Wastewater Treatment for Pollution Control

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Abstract

Performance of a Dynamic Roughing Filter (DRF) coupled with a Horizontal Subsurface Flow Constructed Wetland (HSSFCW) in the treatment of a wastewater was studied in tropical conditions. The results show that in HSSFCW planted with *Cyperus papyrus* and *Phragmites mauritianus* in series, the removal rates of TDS, TSS, COD and BOD_5 were 72.07%, 80.01%, 81.22% and 78.37%, respectively, while in the second HSSFCW planted with *Cyperus papyrus* only, the removal rates were 71.00%, 79.00%, 73.76 and 75.78%, respectively. HSSFCW planted with mixed macrophytes, performed better than a HSSFCW planted with single macrophyte. This was attributed to synergetic effects of *Cyperus* horizontal roots and Phragmites vertical plant roots weaved and entangled in cell 1 providing a good filter mat and a better bacterial attachment. Thus the use of two macrophytes planted in series was recognized to be responsible for better performance of HSSFCW cell 1 in pollutants removal from wastewater.

Key words: Horizontal Subsurface Flow Constructed Wetland (HSSFCW), Biochemical Oxygen Demand (BOD_5), Dissolved Oxygen (DO), and Macrophytes.

Introduction

The use of Constructed Wetlands (CW) is now recognised as an accepted low cost eco-technology that is especially beneficial to small communities that cannot afford expensive conventional treatment systems [1-4]. Dynamic Roughing Filter (DRF) used for wastewater filtration and sedimentation reduce greatly the total suspended solids. DRF coupled with a Horizontal Subsurface Flow Constructed Wetland (HSSFCW) in the treatment of a wastewater can efficiently remove the suspended organic matter from wastewater. The available experiences with DRF applications in drinking water treatment have indicated that these systems have potential for being used in combination with subsurface flow constructed wetlands for upgrading waste stabilization ponds effluents. [5, 6]

Kigali Municipal wastewater was considered to have huge pollutants that contaminate Nyabugogo River leading to eutrophication of the water. A model of wastewater was constituted in the laboratory to attempt the approach of efficient removal of pollutants from the foresaid municipal wastewater. This paper reports on the study done on DRF-HSSFCW system for the treatment of municipal wastewaters. Aquatic plants in series were used to study the synergism of two macrophytes in comparison to one single plant in tropical conditions.

Materials and Methods

Experimental set up:

Our experiments were done in engineered plant called DRF-HSSFCW system constructed near the University of Dar es Salaam Waste Stabilisation Ponds (WSPs). The DRF unit had a length of 2.2m, a width of 0.7m, and a depth of 0.6m. It was filled with coarse gravel (18-30mm of particle size) in bottom layer of 10cm of thickness, middle gravel size (12-18mm) in the middle layer of 20cm of thickness, and finer gravel size (8-12mm) in top layer of 30cm of thickness. The DRF was operated at 0.41m/day of filtration rate.

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Each HSSFCW cell measuring 2m x 0.60m x 0.60m was filled with gravel as described in DRF system and the bed slope of HSSFCW cells was 1%. Wastewaters were mixed in a ratio of 8:1:1 for domestic wastewater, abattoir wastewater and soft drinks wastewater, respectively. The mixed wastewater was first treated in the DRF system. The effluent from the DRF was directed to the HSSFCW system. The schematic layout of DRF-HSSFCW units is shown in Figure 1.

