Treatment of Landfill Leachate by Subsurface-Flow Constructed Wetland: A Microcosm Test

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Abstract: A microcosm test was conducted to evaluate the role of vetiver grass (*Vetiveria zizanioides*) and different substrates (including coal refuse, fly ash, cinder, soil and gravel) in purifying landfill leachate collected at Likeng landfill site of Guangzhou City, which contained high levels of COD (1354 mg/L) and NH_4^+-N (502 mg/L). The experiment lasted for 75 days with the major findings of present study as follows:

1. The COD removal efficiency of every batch ranged from 33% to 73%, NH_4^+-N from 46% to 74%, NO_3^--N from 72% to 94%, TKN from 46% to 73%, TP from –127% to 90%, and TSP from –1714% to 92%.
2. The wetland microcosm using coal refuse as a substrate had the best performance in removing NH_4^+-N, TKN, TP, TSP and TSS, while the wetland microcosm using cinder as substrate had the best performance in removing COD, NO_3^--N and TSS.
3. With the addition of sawdust as a carbon source, the process of denitrification was significantly promoted, however the removal of all compounds except NO_3^--N was inhibited and the growth of vetiver grass was significantly inhibited. The addition of sawdust also led to a reduction in the aboveground, belowground and total biomass of vetiver grass.
4. The concentration of NH_4^+-N in leachate greatly influenced the function of vetiver grass in the wetland microcosm.
5. Prolonging the HRT can significantly enhance the removal efficiency of NO_3^--N.
6. Vetiver grass played an important role in the purification of landfill leachate in the wetland microcosm. The COD, NH_4^+-N, TKN, NO_3^--N, TP, TSP and TSS removal efficiency of wetland microcosms planted with vetiver grass were greater than wetland microcosms without vetiver grass, 9.09%, 12.93%, 15.72%, 104.8%, 17.44%, 57.02% and 1.61%, respectively.

Key words: landfill leachate, constructed wetland, *Vertiveria zizaniodes*, microcosm test

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1 INTRODUCTION

A constructed wetland application for nitrogen-rich wastewater treatment has received more and more concerns recently. Two main nitrogen removal mechanisms in constructed wetlands are bacterial denitrification and plant accumulation (Knight, 1993). Studies show that even with the most conservative estimates, plant uptake could account for <10% of nitrogen removal; and bacterial denitrification seemed to be the dominant process removing nitrogen within a wetland. Wastewater treatment wetlands usually receive most of their nitrogen in form of ammonium (NH_4^+-N) or organic nitrogen. These forms of N must be converted to NO_3^--N before denitrification can occur. The vertical-flow beds (VFBs) wetland have been proved to provide a very high nitrification capacity. However, wetlands receiving highly nitrified wastewater have a poor performance in removing nitrate due to inadequate labile organic carbon supply or a short Hydraulic Retention Time (HRT).

countries (Sanguankaeo *et al.*, 2000; Bevan *et al.*, 2000). Previous studies showed that *V. zizanioides* is able to tolerate extreme soil conditions including heavy metals, swine wastewater, etc. (Liao *et al*., 2000). There was however no thorough studies on vetiver grass growing in constructed wetlands receiving landfill leachate, rather a static experiment on vetiver grass incubated in different concentrations of diluted landfill leachate (Xia *et al*., 2000). This experiment aimed to: (1) screen the most suitable waste material from coal refuse, fly ash, cinder, soil and gravel as a growth substrate for a constructed wetland planted with vetiver grass and receiving landfill leachate. Coal refuse, fly ash, cinder, soil and gravel are materials commonly available in Guangdong Province; and (2) evaluating the effects of NO_3^--N removal efficiency using additional carbon and HRT.

