A COMPARISON OF VERTICAL SUB-SURFACE FLOW AND HORIZONTAL SUB-SURFACE FLOW CONSTRUCTED WETLAND MESOCOSMS IN TROPICS

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ABSTRACT

Constructed wetland systems for wastewater treatment where water, plants and microorganisms interact to improve the quality of water have become a growing technology in many parts of the world, due to their advantages over the conventional systems. However, these systems are not yet widely spread in developing countries due to lack of information and expertise, even though the pollution control has become a major challenge in these countries.

This study compares the purification performances of laboratory scale vertical subsurface flow (VSSF) and horizontal subsurface flow (HSSF) constructed wetland mesocosms at tropical conditions, with an aim to provide future design parameters at pilot scale. Four wetland mesocosms of size 1.4 m x 0.5 m x 0.5 m (L x W x H) were constructed and two of them arranged as VSSF system while the other two arranged as HSSF system. An emergent macrophyte specie; cattail (*Typha angustifolia*), gravel media (size 10 – 20 mm) and synthetic wastewater were used in this study at 10 cm/day hydraulic loading rate (HLR) or.2 days hydraulic retention time (HRT). Sampling was carried out from both influent and effluents of each wetland system over a five month period, and wastewater quality parameters such as the BOD_5, TSS, NH_4^+-N, NO_3^--N, PO_4^{3-}, FCU, TCU, pH, Dissolved Oxygen (DO) and Electrical Conductivity (EC) were analyzed. Results prove that both systems are capable in reducing pollutant loads in wastewater effectively. However, VSSF systems perform better than HSSF systems in reducing BOD_5, FCU, TCU and NH_4-N showing average percentage removals of 89.8%, 96.6%, 97.3%, .84.6% and 87.1%, 93.1%, 96.9, 73.3% in VSSF and HSSF systems respectively.

***Key words*:** Constructed wetlands, Vertical Subsurface Flow, Horizontal Subsurface Flow, mesocosms, tropics, synthetic wastewater, Hydraulic Retention Time, Hydraulic Loading Rate

1. INTRODUCTION

There is a growing demand for the development of appropriate and affordable wastewater management technologies particularly in developing countries like Sri Lanka to reduce the pollution of fresh water resources from unacceptable ways of wastewater discharges. Compared to conventional wastewater treatment technologies, constructed wetlands offer low cost, easy to operate, efficient and robust treatment [1] and have become a widely use technology recently in many parts of the world with good results [2]. As the treatment performance of constructed wetlands is expected to be higher in tropical regions due to the higher temperatures and associated higher bacterial activities [3], they are currently being studied as a wastewater treatment technology in tropical countries for many kinds of wastewaters including agricultural runoff, landfill leachate, mine drainage, sludge dewatering and municipal wastewaters from small communities [1].

Contaminated waters flowing through constructed wetlands are cleansed by physical, chemical and biological activities [4]. However, the treatment performance of a constructed wetland depends on various factors like inflow pollutant characteristics, wetland design, hydraulic and nutrient loading rates, climatic variations and essentially the required effluent characteristics [5]. In addition, it has to be designed specifically to suit the local climatic conditions to take advantages of unique wetland properties to accomplish direct objectives [6].

Basically there are two types of constructed wetlands; sub-surface flow (SSF) wetlands which maintain the water level below the filter media and free water surface (FWS) wetlands which expose the water surface to the atmosphere. Distinctive advantages of SSF systems over FWS wetlands include, lack of odour problems, lack of mosquito breeding and other insect vector problems and the minimal exposure of contact with wastewaters to general public [7]. SSF constructed wetlands can be further divided according to the flow direction as horizontal SSF (HSSF) and vertical SSF (VSSF) wetlands. It is expected to have a much greater oxygen transfer capacity in VSSF systems over the HSSF systems and hence VSSF can achieve very good results in removing organic material and to enhance the nitrification [8].

The objective of this study is to evaluate the pollutant removal performance of sub-surface flow wetland systems (HSSF & VSSF) at tropical condition using synthetic wastewater at laboratory scale with cattail (*Typha angustifolia)* as wetland vegetation and gravel (10 – 20 mm) as the substrate media at a constant HLR.