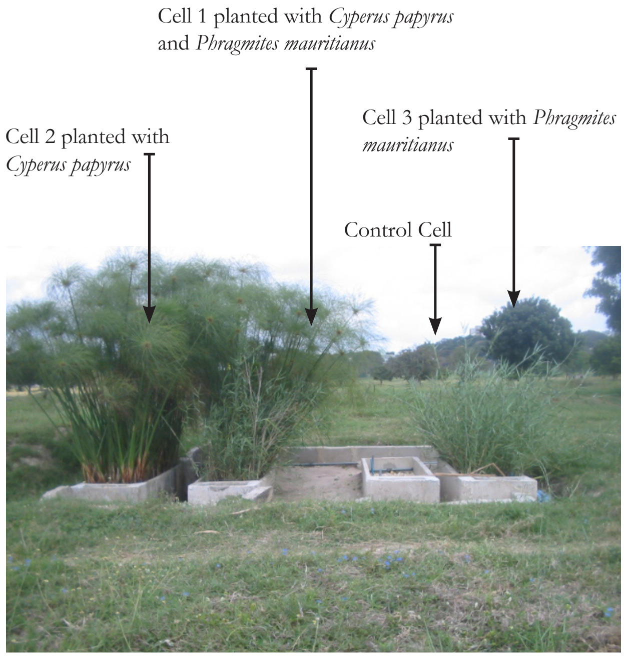


Figure 1: Plan Layout for Mixed Wastewater Treatment Plant

Figure 1 shows that the treatment plant promotes good environmental health conditions in that the wastewater is in subsurface layer, no bad smell or breeding of insects that transmit diseases to human and animals.

Preliminary Activities and Data Collection:

Daily sampling was done, i.e. 112 samples were collected during 28 days. Flow measurements were determined at the inlet (inflow) and outlet (outflow) of each HSSFCW cell. The flow rates were adjusted manually and measured using graduated cylinder (or beaker) and a stopwatch. Samples for determination of physical and chemical parameters were collected at the inlet, and outlet of each cell. The pH and temperature were determined in-situ by Metrohom pH meter model 704, and daily and hourly Dissolved oxygen(DO) concentration was measured using YSI DO meter model 50B. BOD_5 was measured using OxiTop® model. Total suspended solids and chemical oxygen demand were determined in accordance with standard method. [1]

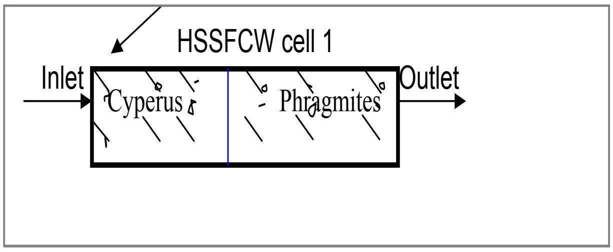


Figure 2: Cell 1 planted with *Cyperus papyrus* and *Phragmites mauritianus* in series

Results and Discussions

From Table 1, it is obvious that pre-treatment by DRF of mixed wastewater prior to reaching HSSFCW has a great impact on the performance of the HSSFCW system. DRF equalizes the flow and waste strength providing a uniform waste feed to HSSFCW. This is a very useful buffering capacity to the system. The reduction of Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Chemical Oxygen Demand (COD) and BOD_5 was significantly exhibited by DRF system. In DRF system, the removal rates of TDS, TSS, COD and BOD_5 were 53.24%, 65.00%, 53.00% and 64.00%, respectively. Thus the influence of the DRF on TDS, TSS, COD and BOD_5 removal efficiencies was evident.
The reduction of TDS and TSS was due to filtration rate set at 0.41m/day, which enhanced sedimentation and filtration processes in DRF system. After this pre-treatment, DRF effluent was directed to the HSSFCW system, which had significantly removed organic matter (see Table 2).

The results shown in Table 2 indicate that HSSFCW cell 1 had better removal efficiencies of TDS, TSS, COD and BOD_5 concentrations by 72.07%, 80.01%, 81.22%, and 78.37%, respectively than cell 2. This may be attributed to filtration process by weaved and entangled roots of two macrophytes planted in series. However, BOD_5 removal in constructed wetlands is generally considered to be principally a microbial processes specially executed by attached bacteria.[7, 8] The DO supplied by plant through photosynthesis process enhanced the oxidation of organic carbon in rhizosphere. [3, 9, 10]