2 MATERIALS AND METHODS

2.1 Materials Collection

The five substrates chosen for experiment were: coal refuse, fly ash, cinder, soil and gravel. Coal refuse, came from a coal refuse waste dump at Renhua County of Shaoguan City in Guangdong Province; fly ash, came from Guangzhou Power Plant; Cinder, came from a community of Haizhu District in Guangzhou city; soil, came from Botany Garden in Sun Yatsen University; gravel, came from a stone processing field. All were processed to less than 5cm particle size. The basic physico-chemical properties of these substrates are shown in Table 1. Dried sawdust used as an additional carbon source was collected from a Wood Plant in Sun Yatsen University.

Table 1 Selected properties of the substrates used in experiment

Substrate	pH	EC (ms cm^{-1})	Organic C (%)	Total KN (mg kg^{-1})	Total P (mg kg^{-1})
Coal refuse	7.85±0.21	0.41±0.03	1.85±0.56	598±88	345±14
Fly ash	10.26±0.31	0.63±0.07	0.51±0.13	272±113	700±11
Cinder	7.61±0.15	0.30±0.04	0.44±0.05	360±36	522±31
Soil	4.70±0.14	0.14±0.04	1.66±0.03	297±133	420±15
Gravel	9.40±0.21	0.08±0.01	0.06±0.01	16±10	194±28

24 PVC tanks, dimensions were 0.465 m length_0.30 m width_0.32 m height. The rate of landfill leachate flowing into the 24 wetland microcosms were controlled by 24 transfusion pipe sets.

Landfill leachate was taken from a secondary biochemical pool, which received high concentration landfill leachate from the Likeng Landfill site in Guangzhou City.

Slips of vetiver grass were provided by Dr. Xia Hanping of South China Institute of Botany. Upon harvesting, the roots were washed clean, dead leaves removed, then pruned to 0.2 m aboveground and 0.1 m under-grounds and immediately planted in the wetland microcosms topsoil.

2.2 Experiment Methods

Since April 2001, 24 wetland microcosms, including 8 treatments and triplicates, using coal refuse, fly ash, cinder, soil and gravel as substrates, were set up in a greenhouse at Sun Yatsen University (Table 2). Each wetland microcosm was made up of a PVC tank, substrates, topsoil, and 9 individual vetiver grass plants (Fig. 1). Two pieces of board put into the tank to form three compartments-inlet compartment, processing compartment, and outlet compartment. The board at the center of processing compartment served as an internal baffle to prevent short-circuiting. To make wastewater flow easily from the inlet compartment to the outlet compartment, many 0.005 m diameter holes were drilled into the placed in the bottom, while above was filled with 0.06 m of soil. Design of the inlet and outlet compartments ensured water level control and easy sampling.

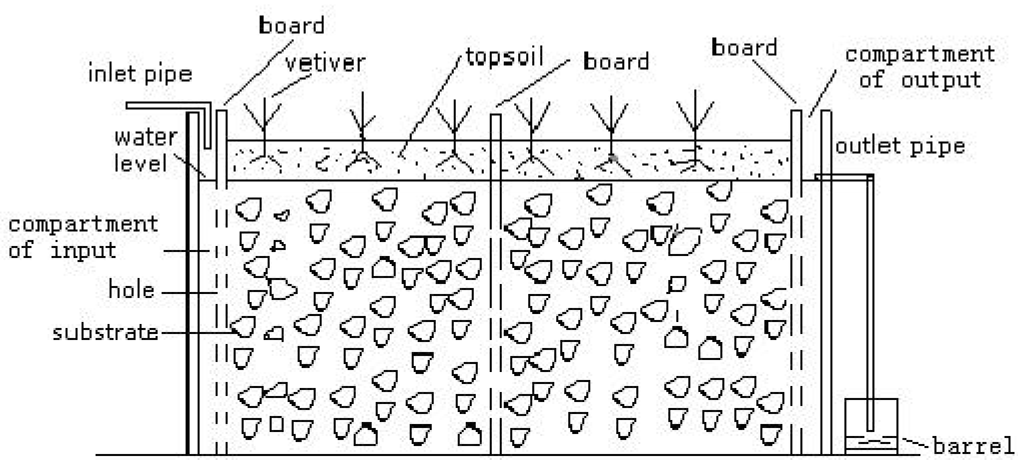
Batch 1-5 were set up to test the pollutant removal performance of five substrates. Batch 5-7 were established to test the effect of nitrate removal efficiency with the addition of carbon. Batch 7-8 were set up as the control to test the performance of Vetiver grass in a constructed wetland.

