Use of horizontal subsurface flow constructed wetlands with recirculation as post-treatment of UASB reactor effluent

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Abstract
The main objective of this research was to investigate the performance of sub-superficial flow constructed wetlands (CW) as a post-treatment of the effluent from a UASB reactor, operating with total effluent recirculation. The UASB reactor (working volume of 73.6 m³) has been operated at a hydraulic retention time of 8.5 hours since 2008. The CW consists of four parallel gravel-based cells, each 7.0 m x 18.0 m, with horizontal subsurface flow through a depth of 0.8 m. Two cells are planted with *Typha sp.* and the other two, with *Cyperus alternifolius sp*. The main operating conditions of the CW are: total hydraulic retention time equal to 1.95 days, surface loading rate equal to 0.48 $m^3.m^{-2}.d^{-1}$ and organic loading rates varying from 0.05 – 0.11 $kgCOD.m^{-2}.d^{-1}$. The treatment process was monitored and evaluated with total effluent recirculation from January to June of 2012, as well as without effluent recirculation from July of 2012 to January of 2013. After 12 months of continuous monitoring, the UASB/CW system produced quite satisfactory results in terms of COD removal, and also very low solids concentration in the final effluent. The COD removal efficiencies ranged between 66 and 85% sufficient to maintain the COD concentration in the final effluent in the range of 60 to 120 $mg.L^{-1}$. The TSS concentrations in the CW effluent always remained below 30 $mg.L^{-1}$. However, there was no significant removal of orthophosphate and ammonia in CW with or without recirculation of the final effluent. The minimum effluent thermotolerant Coliforms density values were 10^4 MPN/100mL and the statistical tests showed no significant difference for the CW planted with different species of macrophytes.

Keywords
Constructed wetlands; effluent recirculation; post-treatment; UASB reactor

INTRODUCTION

Taking into account the Brazilian climatic conditions, especially in the north and northeast region, where the minimum recorded winter temperatures are usually above 20° C, the use of UASB reactors present some attractiveness. Nevertheless, one may point out some disadvantages, such as: BOD effluent concentration frequently above 60 $mg.L^{-1}$, TSS effluent concentration between 40 and 80 $mg.L^{-1}$, less than one logarithmic order for Coliforms removal and practically no efficiency for nutrient removal (Jordão *et al*., 2007).

Considering the requirements in the Brazilian environmental legislation, effluents of UASB reactors require a polishing treatment in order to meet legal standards.Therefore, the challenge imposed is how to improve the quality of the effluents from UASB reactors without necessarily causing an increase in operational complexity of the sanitary wastewater treatment plants (WWTP).

In this context, constructed wetlands (CW) can be a good option. When compared to other wastewater treatment processes, CW present some advantages such as: low construction cost and simplicity regarding operation and maintenance. However, when used as a technology for polishing effluents from UASB reactors, some studies report nutrients limitation and pathogens removal

(Mandi *et al*., 1998; Kaseva, 2004; Brix *et al*., 2007; El-Khateeb *et al*., 2008). On the other hand, Brix and Arias (2005) proposed recirculating the effluent of a vertical CW and concluded that this configuration resulted in lower nitrogen and phosphorus concentrations in the final effluent.

The objective of this research was to investigate the performance of sub-superficial flow CW as a post-treatment of the effluent from a UASB reactor, operating with total effluent recirculation, by assessing the removal of organic matter, Coliforms and nutrients. In addition to that, the study aimed to investigate the occurrence of operational problems, management of macrophytes and the influence of recirculation on the quality of the final effluent.

METHODS

Description of the treatment system

The WWTP is defined as a small treatment system, located in *Lauro de Freitas* city, *Bahia* state, Brazil (12°53'41''S and 38°19'03''O) designed to treat sanitary wastewater from a population approximately equal to 1,000 inhabitants (maximum daily flowrate equal to 8.6 m³ per hour) and it has been operating since 2008. The layout consists of an UASB reactor (3.8 x 3.8 m) with a useful height of 5.1 m, which correspond to a cross section of 14.4 m², working volume of 73.6 m³ and hydraulic retention time of 8.5 hours followed by constructed wetlands (CW) and a disinfection step with application of sodium hypochlorite solution (Fig. 1).