Therefore, both aerobic and anaerobic processes influenced organic matter removal in HSSFCW cells. Removal efficiencies of TDS, TSS, COD and BOD_5 are shown in Table 2. Similar removal rates of the parameters shown in Table 2 have been reported elsewhere to range between 50% and 90%.[1, 5, 11]

Table 1: Performance of HSSFCW cells planted with macrophytes treating mixed wastewaters (mean values)

Parameters	Inflow to DRF from tank	Effluent from DRF to Cells	Cell 1 outflow	Cell 2 outflow
TDS [mg/l]	790.00 ± 160.94	369.42 ± 71.05	103.17 ± 5.76	105.25 ± 7.03
TSS [mg/l]	416.21 ± 61.09	132.17 ± 21.25	28.42 ± 3.88	29.46 ± 4.17
COD [mg/l]	450.60 ± 73.88	211.90 ± 32.68	39.80 ± 6.39	55.60 ± 4.85
BOD_5 [mg/l]	347.22 ± 23.51	128.88 ± 4.93	27.88 ± 6.66	31.22 ± 7.22

Table 2: Removal efficiencies in HSSFCW cells planted with macrophytes treating mixed wastewaters

Parameters	Cell 1 removal rate [%]	Cell 2 removal rate [%]
TDS [mg/l]	72.07	71.00
TSS [mg/l]	80.01	79.00
COD [mg/l]	81.22	73.76
BOD_5 [mg/l]	78.37	75.78

Concerning total dissolved solids**,** Figure 3 shows the daily variation of total dissolved solids (TDS) in DRF-HSSFCW system. The average values of TDS in DRF system were 790 ± 160.94 mg/l at the inlet and 369.42 mg/l at the outlet while the mean values of TDS effluents from the HSSFCW cells 1 and 2 were 103.17 ± 5.76 mg/l and 105 ± 7.03 mg/l respectively (Table 1). The reduction of TDS by DRF and HSSFCW was evident. In DRF, the removal of TDS was due to the physical process of settling and filtration and chemical precipitation and adsorption. In HSSFCW, plants are reported to have a positive effect on TDS removal by reducing water velocity and by encouraging filtration and biodegradation in the root network. [12]

This may be attributed to the presence of weaved and entangled roots, which enhanced the filtration process of mixed wastewater in cell 1 than in cell 2. The removal efficiencies of TDS in cells 1 and 2 were 72.07% and 71.00%, respectively. Cell 1 exhibited a better removal of TDS than cell 2.

Concerning Total Suspended Solids:

The reduction of TSS concentration was consistently exhibited by DRF. Overall DRF removed 65.0% of the influent from mixing tank. Similar results were reported elsewhere to range between 40% and 70%.[5, 6]

The effluent from DRF was directed to the HSSFCW system and a higher reduction in concentration of TSS was observed in cells 1 than in cell 2. The removal rates for cell 1 and cell 2 were respectively 80.01% and 79.00%. Cell 1 planted with *Cyperus* and *Phragmites* in series performed better than mono-plant cell 2. This was due to weaved and entangled roots of cell 1, which enhanced the filtration process of TSS from the DRF effluent (see Figure 4).

Figure 4 shows that the mean value of TSS effluent from cell 1 was 28.42 ± 3.88 mg/l while the TSS effluent of cell 2 had a mean value of 29.46 ± 4.17 mg/l. The root mat of cell 1 helps settling and better filtration of suspended solids hence good reduction in total suspended solids of the effluent. Attachment and accumulation of solids in the bed medium can be also considered to be the main process, which lead to the removal of TSS in the HSSFCW system. It has been also reported that gravitational settling and mechanical particulate filtration occurred when wastewater passes through substrate material (gravel) to the other solids removal processes in Horizontal Subsurface Constructed Wetlands.

