REMEDIATION OF MUNICIPAL SOLID WASTE LANDFILL LEACHATE BY USING SUBSURFACE FLOW CONSTRUCTED WETLAND WITH LOW PERMEABLE REACTIVE MEDIA

Chayanid Witthayaphirom[1], Chart Chiemchaisri[2],
Wilai Chiemchaisri[3]and, Jiro Takemura[4]

[1] Department of Environmental Engineering, Faculty of Engineering, Kasetsart University, Bangkok, Thailand, Tel. (662) 7970999 ext. 1003, e-mail: chayanidwit@gmail.com
[2] Department of Environmental Engineering, Faculty of Engineering, Kasetsart University, Bangkok, Thailand, Tel. (662) 7970999 ext. 1010, e-mail: fengccc@ku.ac.th
[3] Department of Environmental Engineering, Faculty of Engineering, Kasetsart University, Bangkok, Thailand, Tel. (662) 7970999 ext. 1015, e-mail: fengwlc@ku.ac.th
[4] School of Civil and Environmental Engineering, Tokyo Institute of Technology, Tokyo, Japan, Tel. (813) 57342592, e-mail: jtakemur@cv.titech.ac.jp

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Abstract

This research was carried out to investigate the efficiencies of leachate treatment by using subsurface flow constructed wetland (CW) with low permeable reactive media and guinea grass (Panicum maximum TD 58). Pilot scale CW was examined at hydraulic loading rate (HLR) of 0.028 m/d and hydraulic retention time (HRT) of 10 d. Two different types of media in CW were used i.e. system 1: clay and sand mixture at ratio of 40:60 (%w/w) and system 2: clay, iron sludge and sand mixture at ratio of 30:10:60 (%w/w). The results showed that the performance of system 2 was better in terms of pollutant removal efficiencies. Average BOD, COD and TKN removals were 76.1, 68.5 and 73.5% respectively. Methane, carbon dioxide and nitrous oxide emissions during the treatment of CW were 8.2-52.1, 69.1-601.8 and 0.04-0.99 $mg/m^2.d$ respectively. The use of CW with reactive media in system 2 and vegetation resulted in lower GHG emissions. The results show that CW with low permeable reactive media could be effectively used to remediate leachate from the landfill site.

Keywords: Constructed wetland, Greenhouse gas, Iron sludge, Leachate, Panicum maximum TD 58, Permeable reactive barrier

Introduction

Leachate is a highly concentrated wastewater including COD, BOD, SS, NH_3, heavy metals and other toxic substances generated as by-product from municipal solid waste landfill. It poses a hazard threat to the environment in terms of air, surface water and ground water pollution. In order to prevent environmental deterioration from discharging this polluted wastewater, proper leachate treatment or pollution control system needs to be provided. Conventional leachate treatment systems available in developing countries are generally low-cost technologies such as stabilization pond, aerated lagoon or land treatment. Nevertheless, those treatment technologies are usually employed only during the operation stage of solid waste disposal site. After the site closure, most of the treatment systems are not well operated or poorly maintained due to lack of post-closure operation and maintenance cost. The control of leachate migration off the site after landfill closure is not an easy task because of high variations of leachate quantity and characteristics with time. Subsurface flow constructed wetland (CW) which utilizes coarse media with high permeability and vegetation has been proven to be an efficient treatment method for landfill leachate treatment [1]. Its main treatment functions include biological treatment using attached growth on the media and plant root and plant uptake of nutrients. Meanwhile, the treatment technology using low permeable media like clay and sand mixture has been also successfully applied for reducing groundwater pollution from solid waste disposal site. It is also anticipated that vegetation could also enhance the performance of CW by improving soil porosity and oxygen diffusion for the microbial activities. In our previous investigations, vegetation has provided positive effect on leachate treatment in soil-plant system while also helped reducing greenhouse gas (GHG) emission during it treatment [2, 3]