After the wetland microcosms were set up in late April, Hoagland's nutrient solution was added to each tank every day until early August 2001. Landfill leachate (with mean COD 1291 mg/L, mean NH_4^+-N 383 mg/L) was fed into the wetland microcosms every day at the HRT of 5 days. This operation lasted 35 days. Then, landfill leachate (with mean COD 1465 mg/L, mean NH_4^+-N 711 mg/L) was added to the wetland microcosms every day at a HRT of 10 days, over a period of 40 days.

Table 2 Experiment design

Treatment	Substrates	Plant
Batch 1	50%coal refuse +50% sawdust	vetiver
Batch 2	50%fly ash+50% sawdust	vetiver
Batch 3	50%cinder+ 50%sawdust	vetiver
Batch 4	50%soil+ 50%sawdust	vetiver
Batch 5	50%gravel + 50% sawdust	vetiver
Batch 6	80%gravel + 20% sawdust	vetiver
Batch 7	100% gravel	vetiver
Batch 8	100% gravel	without plant

Fig. 1 A cross-section view of the subsurface flow wetland microcosms



Changes in pH, electric conductibility (EC), chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), ammonium-N (NH_4^+-N), nitrate-N (NO_3^--N), total phosphorus (TP), total soluble phosphorus (TSP) and total suspended solid (TSS) were measured by monitoring the effluent entering and effluent discharging from the tanks. At the end of the experiment, the aboveground and roots of the vetiver grass were harvested and substrates were sampled for analysis.

2.3 Chemical Analysis

Samples not analysed on the same day were preserved in cold store at 4_. Sample handling and analysis were performed as described in the Standard Methods (APHA, 1992). Water samples were analyzed for pH, EC, COD, TKN, NH_4^+-N, NO_3^--N, TP, TSP, and TSS. Substrate samples were analyzed

Biomass, TKN, TP. Plants were dried to a constant weight at 80_ in a forced air oven and weighed to get biomass data. These were then digested with a modified macro-Kjeldahl digestion method for analysis of TKN and TP.

2.4 Calculation and Statistical Methods

The removal efficiency equation adopted here was as follows:

Removal efficiency(%)= (inlet pollutants-outlet pollutants)/inlet pollutants_100%

Treatment efficiencies were tested by ANOVA and differences between means were tested by least significant difference (LSD) test, using the SPSS statistical program.

3 RESULTS AND DISCUSSION

3.1 Basic Characteristics of the Landfill Leachate

Basic characteristics of the inlet landfill leachate are shown in Table 3. The inlet concentration of COD, TKN, NH_4^+-N, NO_3^--N, and TSS were very high. Moreover, the inlet concentrations of COD, TKN, NH_4^+-N, and $NO3^-$-N at the HRT of 5 days was significantly higher than that at 10 days HRT. This indicated that, the quality of inlet landfill leachate fluctuated with time.

Table 3 Basic characteristics of the landfill leachate

HRT		pH	EC mS cm^{-1}	mg L^{-1}						
				COD	TKN	NH_4^+-N	NO_3^--N	TP	TSP	TSS
5 days	Min. value	6.64	6.53	841	91	26	6.6	1.95	0.88	527
	Max. value	8.71	8.70	1553	619	561	76	4.50	2.05	2313
	Mean value	7.43	8.01	1291	433	383	28	3.55	1.17	1164
10days	Min. value	6.42	7.40	1271	572	544	31	2.03	0.16	250
	Max. value	8.57	10.00	1668	910	851	90	4.38	1.22	1383
	Mean value	7.49	8.82	1465	752	711	56	2.85	0.66	788

3.2 Removal Efficiencies of Substrates

The removal performance of coal refuses, fly ash, cinder, soil, and gravel are presented in Table 4. The results show that different substrates had different effects on the removal efficiency of pollutants. The cinder substrate treatment (Batch 3) showed the best performance in removing COD, NO_3^--N and TSS (73, 80 and 75%, respectively, at the HRT of 5 days; and 66, 94 and 60%, respectively, at the HRT 10 days), and also the second best performance in removing NH_4^+-N, TP and TSP (63, 75 and 47% at the HRT of 5 days; and 69, 44 and-309% (an exception) at a HRT of 10 days).

