compound adsorption rate is controlled by pH as well as the oxidation potential in the substratum (Reddy and D’Angelo, 1977). Therefore, as the operation period increases, the system tends to be saturated with phosphorus compounds and, as a consequence, a decrease in the removal efficiency occurs. Such a decrease may relate to the substratum saturation (washed sand) with precipitated compounds of phosphorus (Tanner et al., 1999; Sousa et al., 2001).

**Faecal coliforms removal**

With regard to the removal of pathogens Figure 3 is presented, where the removal efficiency of faecal coliforms is plotted as a function of time of operation for the three wetland systems. During the first year the wetland systems with the same hydraulic load produced the same final FC concentration. However in the subsequent years the wetland system without vegetation tended to have a higher FC effluent concentration than the units with macrophytes. This corroborates the results obtained by Rivera et al. (1995), Sousa et al. (2001), Ceballos et al. (2001) and Meira et al. (2002) who all observed the influence of macrophytes on the FC removal efficiency. The exact mechanism of FC removal in wetlands has not yet been established. Physical, chemical and biological phenomena all
have influence. Among the physical factors are the plant density affecting filtration (roots), fixation of biofilm, sedimentation and adsorption. Chemical factors are oxidation and bioicide excretion by some macrophytes. Finally, biological factors (Rivera et al., 1995) include the production of chemical compounds that inhibit the development of other organisms (antibioses), as well as predation of nematodes and parasites and natural decay.

**Conclusion**

During the three years of monitoring the removal efficiency of COD was in the range of 70 to 86% in three wetland systems operated with UASB effluent at a hydraulic load of 2.3 to 3.3 cm/d. Initially no significant difference was observed between the efficiency of units with or without macrophytes but from the second year onwards the units with vegetation were more efficient. Under the experimental conditions the removal efficiency of phosphorus in the wetlands with sand as medium was high in the initial period (> 90%), but decreased with time and eventually became small. Nitrogen removal efficiency also decreased gradually during the operational period and was much larger in the units with macrophytes than in the one without. Faecal coliforms were removed more efficiently in wetland systems with macrophytes (removal efficiency of 4 log units) than in the unit without plants (3 log units).

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**References**