Methodology

Two pilot-scale subsurface flow constructed wetland (CW) units of 1 m width, 2 m length (having 1.5 m of media), and 1 m depth, as the schematic shown in Figure 1, were used. The inlet and outlet zones of the experimental unit were filled with 30-60 mm gravel of 0.80 m depth. In between, CW made from clay: sand mixture at 40:60 (%w/w) was provided in one unit (system 1) and clay: iron sludge: sand mixture at 30:10:60 (%w/w) was provided in another unit (system 2). In this study, clay was obtained from local soil and iron sludge (in the form of iron oxide) was brought from sludge storage pond of existing advanced leachate treatment system using chemical coagulation and filtration system at the same solid waste disposal site. The main purpose for introduction of iron sludge in reactive media in system 2 was to investigate its effect in suppression of methane production during the treatment [4]. The properties of media used in this study are shown in Table 1. Two PVC pipes (1 inch diameter) were provided for sampling of water (so called port 1 and port 2) at every 0.5 m distance under the plant root zone. The CW media depth in both units was set equally at 0.8 m. Guinea grass (Panicum maximum TD 58) which has been cultivated in our previous research [3] was used as vegetation in both units with an initial plant density of 20 rhizomes/m^2. Leachate obtained from closed landfill cell at the solid waste disposal site where experimental units were installed was fed into the system from a storage tank by gravity. A control valve was used to adjust the feed flow rate to that hydraulic loading rate (HLR) to the system was maintained at 0.028 m^3/m^2.d. The water depth in the experimental unit was maintained at about 0.7 m. This was equivalent to hydraulic retention time (HRT) of 10 d. This experimental condition was pre-determined to be sufficient for leachate purification in our previous study [1].

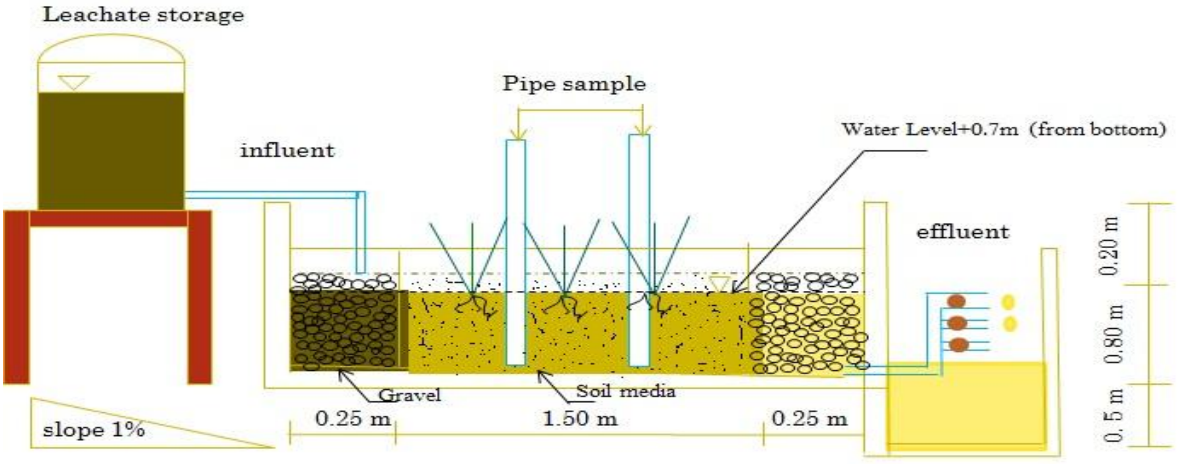

Figure 1. Schematic of pilot-scale subsurface flow constructed wetland

Table 1. Properties of Media

Parameter (unit)	System 1 (clay:sand)	System 2 (clay:iron sludge:sand)
pH (-)	6.45	6.84
Porosity (%)	40.16	40.14
Salinity, NaCl (%)	0.27	0.49
Electrical conductivity (dS/m)	2.49	3.87
Bulk density (kg/m^3)	1,620	1,540
Hydraulic conductivity, k (m/s)	2.93×10^{-6}	5.72×10^{-6}
Soil Texture	Sandy loam	Sandy loam
Sand (%)	65.36%	69.36%
Silt (%)	11.55%	5.22%
Clay (%)	23.09%	25.42%

