

Constructed Wetland System as Secondary Treatment for Stabilization Pond Domestic Effluent

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Received: March 19, 2013 Accepted: April 16, 2013 Published: June 25, 2013

doi:10.5296/jee.v4i1.3915 URL: <http://dx.doi.org/10.5296/jee.v4i1.3915>

Abstract

Alternatives for improving sewage management to avoid degradation and unnecessary waste of hydrological resources are a worldwide concern. Wastewater treatment by the constructed wetlands process using macrophytes is considered a robust system, due to its low cost and straightforward means of operation and repair. In this study, a horizontal flow constructed wetland system performance is evaluated. The system applied cattail as secondary treatment for a stabilization pond in a sewer treatment plant. Basically, these systems are based on channels filled with highly porous media, which detains high hydraulic conductance, providing the right support for macrophyte and biofilm growth. The horizontal flow constructed wetland revealed superior capacity and stability when removing COD, BOD, phosphorous and *Escherichia coli*. Also, cattail macrophyte developed in medium conditions where it was inserted. The results allowed a better comprehension about the phenomena associated to constructed wetlands pollutant removal capabilities.

Keywords: Wastewater, Secondary treatment, *Typha* sp, Constructed wetland, Domestic effluent

1. Introduction

In the last few decades, environmental pollution has become a public matter in both developed and third world countries. The reason behind such awareness is due to a rapid economic development intensely related to natural resources exploration, which had been previously left untouched (Mant et al., 2005).

The lack of potable water is a growing issue, both in terms of quantity and quality, which has lead humanity to look for many alternatives in order to improve water management and its persistence in our environment (Conte and Leopoldo, 2001). Sewage treatment seeks a way to avoid degradation and unnecessary waste of hydrological resources, thus becoming an important matter in Brazilian water treatment (Tonetti et al., 2009).

Amongst many alternatives, wastewater treatment by the constructed wetlands process using macrophytes is considered a robust system, due to its low cost and straightforward means of operation and repair. Such features fit perfectly the climatic conditions of tropical countries which have available areas where these systems can be implemented, as in Brazil (Brasil and Matos, 2008).

Basically, these systems are based on channels filled with highly porous media, which detain high hydraulic conductance (usually gravel or thick sand), providing the right support for macrophyte and biofilm growth, besides the fundamental role as a filter to some pollutants. The constructed wetlands are divided according to their flow, which can be either vertical or horizontal and surface or subsurface (Calijuri et al., 2009).

Studies involving real-scale and contained experiments have shown that built wetlands have some important capabilities related to the reduction of organic matter, suspense solids, nitrogen, phosphorous and pathogenic organisms. This decrease is caused by the combined activity of many factors, such as: sedimentation, filtration, precipitation and chemical adsorption, as well as microbial and vegetable interactions. Constructed wetlands are broadly used in various countries as an ultimate resolution in wastewater treatment and improvement, when it comes to river and lake water (Pereira et al., 2007).

In this study, a horizontal flow constructed wetland system performance is evaluated. The system was built in pilot scale with cattail (*Typha* sp.) as secondary treatment for a stabilization pond in a sewer treatment plant located at Bandeirantes-PR, Brazil. The purpose was to verify the ability of the wetland to decrease physical-chemical and microbiological parameters, such as color, turbidity, organic matter, conductivity, biochemical oxygen demand (BOD), chemical oxygen demand (COD), phosphorous, nitrogen, total coliforms and *Escherichia coli*.

2. Materials and Methods

The experiment proposed in this study was implemented in a sewer treatment plant located at Bandeirantes-PR, Brazil. The local population is composed of 33,732 inhabitants, of which 27,220 represent the urban citizens, and the other 6,012 represent the rural population. This population is found in a 444.3 km² area, whereas 12 km² is the urban area (PMB, 2005).

This city owns a sewer network which reaches 98% urban sewage capture and treatment. Treatment in this network is done by auto depuration processes, stabilization ponds and dual anaerobic ponds systems followed by a facultative pond. The station is located near the “Ribeirao das Antas” river, where the treated wastewater is released.

In order to accomplish the secondary treatment proposed, part of the effluent from the stabilization ponds was used. The wetland was built in pilot scale, above ground, in cement blocks with impermeable internal walls with the following dimensions: 0.65 m height, 0.60 m substrate height, 1.30 m width, 2.15 m length and 1.82 m² surface area (Figure 1); functioning in horizontal substrate flow and vertical percolation with an escape system in the lower area.



Figure 1. Constructed wetland system of horizontal flow installed in stabilization pond (sewage treatment station of Bandeirantes-PR, Brazil). On the left, there is the reservoir connected to the hydraulic loading rate (HLR) control.