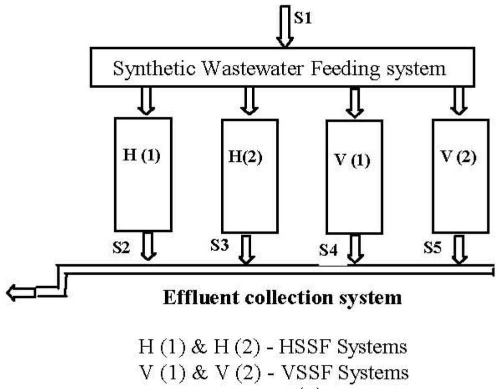
2. MATERIALS AND METHODS

Wetland Mesocosm Arrangement

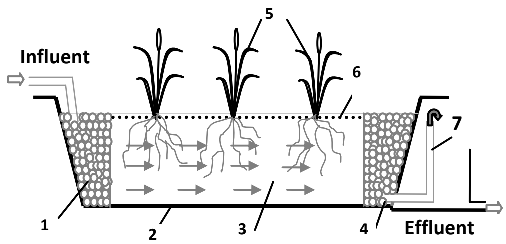
As illustrated in Figure 1 (a), four wetland mesocosms of size 1.4 m x 0.5 m x 0.6 m were constructed by wood and a thin fiberglass coating was applied to prevent water leaking. After that, two of them have arranged as HSSF wetland system (Figure 1(b)) and the other two were arranged as VSSF wetland system (Figure 1 (c)). To facilitate easy distribution and collection of wastewaters in each system, the inlet and outlet zones of HSSF systems and the drain field of VSSF systems were filled with 30 – 50 mm gravel. Also, 10 – 20 mm gravel was used as the wetland media in this study. In addition, 10 cm deep surface layer of soil (< 5 mm particle size) was laid on top of the wetland media to support the vegetation. A nylon mesh is used between the soil and gravel layers to prevent sinking of soil into the gravel layer. Then each system was planted with eight cattail (*typha angustifolia*) rhizomes of 30 cm long containing at least two nodes. Soon after planting, the systems were kept at saturation condition for four weeks until they grow properly. Thereafter the systems were allowed to run with tap water for another two weeks, and then the each system was fed with synthetic wastewater through a distribution system for about five months at 10 cm/day HLR (2 days HRT). The flow adjustment was monitored daily to minimize errors.

Synthetic Wastewater preparation

Wastewater preparation was done artificially by adding 6 g of Urea, 20 g of Sugar, 1 g of Ammonium Chloride, 10 mg of Potassium Hydrogen Phosphate, 100 mL of Fertilizer solution and 650 mL of sludge in 250 L of tap water. The sludge was collected from municipal gulley suckers used to empty septic tanks in Kandy region, and stored in a refrigerator below 4^0C for about two weeks. After adding all the ingredients in 250 L tap water, it was mixed thoroughly and pumped into an overhead tank. Then, each mesocosm was supplied wastewater from this tank evenly through the distribution system.



(a)



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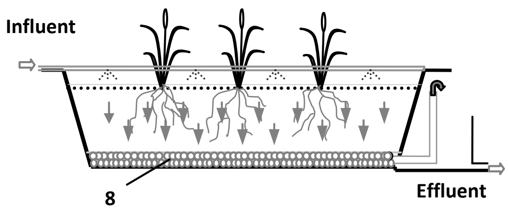

(c)

Figure 1; (a). Wetland mesocosm arrangement [S1 – S5 are sampling points], (b). Schematic diagram of a HSSF wetland system, (c). Schematic diagram of a VSSF wetland system, 1. Inlet zone, 2. Impermeable barrier, 3. Wetland media, 4. Outlet zone, 5. Wetland Vegetation, 6. Water level, 7. Swivel pipe, 8. Drain field.

Sampling and Analysis of wastewater

Influent [S1] and effluent [S2 to S5] samples from each wetland mesocosm were collected in 500 mL cleaned plastic bottles and immediately transferred into the environmental laboratory of the Department of Civil Engineering, University of Peradeniya. Wastewater quality parameters such as pH, EC and DO were measured using the pH meter, EC meter and DO meter respectively. FCU and TCU counts were estimated by using the membrane filtration technique. BOD_5, TSS, NH_4^+-N, NO_3^--N and PO_4^{3-} were also determined by following Standard Methods of water and wastewater analysis [9]. Then the removal efficiency (RE) of each parameter was calculated using equation (1).

$$RE = \frac{C_i - C_o}{C_i} \times 100\% \text{ ....(1)}$$

Where, C_i and C_o denotes the influent and effluent concentrations of wastewater parameters respectively.

3. RESULTS AND DISCUSSION

Table 1 shows the average wastewater characteristics at the influent (synthetic wastewater) and at effluents of VSSF and HSSF systems over the study period. From this table it is noted that, there is a high variation in influent wastewater characteristics together with a very high variation in FCU and TCU counts.

Table 1: Average wastewater characteristics of the influent (synthetic wastewater) and effluents of VSSF and HSSF wetland systems.