The characteristics of leachate used in this study are shown in Table 2. The performance of CW in leachate purification was monitored over 240 days by comparing influent, treated water along the treatment pathway and effluent qualities on weekly basis. Wastewater quality analyses included pH, electrical conductivity (EC), color, oxidation-reduction potential (ORP), salinity (NaCl), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), suspended solids (SS), total dissolved solids (TDS), ammonia (NH_3 in mgN/l), total kjeldahl nitrogen (TKN), nitrite (NO_2^- in mgN/l), nitrate (NO_3^- in mgN/l), and total phosphorus (TP). The analyses of those parameters were performed according to Standard Methods for the Examination of Water and Wastewater [5]. Moreover, soil samples were collected as composite samples between inlet, middle and outlet parts and characterized for pH, EC, organic matter, organic carbon, moisture content, NH_3-N, NO_3-N, TKN and TP at the beginning and the end of experiment. Water permeability of media was determined in the experiment unit before and after experiment by using constant head method. The growth of plant was determined in terms of shoot height, root length, number of leaves and total dry weight at the beginning and the end of experiment.

Table 2. Characteristics of Leachate

Parameter (unit)	Range	Average
pH (-)	7.53-8.79	8.33
EC (dS/m)	11.5-25.9	19.2
Color (Pt-Co unit)	437.5-1,250	911.1
NaCl (%)	0.19-0.50	0.35
ORP (mV)	(-396)-(-212)	-265
TSS (mg/l)	230-810	575
TDS (mg/l)	8,140-13,520	10,610
BOD (mg/l)	704-1,434	922
COD (mg/l)	2,200-3,145	2,694
TOC (mg/l)	712-1,279	993
NH_3-N (mg/l)	56.7-178.7	101.8
TKN (mg/l)	112-296	190.5
NO_2-N (mg/l)	0.1-1.3	0.4
NO_3-N (mg/l)	0.2-3.5	1.2
TP (mg/l)	4.8-11.6	5.2

During the treatment, GHG emission was also evaluated using close flux chamber technique on monthly basis. The details of flux measurement methodology can be found elsewhere [6]. The determination of gas emission was conducted over bare soil and soil with plant at a distance of 0.25, 0.75 and 1.25 m length so called inlet, middle and outlet point of soil media respectively for comparison to investigate the effect of plant on reducing GHG emission. Methane and carbon dioxide were analyzed by Shimadzu GC-14B whereas nitrous oxide was analyzed by Shimadzu GC-Clarus 580 respectively. The gas flux was determined from their concentration increase in the chamber as described in the following equation.

$$F = (V/A)*(\Delta C/\Delta t)*(298)/(273+T) \quad (1)$$

Where F is the gas flux ($mg/m^2.d$) at 25ºC, V is the chamber volume (m^3), A is the area enclosed by the chamber (m^2), $\Delta C/\Delta t$ is the gas concentration gradient ($mg/m^3.d$) and T is temperature of the air within chamber (ºC)

