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Comparison of Treatment Performance between Constructed Wetlands with Different Substrates

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Abstract

Constructed wetlands are manmade systems that mimic the functions of natural wetlands. The aim of the present study is to examine effect of substrate on organic and nutrient removal in constructed wetlands. With this in mind, we have designed, constructed and operated two pilot-scale horizontal subsurface flow constructed wetlands having two different substrates, gravel and pebble, in our open-air laboratory receiving pre-treated domestic wastewater. The removal efficiency of COD, BOD, TN, and TP was increased from 39 to 69%, 29 to 56%, 23 to 45%, 25 to 75% and 35 to 74%, 33 to 50%, 16 to 31% and 15 to 58% when there was an increase in hydraulic residence time from 2 days to 8 days in the first and second units respectively. It was found that substrate type influenced concentration reduction.

Keywords: *Constructed Wetlands, Organic, Nutrient, Substrate, **H**ydraulic Residence Time.*

1. Introduction

Activated sludge, trickling filter, and rotating biological contractor systems are some of the biological treatment processes that are applicable for domestic wastewater treatment. These systems not only have high operation and investment costs but also difficult to operate and maintain with invariable removal efficiencies. In order to improve the treated wastewater quality, these systems require tertiary treatment process, such as a polishing pond, oxidation pond, or constructed wetland [1, 2].

Wetlands are areas that are wet during part or all of the year. Natural wetlands have long been recognized as capable of reducing the pollution load of the adjacent water bodies. Wetlands may be artificially constructed either to reintroduce a wetland in an area or to treat wastewater, in which case they are also referred to as treatment wetlands. Constructed wetlands are manmade systems that mimic the functions of natural wetlands. Recently, constructed wetlands have gained much interest for treating domestic, industrial and agricultural wastes and are considered as an effective secondary or tertiary treatment method. The wetland is constructed in shallow pits installed with a drain pipe in a bed of pebbles or gravels and sand layers planted with native vegetation. An impermeable membrane is provided at the bottom to prevent percolation of wastewater into the soil or aquifer below. The vegetation may be emergent macrophyte, floating plant or submerged plant species.

As the wastewater flows through the constructed wetland, it is treated by the various processes of sedimentation, filtration, oxidation, reduction, adsorption, precipitation, bacterial metabolism, nitrification, denitrification, and plant uptake [3]. Constructed wetlands have the potential to treat a variety of wastewaters by removing organics, suspended solids, pathogens, nutrients and heavy metals [4]. The use of constructed wetlands has proved to be a reliable solution in developed countries. It is finding wider acceptability among developing countries, as it appears to offer a more economical and ecologically acceptable solution to water pollution management problems. It is especially useful for small communities that cannot afford the conventional high-cost treatment methods.

The basic types of treatment wetlands are free water surface (FWS) wetland and subsurface flow (SSF) wetland. The SSF constructed wetland is further classified into horizontal subsurface flow (HSSF) and vertical subsurface flow (VSSF). The constructed wetland is a natural biological treatment process that is normally used to treat variety of wastewater such as sewage [5, 6, 7, 8], polluted river [9, 10], farmyard runoff [11], landfill leachate [12], swine effluent [13], dairy parlor wastewater [14] and residual dyebath [15].

The main characteristics affect the removal efficiency of constructed wetland are the hydraulic residence time, vegetation type and porous media. The aim of the present study is to examine effect of hydraulic residence time on organic and nutrient removal in constructed wetlands. With this in mind, we have designed, constructed and operated two pilot-scale horizontal subsurface flow constructed wetlands having two different substrates in our open-air laboratory

2. Materials and Methods

The study site is located in the SRM University (latitude 12°42' N, longitudinal 80° 02' E) campus, Kattankulathur, Southern part of India. The climate of the area is tropical with an average annual rainfall of 1330 mm. The mean minimum and maximum temperatures during the study period were 19°C and 42°C respectively.

2.1 Materials and Methods

Two horizontal subsurface flow constructed wetland units (0.6 x 0.41 x 0.3) m size were designed and built at our open-air laboratory. Two different porous media gravel and pebble used a substrate.