Concerning COD, Figure 5 shows that DRF system reduces the COD concentration by 53.00%. The effluent from DRF was directed to the HSSFCW cells 1 and 2. Cell 1 has reduced the COD concentration by 81.22% while cell 2 had a COD removal rate of 73.76%. The average value of COD effluent from cell 1 was 39.80 ± 6.39 mg/l while cell 2 had a mean value of 55.60 ± 4.85 mg/l only at the outlet. It is clear that Cell 1 planted with two plants in series performed better than cell 2 planted with one. Both anaerobic and aerobic degradations of organic matter were most likely responsible for COD removal in the HSSFCW system. But in cell 1, the translocation of oxygen through the root system may have enhanced the aerobic degradation. This might be due the higher oxygen supply and the bio-film growth on root zone of two plants. [4, 5, 12-15] Also, the processes of sorption (by gravel bed), precipitation and uptake (by microorganisms and plants) appear to have occurred in the HSSFCW system.

Concerning biochemical oxygen demand, Figure 6 shows the performance of the HSSFCW cells planted with macrophytes. A better BOD_5 removal is exhibited by cell 1. The average value of BOD_5 concentration at the outlet of cell 1 was 27.88 ± 6.66 mg/l while cell 2 had 31.22 ± 7.22 mg/l. The BOD_5 effluent from cell 1 has a lower concentration than 30 mg/l, which is the maximum recommended BOD_5 value for effluent disposal in the receiving water bodies. [16, 17] The relatively high average temperature in Dar es Salaam (27.8^{o}C) throughout the day could have accelerated the biodegradation process in HSSFCW system. Cell 1 had a BOD_5 removal rate of 78.37% while cell 2 removed only 75.78% of BOD_5 from mixed wastewater. The BOD_5 removal rates from domestic sewage in HSSFCW have been reported by several researchers to range between 60% and 90%. [1, 4, 15]

The basic treatment mechanisms include filtration, biodegradation (microbial interactions with organic matter as BOD_5), chemical precipitation and adsorption as well as uptake by vegetation and microorganisms in the HSSFCW system. [8, 12] Biofilm development appeared to be enhanced on small gravel particles and entangled roots because there is an increase in surface area. Thus, thick weaved roots mat of HSSFCW cell 1 planted with two macrophytes in series provides a conducive microenvironment allowing various microbial processes to take place.