The coal refuse treatment (Batch 1) showed best performance in removing NH_4^+-N, TP and TSP (74, 90 and 92% at the HRT of 5 days), and the second best performance in removing COD, NO_3^--N and TSS (70, 77 and 63% at the HRT of 5 days).

The fly ash treatment (Batch 2) showed the poorest performance in removing all items except TP and TSP, while the soil-based batch (Batch 4) had the lowest performance in removing TP and TSP accordingly. The gravel-based treatment (Batch 5) possessed a mean performance in removing all items.

The removal ability of most treatments declined from the HRT of 5 days to 10 days HRT in all items except NO_3^--N. The differences in removal capacity among these treatments (except batch 2) were lowered to zero according to the LSD test. In contrast most authors reported removal performance of wetlands were enhanced by prolonging HRT. This may be due to the high concentration of inlet landfill

3.3 Effects of Addition Carbon Supply and HRT on Nitrate Removal Efficiency

Gravel is a widely reported substrate used in constructed wetlands due to its good hydraulic conductivity. In the present experiment, it was also found to have good hydraulic conductivity. Thus, gravel can still be considered as a substrate for subsurface-flow constructed wetlands planted with vetiver grass and receiving landfill leachate. Fly ash and soil have been reported to act as substrates in surface flow wetlands (Yin *et al.*, 1999), but the results presented here indicate that it's hydraulic conductivity and pollutant-removal performance was poor. So far, there are no reports on coal used as a substrate of constructed wetlands. However in this experiment, coal refuse was a good candidate as substrate in treating NH_4^+-N-rich, TP-rich and TSP-rich wastewater. However, cinder was not a good substrate for subsurface-flow constructed wetlands.

Table 4 Comparison of pollutants removal efficiencies in wetland microcosms with different substrates at different HRT

Items		COD RE(%)	NH_4^+-N RE(%)	TKN RE(%)	NO_3^--N RE(%)	TP RE(%)	TSP RE(%)	TSS RE(%)
HRT =5d	Batch 1	70.40a ±1.07	74.06a ±0.55	72.91a ±3.59	77.21a ±9.16	90.47a ±0.43	91.62a ±1.08	66.29a ±2.55
	Batch 2	45.86c ±1.04	46.50d ±1.11	48.87d ±0.59	-6.89c ±17.91	51.18cd ±2.51	44.37b ±3.55	39.92b ±6.13
	Batch 3	73.37a ±1.34	63.37b ±0.10	64.34b ±3.14	80.27a ±2.67	75.43ab ±1.33	47.36b ±5.90	63.90a ±7.35
	Batch 4	60.88b ±0.58	61.27bc ±1.39	59.89bc ±1.41	68.57ab ±7.09	45.07d ±12.24	14.17c ±12.10	60.08a ±0.51
	Batch 5	64.34b ±1.39	57.65c ±1.81	57.97c ±1.87	63.20b ±2.57	74.73bc ±1.36	35.39b ±6.87	57.96a ±6.27
HRT =10d	Batch 1	52.16c ±0.31	68.13a ±1.41	65.00a ±0.98	84.82a ±4.64	81.62a ±2.37	26.44a ±8.54	44.02b ±9.46
	Batch 2	32.95d ±1.70	47.07b ±1.87	46.47b ±1.15	42.09b ±7.10	41.72c ±4.04	-5.00a ±3.78	9.87c ±7.86
	Batch 3	65.76a ±5.19	69.24a ±4.05	66.97a ±3.24	93.65a ±1.95	43.62bc ±8.01	-308.46b ±42.33	59.62a ±3.90
	Batch 4	50.62c ±1.09	68.50a ±1.96	65.49a ±1.17	83.37a ±0.73	-127.32d ±50.54	-1713.77c ±310.24	44.81b ±8.22
	Batch 5	59.78b ±0.63	67.35a ±2.76	64.31a ±1.57	91.40a ±2.46	39.92c ±3.78	-280.90db ±52.49	46.27ab ±2.50