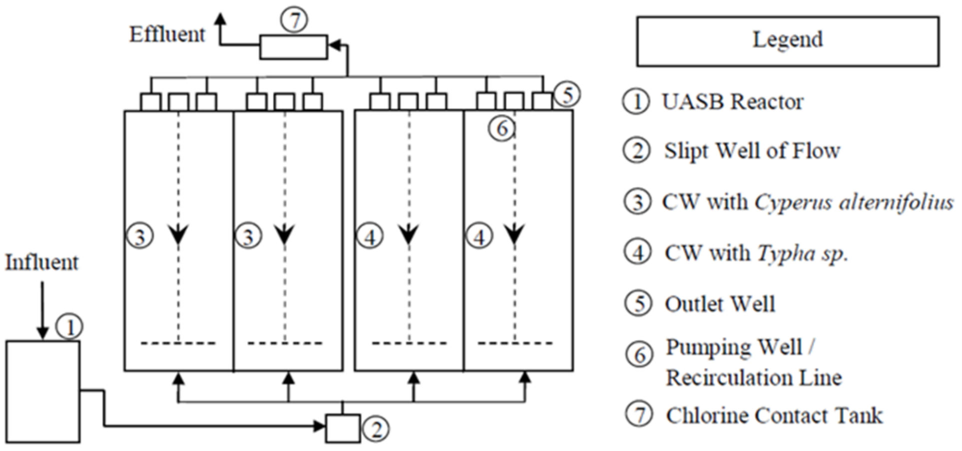

Figure 1. Layout of the wastewater treatment plant located in *Lauro de Freitas* city, Brazil.

The CW consists of four parallel gravel-based cells, each 7.0 m x 18.0 m, with horizontal subsurface flow through a depth of 0.8 m and they are composed of the following parts: inlet zone, zone of planted filter bed and outlet zone (Fig. 2). Two cells are planted with *Typha sp*. and the other two, with *Cyperus alternifolius sp*.

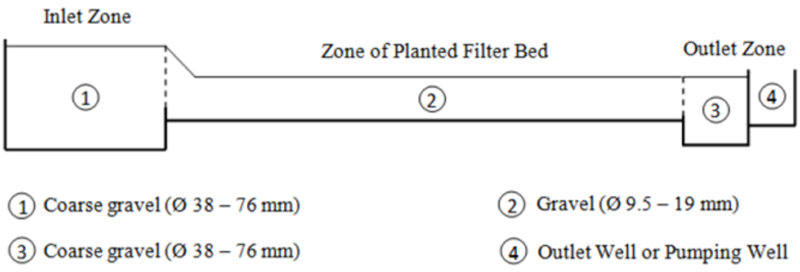

Figure 2. Schematic section of a constructed wetland unit.

The inlet zone also called influent distribution bed, in addition to promoting the homogenization of recirculated effluent before the medium filter, also prevents the occurrence of clogging by retaining solids, which are inevitably present in the effluent from the UASB reactor. The dimensions and operating conditions of the CW are given in Table 1.

Table 1. Dimensions and operating conditions of the constructed wetlands.

Dimensions:	Length (m)	Width (m)	Dept (m)
Inlet zone	3.0	7.0	2.0
Planted filter bed	14.0	7.0	0.8
Outlet zone	1.0	7.0	1.3

Operating conditions:	
Total Hydraulic Retention Time (days)	1.95
Surface Loading Rate ($m^3.m^{-2}.day^{-1}$)	0.48
Organic Loading Rate$_{range}$ (kg COD. $m^{-2}.day^{-1}$)	0.05 – 0.11
Organic Loading Rate$_{average}$ (kg COD. $m^{-2}.day^{-1}$)	0.09
Nitrogen Loading Rate $_{range}$ (kg TKN. $m^{-2}.day^{-1}$)	0.007 – 0.03
Nitrogen Loading Rate $_{average}$ (kg TKN. $m^{-2}.day^{-1}$)	0.02
Phosphorus Loading Rate$_{range}$(kg P-$PO_4^{-3}.m^{-2}.day^{-1}$)	9.6×10^{-4} – 3.3×10^{-3}
Phosphorus Loading Rate$_{average}$(kg P-$PO_4^{-3}.m^{-2}.day^{-1}$)	2.6×10^{-4}
Temperature (ºC) $_{range}$	24 - 32