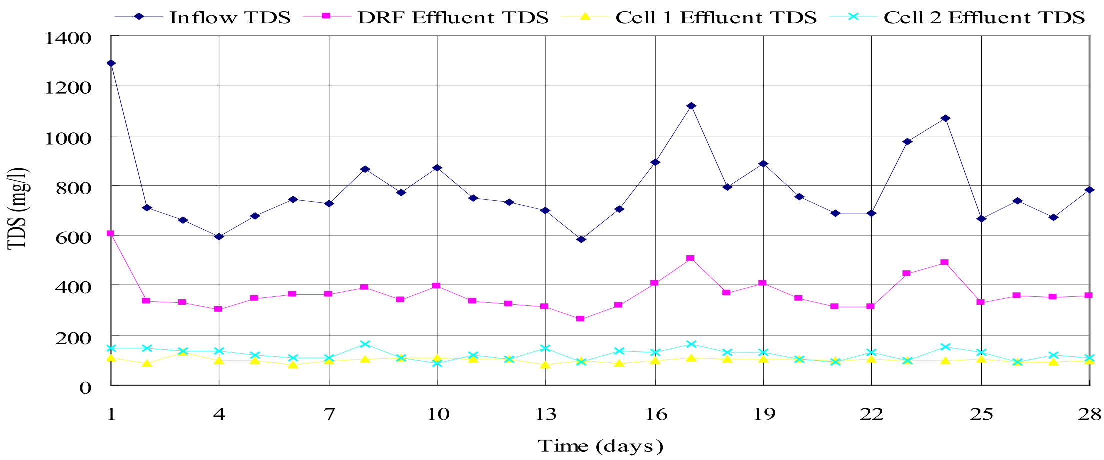


Figure 3. Daily Variation of total dissolved solids in DRF and HSSFCW cells

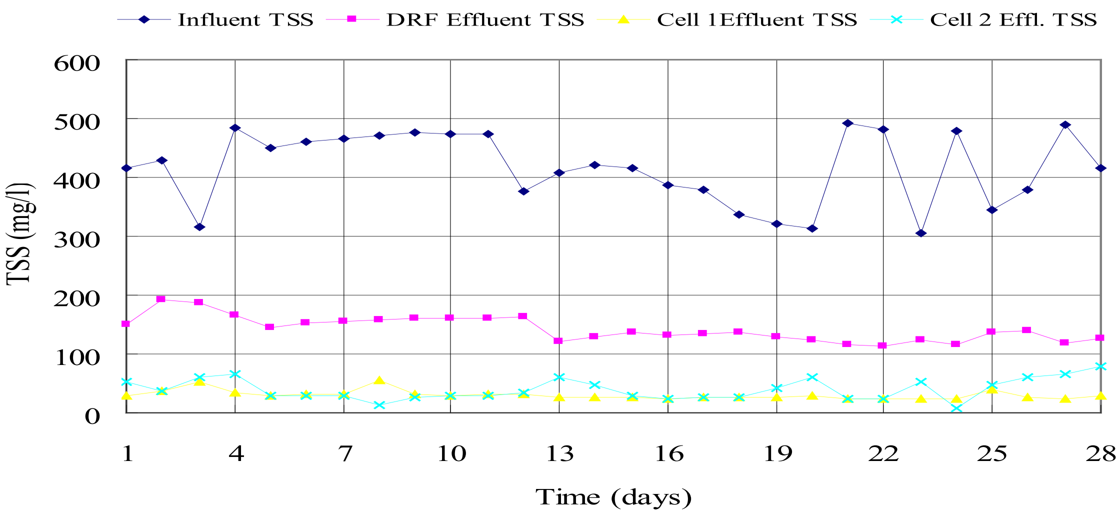


Figure 4. Daily variation of inflow and outflow TSS in DRF and HSSFCW cells