Wastewater Parameter	Influent	Effluents	
		VSSF	HSSF
BOD_5 (mg/L)	28.8 ± 4.0	2.9 ± 1.4	3.6 ± 2.5
FCU/ 100mL	$3.8*10^5$ ± $3.2*10^5$	$2.9*10^3$ ± $3.4*10^3$	$6.5*10^3$ ± $7.1*10^3$
TCU/ 100mL	$6.8*10^5$ ± $6.7*10^5$	$5.2*10^3$ ± $5.9*10^3$	$6.1*10^3$ ± $7.5*10^3$
NO_3^-- N (mg/L)	4.3 ± 2.5	3.1 ± 0.9	1.0 ± 0.9
NH_4^+ - N (mg/L)	17.5 ± 4.9	2.5 ± 2.7	4.3 ± 4.4
PO_4^{3-} (mg/L)	2.4 ± 1.4	0.7 ± 0.8	0.5 ± 0.5
TSS (mg/L)	164.6 ± 61.3	42.8 ± 32.5	39.1 ± 31.0
pH	7.1 ± 0.4	7.0 ± 0.3	7.0 ± 0.2
EC (µs)	248.6 ± 49.4	299.2 ± 50.2	254.3 ± 29.6
DO (mg/L)	4.0 ± 1.8	5.6 ± 1.8	5.5 ± 1.7

This might be due to the fast growing rates of micro-organisms and the type of sludge used to prepare the synthetic wastewater. However, it can be seen that both treatment options are capable to improve the quality of wastewater, including two log removals of TCU and FCU counts.

Table 2 summarizes the average percentage removal efficiencies of the measured wastewater parameters in both HSSF and VSSF wetland systems over the study period. From Table 2, it is easily seen that the VSSF system is more effective in removing or reducing BOD_5, FCU, TCU and NH_4^+ from wastewater, while HSSF system is more effective in TSS, NO_3^-- N and PO_4^{3-} reduction.

Table 2: Average percentage removal efficiencies of wastewater parameters in VSSF and HSSF wetland systems.

Wastewater parameter	VSSF	HSSF
BOD_5 (mg/L)	89.8 ± 5.0	87.1± 9.2
FCU/ 100ml	96.6 ± 2.8	93.1± 5.7

TCU/ 100ml	97.3 ± 1.9	96.9 ± 3.1
TSS (mg/L)	70.1 ± 13.6	72.7 ± 13.6
NO_3^-- N (mg/L)	57.2 ± 22.6	71.0 ± 18.4
NH_4^+ (mg/L)	84.6 ± 12.9	73.3 ± 21.4
PO_4^{3-} (mg/L)	64.9 ± 31.3	73.4 ± 21.6

Results show that the most efficient BOD_5 removal is occurred in the VSSF system in this study. For better reduction of organic matter in a wetland system, there should be a well grown bio-film and sufficient DO and nutrients. The major oxygen source in a subsurface wetland system is the oxygen transmitted by wetland vegetation to the root zone. However, in VSSF system as wastewater is applied from the top by means of a small sprinkler arrangement, and hence there is a possibility to contact and diffuse oxygen to the wastewater. But in HSSF system, wastewater is directly poured into the inlet zone, and hence there is less or no contact with air. This could be the reason for the higher BOD_5 removal in the VSSF system than in HSSF system.

Coliform removal in a wetland system happens by natural die-off, predation, sedimentation, filtration, adsorption and UV radiation. It is observed that high percentage removal of FCU and TCU also achieved in the VSSF system. One of the reasons for this could be the possibility of die off due to UV radiation, associated with the method of wastewater application in the VSSF system. However, as a whole both systems are capable in removing more than 93% of both FCU and TCU.

In contrast to previous studies, better TSS removal is obtained in HSSF system in this study and it is difficult to explain at this stage.

Nitrogen compound removal in a wetland is occurred mainly by biological processes. These processes include ammonification, nitrification, denitrification, nitrogen fixation and nitrogen assimilation [10]. Out of which, nitrification and denitrification are the principal processes for nitrogen reduction in wetlands. Nitrification is highly dependent on the availability of DO in the system while denitrification occurs when anaerobic and anoxic conditions exist in a wetland. Results show that, percentage removal of NH_4^+ is high in VSSF system. Reason could be the higher nitrification rates in VSSF system due to more oxygen availability than in the HSSF system. On the other hand it is observed that the NO_3^-- N removal is high in HSSF system than in VSSF system. This could be due to the less denitrification rates in the VSSF system.

PO_4^{3-} removal in a wetland is associated with the adsorption to wetland media, precipitation with metals (Fe, Al, Mn), bacterial synthesis and plant or algal uptake. Therefore, PO_4^{3-} removal could be enhanced by using a substrate which contains more Fe, Al or Mn metals. However, results of this study show the higher removal of PO_4^{3-} is achieved in the HSSF system. It could be due to the higher adsorption capacity in HSSF system, as it has to flow though the wetland media for comparatively longer length than in VSSF system.

4. CONCLUSION

Experimental results show that subsurface constructed wetland systems provide a viable option for wastewater treatment in tropical regions effectively at 2 days hydraulic retention time. However, compared to HSSF system, VSSF system shows better overall performance in removing pollutants except NO_3^-- N and PO_4^{3-} removal. Therefore, the VSSF effluent should be improved to enhance NO_3^-- N and PO_4^{3-} removal.

5. ACKNOWLEDGEMENTS

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