Notes_Mean±SD(n=3), Treatments with different letters are significantly different ($P<0.05$), and with same letters are not significantly different ($P>0.05$), according to LSD test; RE: Removal Efficiency

The NO_3^--N removal efficiency of HRT at 10 days and 5 days were a function of the ratio of sawdust addition/substrate (v/v). NO_3^--N removal efficiency increased with additional sawdust concentration. Previous studies (Ingersoll *et al.*, 1998; Bake, 1998) showed that nitrate removal in wetlands occurred through plant uptake and denitrification. With high nitrate loading rates typical in treatment wetlands, denitrification is generally considered the dominant mechanism of nitrate loss. The factor controlling denitrification is the C: N ratio. To achieve a much better removal efficiency of nitrate, the ratio of C: N _ 5:1 is a must. In our study, the ratio of C: N of inlet landfill leachate was from 2:1 to 3:1 (see Table 3) hence not optimal conditions for nitrate removal. It was also found that prolonging HRT could greatly increase the nitrate removal efficiency (Table 4), as many other researchers had reported (Ingersoll *et al.*, 1998; Bake, 1998; Bachand *et al.*, 2000).

3.4 Vetiver Grass Growth

Vetiver grass is reported as an excellent species in purifying highly concentrated landfill leachate (Xia *et al.*, 2000), however, concentrated leachate (i.e. inlet COD=1465 mg/L, NH_4^+-N=711 mg/L) greatly influenced the growth and function of vetiver grass. In relatively highly concentrated landfill leachate (i.e. inlet COD=1291 mg/L, NH_4^+-N=383 mg/L), vetiver grew well and purified landfill leachate effectively. Summerfelt *et al*. (1999) reported that highly-concentrated sludge (COD=6855 mg/L, TKN=234 mg/L) was added into a wetland planted with vetiver grass 6 times per day, vetiver grass grew well even after 10 months, indicating that COD concentrations had less influence on vetiver grass than NH_4^+-N concentration. Many other studies have showed that elevated NH_4^+-N exerted toxicity in plants. Liao (2000) found that vetiver grass could grow normally in swine wastewater with its NH_4^+-N concentration less than 200 mg/L. Therefore, landfill leachate should be pretreated to reduce its NH_4^+-N concentration to less than a toxic level (e.g. 383 mg/L), before it is treated in a constructed wetland planted with vetiver grass.

The biomass of vetiver grass in every treatment is showed in Table 5. Batch 7 (no sawdust addition) had the highest biomass among all treatments. Vetiver grass growing on different substrates performed differently, growth performance (biomass) followed the descending order in growth; soil > cinder > gravel > coal refuse > fly ash.

Table 5 Changes of biomass of vetiver grass in every batch

Treatment	Biomass (g)		
	Above-ground	Under-ground	Total
Batch 1	197±31	33±3	230±34
Batch 2	157±26	24±5	181±32
Batch 3	240±21	31±1	271±20
Batch 4	258±35	37±7	294±42
Batch 5	203±24	35±7	238±30
Batch 6	169±35	33±4	201±38
Batch 7	307±28	45±5	352±33
Before test	18±0	8±0	26±0