The waterbed was composed of four 10 cm gravel layers with “3, 2, 1 and small rock” gradations with pre-filtering functions, a 10 cm sand layer (granulometrics ranging from 15 to 20 mm) and a rice straw layer in the upper part. Some samples of the macrophyte grown in waterbeds (*Typha* sp.) were manually taken from their natural environment in an area near the sewer treatment plant. The total biomass was circa 15 kg.

Effluent to be treated from the stabilization pond was conducted by gravity through pipes towards a 200 L reservoir, followed by an input volume control hydrometer and then disposed in the first waterbed parts, denominated input zone, by four perforated hoses disposed in parallel, in a closed circuit, from where it slowly percolated through the filtering material all the way to the final area, denominated output zone. This percolation had a

propensity to flow horizontally using impulse from a bottom declivity. The output tubes were connected to a flexible hose placed there to control the effluent level inside the waterbed. A maximum hydraulic loading rate (HLR) was 260 cm.d^{-1} , with minimum values adjusted to 100 cm.d^{-1} (Figure 2).

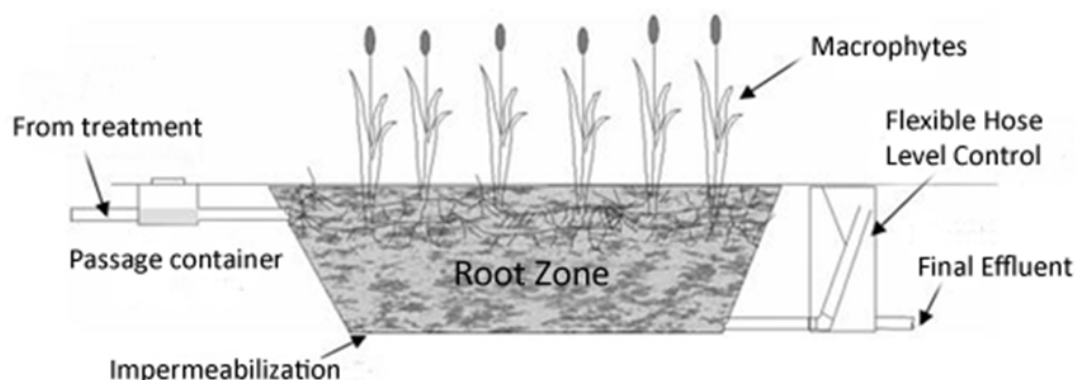


Figure 2. Constructed wetland system scheme with macrophytes according to Sezerino (2006).

In order to perform this study in the time period between June 2005 and October 2005, an effluent output monitoring program was consolidated in the stabilization pond and in the wetland outputs, consisting of a weekly sampling and physical-chemical analysis, and also microbiological tests, carried out in the water and sewage analysis laboratory at “Estação de Tratamento de Água – ETA” (*Water Treatment Plant*) of “Serviço Autônomo de Água e Esgoto (SAAE)” – Bandeirantes – Paraná – Brazil. The experiment was carried out at an average 21°C temperature environment.

According to “Standard Methods for the Examination of Water and Wastewater” (APHA, 2000), Branco (1978) and CETESB (1986), the following parameters were evaluated: pH, conductivity, biochemical oxygen demand (BOD), chemical oxygen demand (COD), color, phosphorous, nitrogen, dissolved oxygen, turbidity, precipitated solids, alkalinity, total hardness, coliforms and *Escherichia coli*.

3. Results

Tables 1 and 2 present the average performance results of the wetland, which received effluent from the stabilization pond, with a hydraulic loading rate (HLR) of 260 cm.d^{-1} and 100 cm.d^{-1} during the monitoring period.

According to Tables 1 and 2, there were no major changes in pH values in both analyzed areas, regardless of HLR, similar to the studies by Mant et al. (2005) and Prochaska et al. (2007). This indicates the existence of a buffer system which stabilizes the pH and thereby maintains the processes and chemical reactions in progress (Bastos et al., 2010).