Sampling and analytical methods

The treatment process was monitored and evaluated with total effluent recirculation from January to June of 2012 (stage 1), as well as without effluent recirculation from July of 2012 to January of 2013 (stage 2). Single samples from UASB reactor and CW were collected twice a week, always at 9:00 am, every three days. The samples were analyzed for COD, total solids (TS), total suspended solids (TSS), total Coliforms (TC), thermotolerant Coliforms (ThC), total Kjeldahl nitrogen (TKN), ammonia, nitrate, nitrite, total phosphorus and orthophosphate. Physicochemical analyses were carried out according to Standard Methods for Examination of Water and Wastewater (APHA, AWWA, WEF, 2005).

Comparisons between the mean values of the pollutant concentration and the averages of the treatment process efficiencies were performed using *Mann-Whitney* two-sample test or *Wilcoxon* rank sum test at a significance level of 5% using the *Minitab* software 14®. Thus, it was possible to evaluate the performance of the treatment process between CW planted with different macrophytes, and during periods with and without the CW effluent recirculation.

RESULTS

Organic matter and solids removal

The efficiency of the UASB reactor at 8.5 hours of HRT was quite satisfactory. Maximum residual values of COD and TSS were 226 $mgO_2.L^{-1}$ and 85 $mg.L^{-1}$, respectively. Analyzing the COD and TSS concentrations obtained in the effluent of the CW, it was found that these units showed excellent performance in removing these pollutants. Applying full effluent recirculation, the COD removal efficiencies ranged between 66 and 85%. However, even while the recirculation pump was switched off, the average COD removal efficiency varied between 52 and 79%.

The statistical tests showed that there was no significant difference between the average of the effluent COD concentrations of CW planted with *Typha sp*. and *Cyperus alternifolius sp*. Our results are similar to those reported by Mbuligwe (2004) and El-Hamouri *et al*. (2007) that reported little or no influence of using different macrophytes for removal of soluble and particulate organic matter in CW. The box-plot graph (Fig. 3) shows the effluent COD concentrations of the UASB reactor and CW throughout the research.

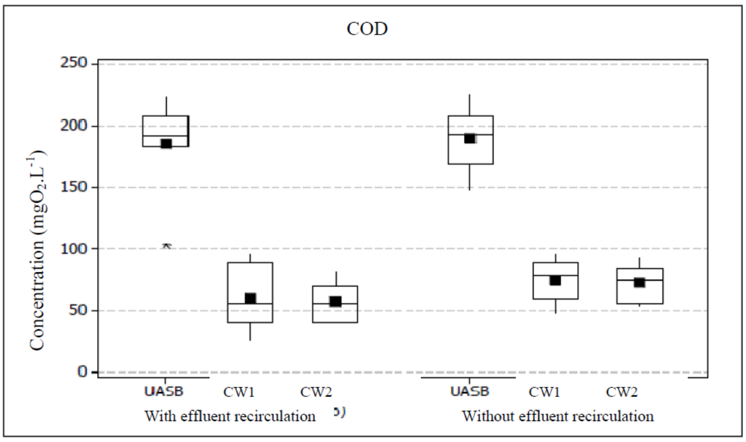

Figure 3. Box plot graph of COD concentrations in the effluent of the UASB reactor, CW1 (*Typha sp*.) and CW2 (*Cyperus alternifolius sp*.).

The efficiencies removal of TSS ranged from 60 to 97% in the first stage of the study and 67 to 96% in the second stage, without significant differences for the CW planted with different macrophytes.The TSS concentrations in the CW effluent always remained below 30 $mg.L^{-1}$.