Results and Discussion

Treatment Performance of the CW System

Table 3 shows average effluent qualities from the pilot-scale CW over 240 days during which total rainfall of 175 mm and average temperature of 37^{o}C was recorded. The volume of fed leachate to each experimental unit was 42 l/d yielding average organic loading of 0.09 kgBOD/m^3.d and 0.27 kgCOD/m^3.d to the system respectively. After treatment, the effluent flow from system 1 and system 2 had average flow of 31 and 24 l/d respectively. The leachate volume was mainly reduced by evapotranspiration in the system. In terms of treatment performance, moderate organic and nutrient (N, P) removals of about 50-80% were achieved in CW system. It was found that the removal rates of pollutants were different between the experimental units using different media. For most of pollutants except color, the removals were higher in the experimental unit in which iron sludge were added into clay: sand mixture. On average, BOD, COD and TKN removals were 76.1%, 68.5% and 73.5% respectively meanwhile those of clay: sand mixture alone were 69.5%, 63.3% and 66.9%. Moderate dissolved solids removals in terms of EC (48.4%) and salinity (54.1%) were also observed in CW system suggesting the removal of salts through precipitation either in media or plant root zone. In aerated peat bio-filter treating leachate, BOD, COD and NH_3 removals of 80%, 90% and 86% were reported at HRT of 5 days [7]. The enhanced treatment in iron sludge amended media can be caused by physical, chemical and biological mechanisms being promoted by sludge addition. This was evidenced in terms of higher SS removals (Table 3) and accumulation of organic carbon (Table 4) for system 2. The enhancement of biological activities was further described in terms of greenhouse gas emission. Moreover, vegetation could also help improving organic and TKN removal possibly through enhancement of oxygen transfer into the soil by plant root system which subsequently promoted aerobic biodegradation by soil microorganisms.

The results of chemical analyses of media before and after the experiment is shown in Table 4. It was found that carbon and nitrogen were partially accumulated in the media resulting in an increase in organic carbon (TOC) and total nitrogen (TN) in both systems. It is anticipated that organic matter are first adsorbed onto the soil and then subsequently biodegraded by microorganisms. In comparison, system 2 had lower initial organic carbon and higher nitrogen content than system 1 due to the presence of iron sludge. After the experiment, the accumulations of pollutants in system 2 matrix were found higher than system 1 in term of organic carbon whereas nitrogen accumulation in both systems were not much different. Significant increase in salt content in media was also observed possibly resulting from the salt crystallization in the media when part of water was evaporated during the treatment. Moreover plants can uptake nutrients mainly nitrogen for their growth. Accumulation of pollutants and microbial in the media led to a decrease in their hydraulic permeability.

Table 3. Effluent Characteristics and Steady State Removal Efficiencies

Parameter	System 1 (clay: sand)			System 2 (clay: iron sludge:sand)			% Removal System1	% Removal System2
	Port 1	Port 2	Eff.	Port 1	Port 2	Eff.		
pH	7.86	7.76	7.71[a]	8.22	8.07	7.79[a]	-	-
EC (dS/m)	13.8	11.5	10.9[a]	13.1	10.9	9.9[a]	43.3	48.4
Color (unit)	572	407	282[a]	622	467	349[a]	70.1	61.5
NaCl (%)	0.26	0.21	0.18[a]	0.24	0.20	0.16[a]	48.3	54.1
ORP (mV)	-231	-205	-159[b]	-230	-184	-155[b]	-	-
BOD (mg/l)	577	399	281[a]	544	342	221[a]	69.5	76.1
COD (mg/l)	1,824	1,331	989[a]	1,630	1,196	849[a]	63.3	68.5
TOC (mg/l)	-	-	561[a]	-	-	490[a]	43.4	50.4
SS (mg/l)	-	-	150[a]	-	-	114[a]	73.9	80.2
TDS (mg/l)	-	-	5,475[a]	-	-	4,887[a]	48.4	53.9
NH_3-N (mg/l)	55	52	31[b]	50	45	28[b]	69.5	73.4
TKN (mg/l)	147	112	63[a]	134	92	51[a]	66.9	73.5
NO_2-N(mg/l)	0.2	0.15	0.05[b]	0.2	0.16	0.04[b]	76.2	80
NO_3-N(mg/l)	0.9	0.5	0.24[b]	0.86	0.66	0.21[b]	78.8	84
TP (mg/l)	3.30	3.03	1.44[b]	3.51	3.17	1.36[b]	71.7	74.4