Table 1. Percentage and values of removal under the samples with HLR of 260 cm.d^{-1}

Parameters	Stabilization Pond Output	Wetland Output	Removal Efficiency (%)
pH	7.4	7.1	-
Color APHA Pt/Co	479	307	35.90
Dissolved Oxygen	2.31	2.61	-
Turbidity (FTU)	58.10	44.73	23.01
Alkalinity (mg CaCO ₃ .L ⁻¹)	237	277	-
Hardness (mg CaCO ₃ .L ⁻¹)	137	193	-
Organic Matter (mg .L ⁻¹ of O ₂ consumed)	31.76	25.33	20.24
Settleable Solids (mL .L ⁻¹)	0.3	0	-
Conductivity (μS)	557	591	-
COD (mg O ₂ .L ⁻¹)	266.33	122.55	53.98
BOD (mg O ₂ .L ⁻¹)	75	61.86	17.52
Nitrogen (mg .L ⁻¹)	31.11	28.33	8.93
Phosphorous (mg .L ⁻¹)	14.35	12.90	10.10
Total Coliforms (UFC .100 mL ⁻¹)	927	139,5	84.95
<i>Escherichia coli</i> (UFC .100 mL ⁻¹)	351	38	89.17

Table 2. Percentage and values of removal under the samples with HLR of 100 cm.d⁻¹

Parameters	Stabilization Pond Output	Wetland Output	Removal Efficiency (%)
pH	7.5	7.0	-
Color APHA Pt/Co	428	230	46.26
Dissolved Oxygen	3.46	4.06	-
Turbidity (FTU)	69.64	26.92	61.34
Alkalinity (mg CaCO ₃ .L ⁻¹)	217	236	-
Hardness (mg CaCO ₃ .L ⁻¹)	118	132	-
Organic Matter (mg .L ⁻¹ of O ₂ consumed)	39.83	17.66	55.66
Settleable Solids (mL .L ⁻¹)	0.2	0	-
Conductivity (μS)	521	566	-
COD (mg O ₂ .L ⁻¹)	275.50	99.83	63.76
BOD (mg O ₂ .L ⁻¹)	112.0	31.55	71.95
Nitrogen (mg .L ⁻¹)	27.42	25.14	8.31

Phosphorous (mg .L⁻¹)	15.51	10.64	31.39
Total Coliforms (UFC .100 mL⁻¹)	321,5	58,5	81.80
<i>Escherichia coli</i> (UFC .100 mL⁻¹)	141,5	20,1	85.79

Concerning the wetlands effluent electrical conductivity, both application rates varied from 521 to 591 μS , below the 661 to 801 μS values obtained by Nogueira et al. (2005), who worked with a vertical flow wetland. Conductivity values were beneath the 700 μS , thus compatible with conditions for cattail establishment, presenting problems only when in a 40 $\mu\text{S}.\text{cm}^{-1}$ environment (Brasil et al., 2005).

When the HLR was decreased, the effectiveness in color and turbidity reduction increased about 46.26% and 61.34%, respectively. This result was due to algae retention, since it can associate with the high occurrence of greenish effluent in the stabilization pond.

4. Discussion

The constructed wetland removed, for maximum efficiency, the organic matter with HLR of 100 $\text{cm}.\text{d}^{-1}$. Suspended, settleable or soluble organic matter removal is generally very high in built wetlands and it occurs by physical and biological processes. These methods include sedimentation, which usually occurs owing to the low flow pace; and filtration, due to the presence of roots and rhizomes and bacteria growth in liquid medium and adhered to biofilm, degrading these pollutants (Calijuri et al., 2009).

Among the parameters that could influence the reduced performance in organic matter removal with 260 $\text{cm}.\text{d}^{-1}$ of HLR, hydrodynamic issues should be considered. A water preferential pathway may have occurred and the contact between effluent and sludge may have been reduced, causing a deficient treatment.

In a HLR of 100 $\text{cm}.\text{d}^{-1}$, COD and BOD values respectively decreased 63.76% and 71.95%, and the reduction was higher with 260 $\text{cm}.\text{d}^{-1}$ of HLR. These results supported the need for HLRs adjustment, which demonstrated that with prolonged retention, the metabolic activity had a high efficiency.

According to Watson et al. (1989) loading rates vary according to each treatment type, project objectives, system types and configurations, as well as performance levels. Surface flow systems typically are loaded less than subsurface systems. HLRs for acid mine drainage systems range from 0.810 to 8,640 $\text{cm}.\text{d}^{-1}$ for example. A rule of thumb of 29.40 $\text{cm}.\text{d}^{-1}$ has only been suggested, but is not representative of every situation.

Chang et al. (2007), evaluated the effect of HLR on the removal of water pollutants. The removal of ammonium, total phosphate, COD and BOD showed minor negative response to an increase in HLR from 20 to 1200 $\text{cm}.\text{d}^{-1}$, while the mass removal rate showed a markedly positive response to HLR. Also, there was no upper limit for mass loading rates when HLR was increased to 120 $\text{cm}.\text{d}^{-1}$. Values up to 541 $\text{cm}.\text{d}^{-1}$ have been reported by Schulz et al. (2003).