These two units were operated in batch mode receiving pretreated campus domestic wastewater. The inlet chamber (0.41x0.12x0.27) m size and outlet chamber (0.12x0.41x0.27) m size were formed by providing fiber sheets as partitions. In the inlet chamber, an opening was provided at the bottom to allow wastewater into the treatment zone. To collect treated wastewater, an opening or a valve guarded by net filter was provided.

One of them filled with a substrate of bottom layer gravel over sand layer coded as PAGS (Fig. 1). The second one was filled with a substrate of bottom layer pebbles over sand layer coded as PAPS (Fig. 2). These two constructed wetland units have a free board of 0.09 m.

The two units were established with an emergent plant species *Phragmites australis* (Fig.3) in two different substrates.

Fig. 1 Constructed wetland pilot unit PAGS

Fig. 2 Constructed wetland pilot unit PAPS

Fig.3. Phragmites australis

3. Results and Discussion

3.1 Influent wastewater characterization

The influent wastewater to the small-scale units was characterized over a six month period (Table 1).

Table 1. Properties of influent wastewater

Sl. No.	*Parameter*	*Concentrations in mg/l*		
		Min	*Max*	*Mean*
1.	BOD	101	3390	643.2308
2.	COD	315	1823	674.9231
3.	TN	2.28	196	60.37231
4.	TP	0.06	32.6	14.01385

The parameters Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Nitrogen (TN) and Total Phosphorus (TP) were determined based on standard methods [16]. (APHA, 1995). The analysis were done immediately after sample collection, otherwise were properly stored.

It was found that there was high concentration of BOD, TN in the samples during the weekdays when the students strength if high. COD is also high probably because of wastewater from the chemistry labs. Normally, municipal wastewater has lesser COD but in the college campus it becomes an important parameter to be treated. Low values of BOD, COD occur during heavy rainfall which indicates clear dilution effect. The concentration of BOD, TN tends to decrease during vacation and increase once university had reopened.

3.2 Results of Pilot Scale Units

The units were filled with water for a period of one month until well establishment of wetland plant species. The pretreated campus domestic wastewater was applied after one month. The systems were operated under four different hydraulic conditions by varying hydraulic residence time as 2, 4, 6 and 8 days (Table 2).

The treatment efficiency was calculated as percent removal R for each parameter which was calculated by the following equation where C_i and C_e are the influent and effluent concentrations in mg/l.

$$R = [1-(C_e/C_i)]x100 \quad (1)$$

Table 2. Results of pilot scale units

Parameter	***Inlet***	***Outlet at HRT 2 Days***	
		PAGS	***PAPS***
COD	174	105	112
BOD	48	34	32
TN	0.30	0.23	0.25
TP	2.25	1.68	1.91
Parameter	***Inlet***	***Outlet at HRT 4 Days***	
		PAGS	***PAPS***
COD	176	98	101
BOD	42	33	31
TN	0.28	0.26	0.27
TP	2.22	1.59	1.42
Parameter	***Inlet***	***Outlet at HRT 6 Days***	
		PAGS	***PAPS***
COD	179	64	78
BOD	39	22	19
TN	0.32	0.22	0.22
TP	2.27	1.38	1.22
Parameter	***Inlet***	***Outlet at HRT 8 Days***	
		PAGS	***PAPS***
COD	161	49	41
BOD	36	16	18
TN	0.22	0.12	0.15
TP	2.19	0.55	0.92

3.3 Organic and Nutrient Removal in PAGS

The COD removal efficiencies were 39, 44, 64, and 69% for hydraulic residence time of 2, 4, 6, 8 days, respectively. The BOD removal efficiencies were 29, 21, 43, and 56% for hydraulic residence time of 2, 4, 6, 8 days, respectively. The TN removal efficiencies were 23, 7, 31, and 45% for HRT of 2, 4, 6, 8 days, respectively. The TP removal efficiencies were 25, 28, 39, and 75% for hydraulic residence time of 2, 4, 6, 8 days, respectively (Fig. 4).

There was a slight difference (5%) in removal between HRT of 2 days and 4 days. As the hydraulic residence time increased to 6 days, there was 19% increase in COD removal when compared to COD removal at 4 days. The COD removal was doubled when there was an increase in HRT from 4 days to 8 days. BOD removal dynamics slightly differs from COD removal dynamics. There was 8% decrease in efficiency when hydraulic residence time increased from 2 days to 4 days. The removal efficiency doubled at 6 days hydraulic residence time and it further increased to 56% at 8 days hydraulic residence time.