Note: a= difference between system 1 and system 2 with statistical significance ($p<0.05$) and
b = no difference between system 1 and system 2 with statistical significance ($p>0.05$)

Table 4. Characteristics of Media before and after the Experiment

Parameter	Before		After	
	System 1	System 2	System 1	System 2
pH (-)	6.45	6.84	6.5	7.1
NaCl (%)	0.27	0.24	0.49	0.78
EC (dS/m)	2.49	3.87	13.9	11.8
TN (mg/kg)	188.31	417.17	903.32	1,166.62
TOC (g/kg)	13.64	11.96	15.36	14.54
Permeability, k (m/s)	2.93×10^{-6}	5.72×10^{-6}	2.26×10^{-7}	1.73×10^{-7}

Growth of Plant in the CW System

During the operation of CW system, the growth of plant (Panicum maximum TD 58) was also studied. It was found that the growth of plant in system 2 was better than system 1 as shown in terms of plant height, root length, numbers of leaves and plant dry weight (Table 5). From these results, it can be concluded that the provision of iron sludge in CW media did not have negative impact on plant growth but on the other hand slightly promoted plant growth. The promotion of plant growth could be due to an improvement on physical properties of media for plant growth or the addition of ferric iron can also help in promoting photosynthesis mechanism of plant chlorophyll. Higher growth of plant in system 2 also promoted water removal through evapotranspiration resulting in lower effluent volume obtained from system 2 compared to system 1.

Table 5. Growth of Panicum Maximum TD 58 during the Experiment

Parameter	Before	After	
		System 1	System 2
Height (m)	0.15	1.01	1.38
Root (m)	0.12	0.21	0.34
No. of leaves	0	55	84
Dry weight (g)	33	2,441	3,254

Greenhouse Gas Emission from the CW System

Table 6 compares average methane, carbon dioxide and nitrous oxide emission rates from soil and soil-plant in CW with different media. Methane, carbon dioxide and nitrous oxide emissions during the treatment of CW were 8.0-52.6, 69.1-570.2 and 0.04-0.69 mg/m^2.d respectively. Among them, carbon dioxide emission was highest followed by methane and nitrous oxide. For all gases, the emission rates from bare soil were higher than soil-plant location indicating that the plant helped reducing greenhouse gas emission possibly due to beneficial effect from oxygen transfer into their root system. The emission was also found highest near the inlet part and gradually decreased along the treatment pathway (Table 7). Comparing between both systems, system 2 had lower emission rates than system 1 for all gases. These results suggested that an introduction of iron sludge into the media helped mitigating greenhouse gas emission during the treatment. This is an expected mechanism as ferric ion amended sludge media could promote the activity of Fe^{3+} reducing bacteria, resulting in a switch in electron flow from methanogenesis to Fe^{3+} reduction [8]. Furthermore, plant–microbe interactions could lead to an efficient iron oxidation and reduction reaction in an oxidized rhizosphere environment [9, 10].

Table 6. Emission Rates (mg/m^2.d) of Greenhouse Gas from the CW System

System	Location	Methane		Carbon Dioxide		Nitrous Oxide	
		Range	Avg.	Range	Avg.	Range	Avg.
1	bare soil	16.3-52.6	31.2	215.7-570.2	380.7	0.21-0.69	0.42
	soil-plant	14.2-46.8	26.6	155.0-536.0	316.1	0.14-0.53	0.31
2	bare soil	11.3-41.7	22.6	112.5-508.9	293.6	0.07-0.43	0.21
	soil-plant	8.0-37.0	17.8	69.1-373.3	259.6	0.04-0.41	0.19

Table 7. Emission Rates (mg/m^2.d) of Greenhouse Gases along the Treatment Pathway