3.5 Role of Vetiver Grass on the Pollutants Removal

A comparison of pollutant removal efficiencies in wetland microcosms between with and without Vetiver grass planting at different HRT's is presented in Table 6. At a HRT of 5 days, differences in all items except TSS removal efficiency was significant or greatly different between planted and unplanted treatments, while there was no difference between planted and unplanted treatments with a HRT of 10 days. This may be due to a high concentration of NH_4^+-N in the inlet which inhibited the growth of vetiver. Therefore, the data collected from a HRT of 5 days was selected for Vetiver grass analysis. The COD, NH_4^+-N, TKN, NO_3^--N, TP, and TSP removal efficiency of wetland microcosms planted with vetiver grass is 9.09%, 12.93%, 15.72%, 104.8%, 17.44%, and 57.02%, higher than wetland microcosms unplanted with vetiver grass, respectively, while the presence of plants did not significantly affected the efficiency of the system in the case of COD and TSS.

Removal efficiencies of NH_4^+-N, TKN, NO_3^--N, TP in planted wetland microcosms were highly significantly different from those in unplanted wetland microcosms, the removal efficiency of COD and TSP in planted wetland microcosms was significantly different from that in unplanted wetland microcosms, while there was no significant difference in TSS removal efficiency between planted and unplanted wetland microcosms, according to the ANOVA test. So the role of vetiver grass in main pollutants removal was very important.

Table 6 Comparison of pollutants removal efficiencies in wetland microcosms between with and without planting vetiver grass at different HRT

Items		COD RE (%)	NH_4^+-N RE (%)	TKN RE (%)	NO_3^--N RE (%)	TP RE (%)	TSP RE (%)	TSS RE (%)
HRT= 5 days	Batch 7	68.43* ±1.03	66.81** ±1.17	70.26** ±1.76	32.98** ±11.67	82.29** ±0.44	55.34* ±3.63	69.10 ±4.30
	Batch 8	59.34* ±1.86	53.88** ±0.76	54.54** ±1.30	-71.82** ±30.06	64.85** ±1.02	-1.68* ±5.23	67.49 ±2.24
	Balance	9.09	12.93	15.72	104.8	17.44	57.02	1.61
HRT = 10 days	Batch 7	46.17 ±7.58	61.80 ±5.06	62.33 ±4.67	38.13 ±5.39	63.12 ±2.71	-51.86 ±32.60	35.58 ±5.02
	Batch 8	48.43 ±4.21	61.36 ±2.69	62.24 ±3.48	22.25 ±1.20	58.12 ±5.56	-59.78 ±24.58	29.88 ±4.63
	Balance	-2.26	0.44	0.09	15.88	5.00	7.92	5.70

Note: Mean±SD (n=3); * significant (P<0.05), ** greatly significant (P<0.01), all tested by ANOVA; RE: Removal Efficiency

4 CONCLUSION

This wetland microcosm experiment demonstrated that a vetiver grass constructed wetland has great potential in treatment of highly concentrated landfill leachate. But vetiver grass was not as effective with concentrated landfill leachate, which should be pretreated to reduce its NH_4^+-N concentration to 383 mg/L or even lower.

Vetiver grass played significant role in purifying landfill leachate in wetland microcosms. Vetiver grass growing on different substrates performed differently, growth performance (biomass) followed the descending growing order of soil > cinder > gravel > coal refuse > fly ash.

Coal refuse was a good substrate for landfill leachate treatment, especially in treating NH_4^+-N-rich, TP-rich and TSP-rich landfill leachate, combined vetiver grass. Cinder was a better choose for treating landfill leachate containing relatively high concentrations of COD, NO_3^--N and TSS in a subsurface-flow constructed wetland planted with vetiver grass. Gravel could also be used in treating landfill leachate, due to its good hydraulic conductivity but had a mean performance in removing pollutants.

Sawdust addition could significantly promote NO_3^--N removal efficiency. When the inlet wastewater ratio of C:N was 2:1-3:1, the ratio of sawdust addition/substrate of 0.60 was the optimal value to get the best NO_3^--N removal efficiency. Sawdust addition might affect the growth of vetiver grass.

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A Brief Introduction to the First Author

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