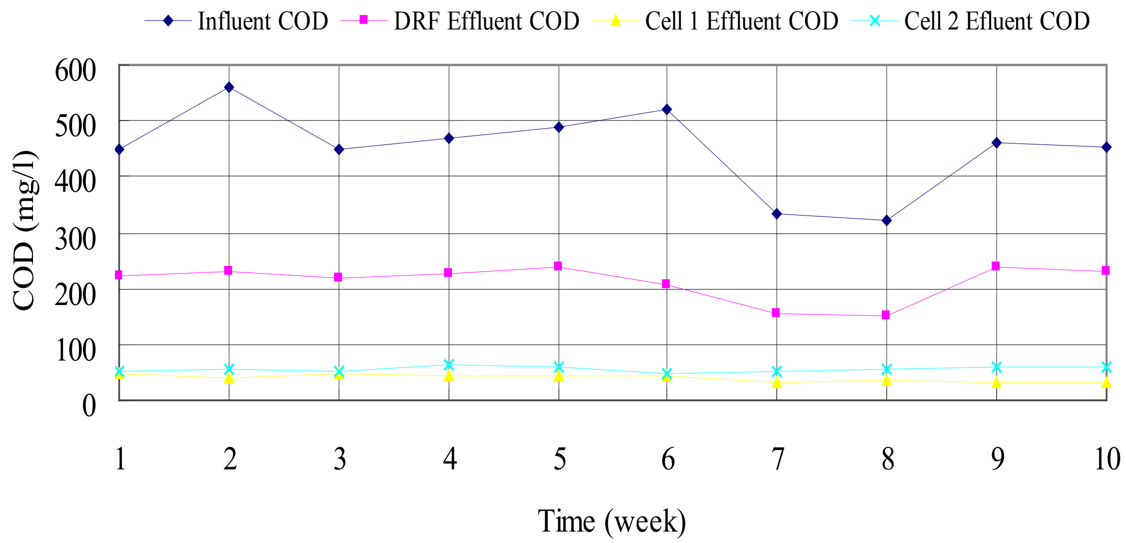


Figure 5. Weeklyvariation of chemical oxygen demand in HSSFCW cells

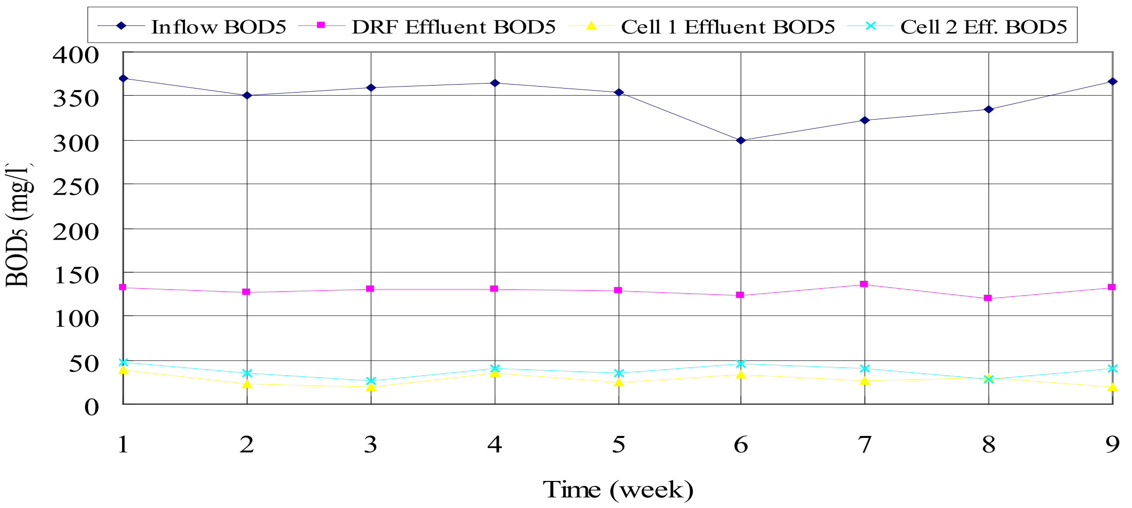
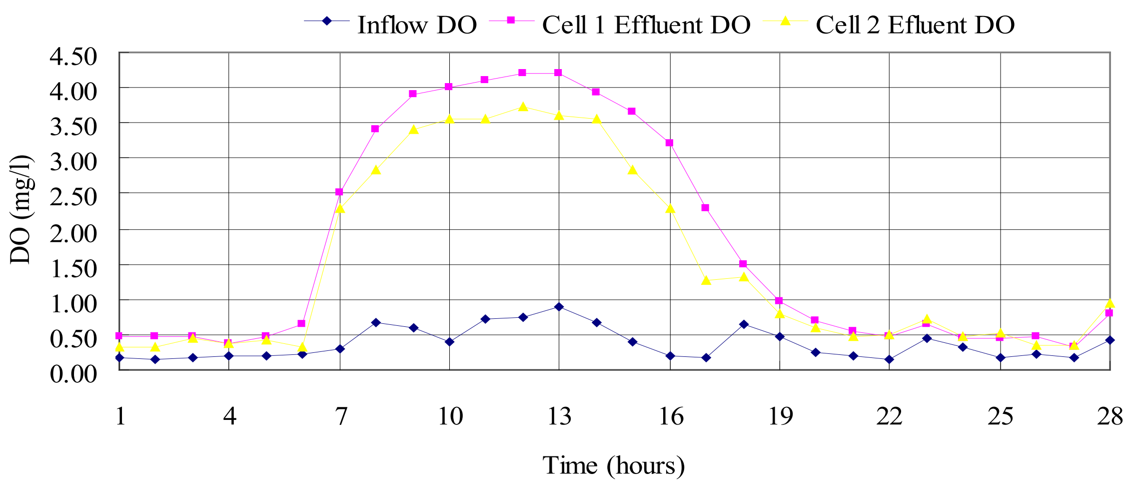