Nutrients and Coliforms removal

The graphs in Figure 4 show that there was no significant removal of ammonia and TKN in CW with or without recirculation of the final effluent.The nitrate concentrations detected in the final effluent of CW varied between 1.5 and 2.1 mg $N\text{-}NO_3^-.L^{-1}$. These results showed an insignificant nitrification, possibly, due to the availability of oxygen offered by the roots of the macrophytes and the contact between the liquid and the atmosphere.

It is well established that sub-surface flow (SSF) constructed wetlands do not promote significant nutrient removal (Batchelor and Loots, 1997; Mandi *et al*, 1998; Dahab and Surampalli, 2001; Kaseva, 2004; El-Khateeb *et al*, 2009). However, we expected that the strategy of recirculating the final effluent would allow the achievement of a better nutrient removal than those reported in the literature. It seems clear that the oxygen transfer is the limiting factor in promoting nitrification. Considering the operational conditions applied, macrophytes were not able to sequester nutrients at rates that allow the effluent concentrations to be below the limit established in Brazilian environmental legislation.

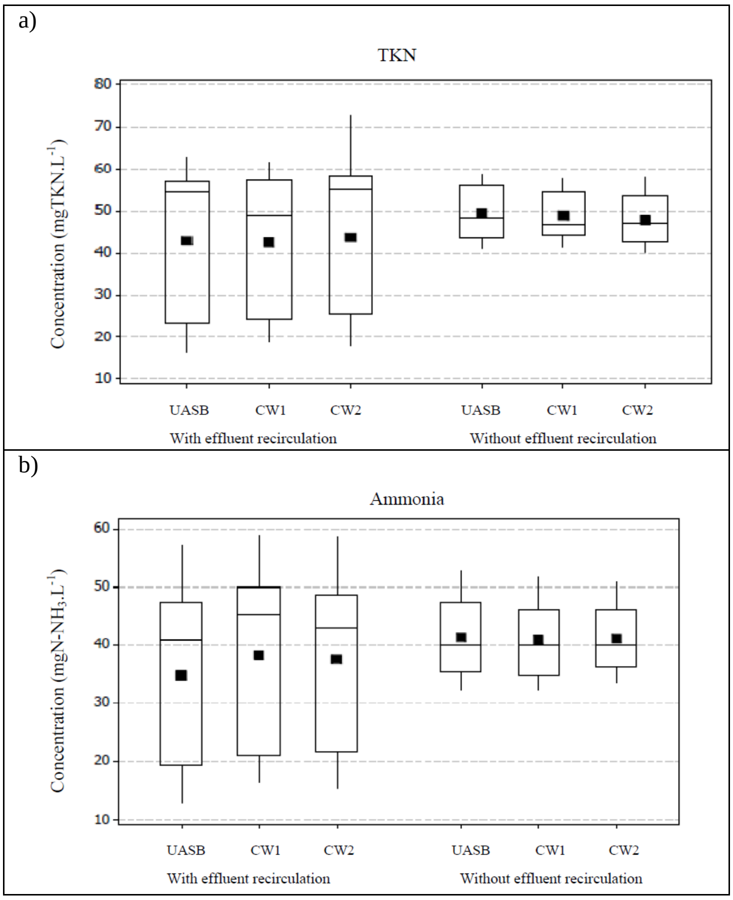

Figure 4. Box plot graph of TKN and ammonia concentrations in the effluent of the UASB reactor, CW1 (*Typha sp*.) and CW2 (*Cyperus alternifolius sp*.).

The different forms of phosphorus in the effluent (Fig. 5) presented the same behaviour as nitrogen. The values of orthophosphate removal during the different stages (with or without recirculation of the final effluent) varied between 0 to 32% and 0 to 23%, respectively. Statistical tests showed no significant difference between these values or for CW planted with *Typha sp*. and *Cyperus alternifolius sp*. We also observed some events in which the effluent orthophosphate concentration was higher than the influent.