System	Gas	Soil w/o Plant			Soil with Plant		
		Inlet	Middle	outlet	inlet	middle	outlet
1	CH_4	40.1	30.0	23.3	35.7	26.5	18.0
	CO_2	483.8	376.5	281.8	432.0	317.8	198.6
	N_2O	0.52	0.41	0.32	0.41	0.31	0.21
2	CH_4	32.5	20.6	14.6	27.3	16.3	10.0
	CO_2	401.8	292.0	187.0	366.1	275.4	137.4
	N_2O	0.29	0.22	0.11	0.27	0.20	0.10

Conclusions

Subsurface flow constructed wetland (CW) with low permeable media was successfully applied to remediate leachate from closed landfill site. Moderate removals of organic and nutrients was obtained during which highest removals of BOD, COD and TKN were 76.1%, 68.5% and 73.5%. The introduction of iron sludge into CW media slightly improved the treatment performance of CW while promoting plant growth. It also helped reducing greenhouse gas emission during the treatment. The growth of Guinea grass (Panicum maximum TD 58) in CW system could be sustained in long term operation and it provided positive effect to the treatment and reducing greenhouse gas emission.

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References

[1] C. Chiemchaisri, W. Chiemchaisri, J. Junsod, S. Threedeach, and P.N. Wicramarachchi, "Greenhouse gas emission from constructed wetland for treating landfill leachate in the tropics," *Bioresource Techmology*, Vol. 100, No. 16, pp. 3808 -3814, 2009.

[2] V. Boonyaroj, C. Chiemchaisri, W. Chiemchaisri, and S. Tudsri, "Treatment of municipal landfill leachate by cover soil with vegetation on tropical landfill," *Thai Environmental Engineering Journal*, Special Volume January-April 2012, pp. 175-179, 2012.

[3] C. Suwunpukdee, C. Chiemchaisri, W. Chiemchaisri, K. Yamamoto, H. Furumai, H. Katayama, C. Chiemchaisri, U. Puetpaiboon, C. Visvanathan, and H. Satoh, "Utilization of concentrated leachate for plant cultivation on municipal solid waste landfill," *Southeast Asian Water Environment 5*, IWA Publishing, United Kingdom, pp. 253-256.

[4] U. Jäckel, and S. Schnell, "Suppression of methane emission from rice paddies by Ferric iron fertilization," *Journal of Soil Biology & Biochemistry*, Vol. 32, No. 11-12, pp. 1811-1814, 2000.

[5] American Public Health Association (APHA), "Standard methods for the examination of water and wastewater," 20th Edition, Washington,D.C., United States, 1998.

[6] C. Chiemchaisri, W. Chiemchaisri, and A. Sawat, "Mitigation of methane emission from solid waste disposal site in the tropics by vegetated cover soil," *Asian Journal of Water, Environment and Pollution*, Vol. 3, No. 2, pp. 29-33, 2006.

[7] P. Champagne, and M. Khalekuzzaman, "A semi-passive peat biofilter system for the treatment of landfill leachate," *Journal of Water Sustainability*, Vol. 4, No. 2, pp. 63-76, 2014.

[8] P. Frenzel, U. Bosse, and P.H. Janssen, "Rice roots and methanogenesis in a paddy soil:ferric iron as an alternative electron acceptor in the rooted soil," *Journal of Soil Biology & Biochemistry*, Vol. 31, No. 3, pp. 421-430, 1999.

[9] S.C. Neubauer, K. Givler, S.K. Valentine, and J.P. Megonigal, "Seasonal patterns and plant-mediated controls of subsurface wetland biogeochemistry," *Journal of Ecology*, Vol. 86, No. 12, pp. 3334-3344, 2005.

[10] E.E. Roden, and R.G. Wetzel, "Organic carbon oxidation and suppression of methane production by microbial Fe (III) oxide reduction in vegetated and unvegetated

freshwater sediments," *Journal of Limnology and Oceanography*, Vol. 41, No. 8, pp.1733-1748, 1996.