Figure 6. Weekly variation of BOD_5 in HSSFCW cells



Figue 7. Hourly variation of DO in the HSSFCW cells

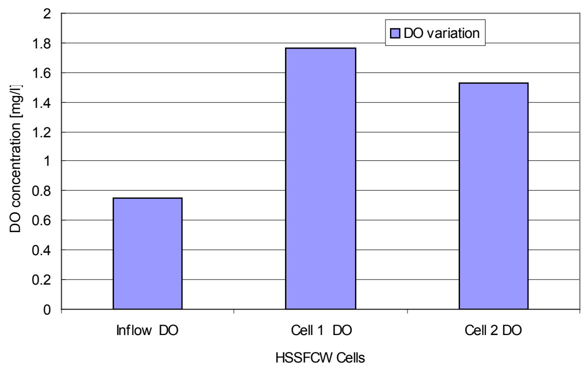


Figure 8: Average Dissolved Oxygen (DO) effluents from HSSFCW cells 1 and 2 planted with macrophytes

In relation to DO, Figure 7 shows that it varied quite significantly with time of the day. From Figure 7, it is obvious that the DO was high between 9h00 a.m. and 15h00 p.m. This was the favorable time of the day when the plant photosynthesis process was intense in HSSFCW macrophytes. Thus, during the day the oxygen released by plant roots to mixed wastewaters was higher (maximum level was about 4.2 mg/l) in cell 1 than in cell 2 (about 3.6 mg/l).

Figure 8 shows that the DO supplied by plants photosynthesis was used for oxidation of organic matter in HSSFCW cells 1 and 2. Macrophytes planted in series supplied more DO to the mixed wastewater in Cell 1 (about 4.2 mg/l) than in cell 2 (about 3.6 mg/l). The average DO effluent found at the inlet of cell 1 was 1.76 ± 1.55 mg/l while cell 2 had 1.53 ± 1.30 mg/l.

The processes of oxidation and nitrification occur in aerobic zones, i.e. in the upper zone of the cells. Considering the amount of DO from macrophytes translocation through the root system of cells 1 an 2, the utilization of DO was higher in cell 1 than in cell 2. Aerobic microorganisms directly use the oxygen for oxidation of organic matter in the rhizosphere of HSSFCW system. [12]

Conclusions and Recommendations

The synergy of two weaved plant roots (*Cyperus* horizontal roots and vertical *Phragmites* roots) for an organic matter entraping (filtration process), increased oxygen release from plant shoots, and good bacterial attachments in cell 1 had a great influence in biodegradation process and in aeration of the system. This increased the nitrification process and the oxidation of organic matter near the roots zone (transition zone). The presence of two synergetic macrophytes planted in series in HSSFCW cell 1 might have influenced significantly the distribution of heterotrophic bacteria (HB) and nitrifying bacteria (*Nitrosomonas, Nitrosospira and Nitrobacter*), which could have attached to the plant roots for biodegradation, bio-remediation, phyto-remediation, and hence better performance. Heterotrophic bacteria were possibly responsible for effective and efficient pollutants removal within the engineered HSSFCW system. The HSSFCW cell 1 planted with two aquatic plants met well the international standard limits for discharge of effluent into receiving bodies. [16, 17] Based on these overall results of the mixed wastewater treatment performance, it is recommended that application of DRF-HSSFCW system be considered as a technically appropriate system for mixed effluents polishing, pollution control and suitable environmental health in tropical countries.

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References

1.Kiwanuka S., Okurut T.O., and Kelderman P. Performance and Experience of a Tropical Integrated Pilot CW in Nutrient Removal in Wetland in Mbwette *et al.* (Eds): *Application of Wetland Systems* & *Waste Stabilization Ponds in Water Pollution Control, University of Dar es Salaam Edition, WSP Project* 2001, Pages 225.