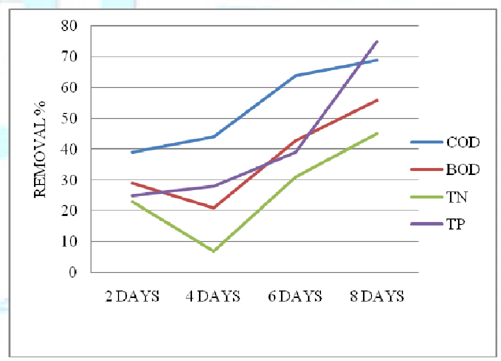

Fig. 4. Organic and nutrient removal in PAGS

TN removal dynamics follows more or less the BOD removal dynamics. There was 2/3 decrease in TN removal efficiency when HRT increased from 2 days to 4 days and 1/3 increase at 6 days hydraulic residence time. The TN removal efficiency further increased to 45% at 8 days hydraulic residence time. There was only 3% increase in TP removal efficiency when there was an increase in hydraulic residence time from 2 days to 4 days. And there was 11% increase at 6 days HRT compared to 4 days hydraulic residence time. But the TP removal efficiency reached 75% at 8 days hydraulic residence time.

Similar study to determine the effectiveness of constructed wetlands to treat tertiary effluent wastewater generated from Paşaköy Advanced Biological Wastewater Treatment Plant [17] showed that TP removal efficiency (60%) might be due to use of gravel substrate. Reference [18] indicate that TP removal rates increased when the hydraulic residence time was prolonged. But, increasing hydraulic residence time from 2 days to 4 days did not improve the efficiency in terms of N and P removal. Similar results was exhibited [19] stating that doubling the reaction.

3.4 Organic and Nutrient Removal in PAPS

The COD removal efficiencies were 35, 42, 55, and 74% for hydraulic residence time of 2, 4, 6, 8 days, respectively. The BOD removal efficiencies were 33, 26, 51, and 50% for hydraulic residence time of 2, 4, 6, 8 days, respectively. The TN removal efficiencies were 16, 3, 30, and 31% for hydraulic residence time of 2, 4, 6, 8 days, respectively. The TP removal efficiencies were 15, 36, 46, and 58% for hydraulic residence time of 2, 4, 6, 8 days, respectively (Fig. 5).

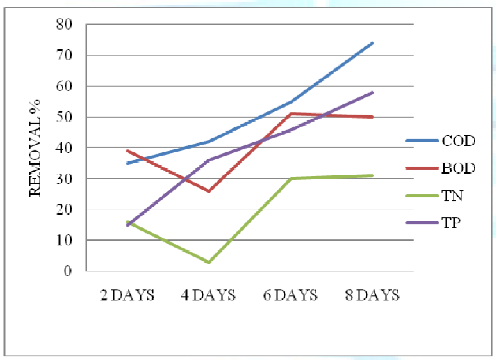

Fig. 5. Organic and nutrient removal in PAPS

The COD removal efficiency gradually increased with an increase in hydraulic residence time irrespective of change in influent COD and resulted in 74% COD removal efficiency at 8 days hydraulic residence time. As the hydraulic residence time increased from 2 days to 4 days, the BOD removal decreased by 7% and increased to 51% at 6 days hydraulic residence time and remained almost same at 8 days hydraulic residence time. The pebbles have smaller media size than gravel. The microbial bio films on the media are responsible for the reduction in BOD by formation of a coat on the media. The TN removal efficiency reduced at 4 days hydraulic residence time when compared to 2 days hydraulic residence time and there was only 1% change in removal efficiency between 6 days and 8 days HRT. When there was an increase in hydraulic residence time, the TP removal efficiency gradually increased and reached 58% at 8 days hydraulic residence time.

4. Conclusions

The influent wastewater is rich in orgnic matter and contains high COD and BOD. Nutrients are present in source wastewater with high variability. Substrate type influenced concentration reduction. The constructed wetland unit filled with gravel substrate planted with *Phragmites australis* was better in the removal of COD and BOD. The constructed wetland unit filled with pebbles substrate planted with *Phragmites australis* was efficient in TP removal. A 6–day hydraulic retention time was found to be sufficient for treatment of domestic wastewater by the experimental two pilot-scale constructed wetlands.

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