According to Otenio et al. (2007), the treatment enabled the effluent release in “Ribeirão das

Antas”, a class 4 river based on CONAMA 357/2005 (Brazil, 2005). Moreover, as shown in Tables 1 and 2, because of the COD and BOD variability of the stabilization pond effluent in different HLRs, the treatment (constructed wetland) improved the physical-chemical and microbiological profile of the effluent to be released.

Tomazela et al. (1999) used water hyacinth (*Eichhornia crassipes*) for final treatment of domestic effluent previously decanted and obtained a COD reduction of 86.87%. Also, Prochaska et al. (2007) decreased by 92% the COD in a final treatment of domestic effluent using a vertical flow with *Phragmites australis*.

With regard to phosphorous, the cattail wetland was able to reduce 31.39% in HLR of 100 cm.d⁻¹. This can be attributed to free phosphorous absorption by *Typha* sp., which had a high growth ratio (leaves and roots).

According to Mazzola et al. (2005), phosphorus removal from the environment occurs through adsorption promoted by decomposing organic matter, insoluble compounds formed with iron and manganese and also by plant absorption. This agrees with Mant et al. (2005), who suggested that phosphorous reacts quickly with a wide variety of surfaces that associate it with a complex reaction series of adsorption and dissociation.

Phosphorous is a basic component that stores and transfers energy to the plant and any metabolic processes occur in its absence. Also, the formation of complexes in phosphorous fixation must be avoided owing to the plant's inability to absorb these compounds. Three parameters contribute to maintain phosphorus availability in the plant: pH establishment in neutral conditions, appropriate soil aeration and permanent incorporation of organic matter. All circumstances allow a humification that increases buffering and enables phosphorous to become available to plants (Sousa et al., 2005).

Prochaska et al. (2007) obtained a phosphorous removal level reaching 64% with *Phragmites australis*, while Mazzola et al. (2007) removed 30% of phosphorous in 72 h treatment using *Typha* sp. in a vertical flow anaerobic reactor.

With regard to the decreased nitrogen values (Tables 1 and 2), the removal was higher in HLR of 260 cm.d⁻¹. The main processes involved in constructed wetlands were: vegetal and microbiological biomass storage, insoluble compounds precipitation and adsorption to the substrate (Calijuri et al., 2009). There is a symbiotic relationship between plants and bacteria through a mechanism that is not yet very clear, which may justify the elements assimilation such as phosphorus and nitrogen by plants and biofilms (Mant et al., 2005).

The removal of total coliforms and *E. coli* was high and greater in 260 cm/d of HLR, reaching 84.95% and 89.17%, respectively (Tables 1 and 2). However, the results using a HLR of 100 cm.d⁻¹ were also elevated and indicate the effectiveness of the system.

In corroboration with these results, Bastos et al. (2010) presented an *Escherichia coli* removal efficiency of 99.96% in a septic tank followed by wetland treatment. Hence, Calijuri et al. (2009) treated a UASB reactor effluent with horizontal flow wetland and they showed a major percentage removal in *E. coli* of 99.72% to 99.99%.

Determinant mechanisms and parameters in coliform removal from constructed wetlands includes temperature, plant roots and biofilm retention, organic matter adsorption, predation, completion and natural death, consequences of biocide effects from macrophytes byproducts and solar radiation. Yet even then, there are no consolidated prediction models of bacterial decay on constructed wetlands (Calijuri et al., 2009).

5. Conclusion

Natural systems are featured technological alternatives in sewage treatment when it comes to sustainability, presenting an improved nutrient cycling; reduced byproducts production; rural landscape fitting; low implementation, operation and repair costs; and efficient sewer disinfection without the addition of chemicals, allowing reutilization of the effluent. These facts demonstrate the necessity of valuing treated sewage.

Under operational conditions tested in this study, the horizontal flow constructed wetland revealed superior capacity and stability when removing COD, BOD, phosphorous and *Escherichia coli*, confirming well known references in this field of study. The treatment was successful in showing a global well performed treatment, according to expectations in the scope of what was previously projected.

Typha sp macrophyte presented a great development and adaptation to the medium conditions where it was inserted, determined by wastewater characteristics.

Results obtained indicate the need for complementary studies, in order to better understand the phenomena and mechanisms associated to nutrient and coliform removal from constructed wetlands. Such data is important to assist in the formulation of improved dimensioning criteria.

Acknowledgement

The authors thank the “Serviço Autônomo de Água e Esgoto (SAAE)”, Bandeirantes-PR, Brazil, for support.

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