2.Kiwanuka S. and Kelderman P. Coliform Removal in a tropical Integration Pilot CW in Wetland in Mbwette *et al.* (Eds): *Application of Wetland Systems* & *Waste Stabilization Ponds in Water Pollution Control, University of Dar es Salaam Edition, WSP Project* 2001, Pages 225.

3. Njau K.N. Seminar Presentation in February, 2005: Experiences of Constructed Wetlands for Wastewater Treatment in Tanzania. Constructed Wetlands & WSPs Research Project- University of Dar es Salaam, pCET, MECHE, CPE. P.O. Box: 35131 Dar es Salaam-Tanzania, July 2004.

4.Senzia A.M., Mashauri D.A., Mayo A.W., Mbwette T.S.A. and Jorgensen S.E. Application of Wetland Systems and WSP in Water Pollution Control in Wetland in Mbwette *et al.* (Eds): *Application of Wetland Systems* & *Waste Stabilization Ponds in Water Pollution Control, University of Dar es Salaam Edition, WSP Project* 2001, Pages 225.

5.Kimwaga R.J. Optimisation of the Waste Stabilisation Pond Effluents Treatment by use of a Coupled Dynamic Roughing Filters and HSSFCWs. Ph.D. Thesis, University of Dar es Salaam 2004, pg. 5-100.

6.Mbwette T.S.A. and Amusa M. Evaluation of the Treatment Efficiency of Gravel Filters on the Effluent from WSP. *The Tanzania Engineers.* 1999, *Vol. 4, No. 4*

7. APHA, AWWA, WEF. Standard Methods for the Examination of Water and Wastewater, *18th Edition, American Publication Health Association (APHA), Washington DC*, 1992.

8. Vymazal J., Brix H., Cooper P.F, Green M.B. and Habert R. Removal Mechanisms in Constructed Wetlands. In: *Constructed Wetlands for Wastewater Treatment in Europe*. Backhuys Publishers. Leiden. The Netherlands, pages. 1-56, 1998

9.Mwegoha, W., Katima, J.H.Y., Mbwette, T.S.A., Njau, K.N., and Jorgensen, S.E. Performance of HSSFCW in polishing Maturation Pond Effluent: The role of Substrates in Wetland in Mbwette *et al.* (Eds): *Application of Wetland Systems* & *Waste Stabilization Ponds in Water Pollution Control, University of Dar es Salaam Edition, WSP Project* 2001, Pages 225.

10.Reed S.C., Crites R.W. and Middlebrooks E.J. Natural Systems for waste management and treatment. *McGraw-Hill, Inc.*1995

11.Kadlec and Knight Suspended Solids. In: *Treatment Wetland pp. 315-338, Lewis Publishers*. 1995

12.Brix H. Treatment of Wastewater in Rhizosphere of Wetland plant- Roots zone method. *Wat. Sc. Techn.*, 1990,*19 (1), 107-118*.

13.Cooper P.F., Smith M. and Maynard H. The Design and Performance of a Nitrifying Vertical Flow Reed Bed Treatment System. *Wat. Sci. Techn*. 1996, *35 (5), 215-220.*

14.Kansiime F. The influence of Cyperus papyrus on the Distribution of Nutrients and their Activity and Dissolved Oxygen in Wetland in Mbwette *et al. Application of Wetland Systems* & *Waste Stabilization Ponds in Water Pollution Control, University of Dar es Salaam Edition, WSP Project* 2001, *Pages 225 (on pages 128-142).*

15.Kimwaga, Mbwette T.S.A., Mashauri D.A., Katima J.H.Y. and Jorgensen, S.E. Potential use of DRF and HSSFCW Treating Waste Stabilisation Pond Effluents in Wetland in Mbwette *et al.* (Eds): *Application of Wetland Systems* & *Waste Stabilization Ponds in Water Pollution Control, University of Dar es Salaam Edition, WSP Project* 2001*, Pages 225, (64-86).*

16.T.B.S. Standards of Physical and Chemical Quality of Portable Water for Tanzania, annex 2.2., 1989

17.WHO. *Report series* 642, Geneva, The World Bank..1995