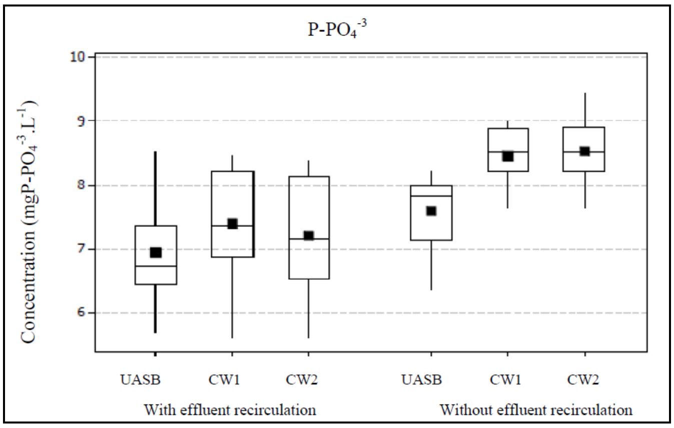

Figure 5. Box plot graph of orthophosphate concentrations in the effluent of the UASB reactor, CW1 (*Typha sp*.) and CW2 (*Cyperus alternifolius sp*.).

Vymazal (2005) reported high nitrogen removal efficiency values at the start of the CW operation, followed by periods of decline and increased performance. The author believes that such variations are due to the growing cycle of the macrophytes. However, in our study, there was no such behaviour, even during periods of pruning and replanting, possibly, because the WWTP has been operating since 2008 and, therefore, the vegetation is well developed.

The CW influent densities of thermotolerant Coliforms varied from 10^5 to 10^7 MPN/100 mL during the monitoring period. The minimum effluent density values were 10^4 MPN/100 mL and the statistical tests showed no significant difference for the CW planted with different species of macrophytes. The Brazilian regulatory requirement for fecal Coliforms concentration, (i.e. 10^3 MPN/100 mL, when disinfection is required) was not satisfied. Therefore, the maintenance of the chemical disinfection step, done by using sodium hypochlorite solution, is still needed.

Maintenance of the CW

To ensure the CW proper treatment efficiencies, it is required intense operation and continued existence of activities such as: removal of weed, pruning of the macrophytes, management of generated vegetal biomass and control of the water level to prevent flooding and hydraulic short circuits.

The removal of unwanted vegetation (grass, forage plants, weed, etc.) that developed in the beds was performed three times a week. We do not measure the production of vegetable biomass, however, it was observed that the *Typha sp*. presents faster vegetative growth than the *Cyperus alternifolius sp*. resulting in frequent pruning demand and increased waste generation.

Despite less need for pruning, the *Cyperus alternifolius sp.* root structure apparently stimulates the clogging of the filter bed. This macrophytes grows forming branches and this feature also makes the access of the WWTP maintenance staff difficult when carrying out pruning and removing fallen branches.

Several studies indicate that the main operational problem for subsurface flow CW is the clogging of the filter bed. The inlet zone of the WWTP is provided with pipes that allow periodic removal of the sludge which accumulates at the bottom of this zone. This operation was conducted every two or three months, but, even adopting this procedure, there was flooding of the first third of the filter bed after intense rainfall, however, there was no loss of quality of the final effluent.

CONCLUSIONS

Although the hydraulic retention time used was fairly low (average of 1.95 days), we concluded that CW are one of the technologies that can effectively treat anaerobically pre-treated UASB reactor effluents. But, the recirculation of the CW effluent has not provided a removal efficiency increase in the parameters analyzed when compared to stage without recirculation. The statistical tests showed that there was no significant difference between the average of the effluent solids, COD, ammonia, orthophosphate and Coliforms concentrations of CW planted with *Typha sp.* and *Cyperus alternifolius sp.* However, some characteristics of these macrophytes require attention during operation and maintenance activities of the CW. Removal efficiencies obtained in this study suggests a need for further research to show that this technology is capable of producing a final effluent, which can meet the Brazilian required standards recommended for nitrogen and phosphorus disposal in receiving water bodies.

ACKNOWLEDGMENTS
The authors would like to thank the Foundation for Research Support of the *Bahia* State, Higher Education Personnel Improvement Coordination of the Brazilian Government, FINEP® Innovation and Research, *Empresa Baiana de Águas e Saneamento S.A.* and College *ÁREA 1* | DeVry Brazil for financial and material support.

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