Waste Management 44 (2015) 164–171

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Water reduction by constructed wetlands treating waste landfill leachate in a tropical region

Yuka Ogata [a,*], Tomonori Ishigaki [a], Yoshitaka Ebie [a], Noppharit Sutthasil [b], Chart Chiemchaisri [b], Masato Yamada [a]

[a] Center for Material Cycles and Waste Management Research, National Institute for Environmental Studies, 16-2 Onogawa, Tsukuba, Ibaraki 305-8506, Japan
[b] Department of Environmental Engineering, Faculty of Engineering, Kasetsart University 50 Ngam Wong Wan Road, Lat Yao Chatuchak, Bangkok 10900, Thailand

ARTICLE INFO

Article history:
Received 30 March 2015
Revised 11 June 2015
Accepted 14 July 2015
Available online 21 July 2015

Keywords:
Constructed wetland
Landfill leachate
Tropical region
Water reduction
Pollutants removal efficiency

ABSTRACT

One of the key challenges in landfill leachate management is the prevention of environmental pollution by the overflow of untreated leachate. To evaluate the feasibility of constructed wetlands (CWs) for the treatment of waste landfill leachate in tropical regions, water reduction and pollutant removal by a CW subjected to different flow patterns (i.e., horizontal subsurface flow (HSSF) and free water surface (FWS)) were examined in both rainy and dry seasons in Thailand. A pilot-scale CW planted with cattail was installed at a landfill site in Thailand. With HSSF, the CW substantially removed pollutants from the landfill leachate without the need to harvest plants, whereas with FWS, it only slightly removed pollutants. Under both flow patterns, the CW significantly reduced the leachate volume to a greater extent than surface evaporation, which is regarded as an effect of the storage pond. Additionally, water reduction occurred regardless of season and precipitation, within the range 0–9 mm d^{-1}. In the case of low feeding frequency, water reduction by the CW with HSSF was lower than that with FWS. However, high feeding frequency improved water reduction by the CW with HSSF and resulted in a similar reduction to that observed with FWS, which exhibited maximum evapotranspiration. In terms of water reduction, with both HSSF in conjunction with high frequency feeding and FWS, the CW provided a high degree of evapotranspiration. However, pollutant removal efficiencies with HSSF were higher than for FWS. The present study suggested that CWs with HSSF and high frequency feeding could be useful for the prevention of uncontrollable dispersion of polluted leachate in the tropical climate zone.

1. Introduction

It is recognized that comprehensive management of waste landfills, including leachate treatment, is still lacking in many developing countries. However, such management is necessary because a rapid increase in landfilled solid waste may result in substantial environmental pollution of the surrounding area. In most regions, including Southeast Asia, the treatment of landfill leachate has largely depended on natural evaporation and purification at stabilization ponds (Johannessen and Boyer, 1999). Advanced physicochemical and biological treatments have been introduced to the landfills in tropical developing countries through the support of international development aid. However, most of these attempts proved to be unsuccessful after this support ended due to the lack of a continuous budget and energy supply, and the poor technical capabilities available for the operation and maintenance of the plant. A sustainable leachate management approach that adapts to economic, technical, and climate considerations in such regions is therefore required. An increasing amount of landfill leachate during the rainy season increases the risk of pollution to the surrounding environment due to the potential for overflow of leachate from the site. The first step in the management of landfill leachate in tropical and developing countries should be the minimization of leachate volume to prevent the uncontrollable dispersion of polluted leachate.

In the past several decades, constructed wetlands (CWs) have been commonly applied in Europe and United States as a sewage treatment to remove nutrients (Vymazal, 2010). Recently, in addition to landfill leachate (Akinbile et al., 2012; Bulc, 2006; Chiemchaisri et al., 2009; Kadlec and Zmarthie, 2010; Polprasert and Sawaittayothin, 2006), their application has been expanded to various other types of wastewater, e.g., livestock wastewater (Kato et al., 2013), wood waste leachate (Tao et al., 2006), and aquaculture wastewater (Lin et al., 2002). Although landfill leachate often contains recalcitrant compounds and inhibitors of

* Corresponding author.
E-mail address: ogata.yuka@nies.go.jp (Y. Ogata).

http://dx.doi.org/10.1016/j.wasman.2015.07.019
0956-053X/

biological reactions, CWs could perform effective treatment of landfill leachate over extended time periods (Bulc, 2006; Kadlec and Zmarthie, 2010). Other than the effect of the CW on pollutant reduction, there has been a growing interest in their ability to reduce water volume (Białowiec et al., 2014; Headley et al., 2012; Milani and Toscano, 2013; Papaevangelou et al., 2012; Pedescoll et al., 2013). However, to the best of our knowledge, there are no reports on the reduction of leachate volume by CWs in tropical regions.

In order to evaluate the feasibility of CWs for landfill leachate treatment in tropical countries, the reduction in the amount, and pollutant load, of leachate was evaluated for a pilot-scale CW with different feed patterns (i.e., free water surface (FWS) and horizontal subsurface flow (HSSF)) at a landfill site in Thailand.

2. Materials and methods

2.1. Site description

A pilot-scale CW (1000 mm [width] × 2000 mm [length] × 1000 mm [depth]), which was made of concrete with water resistance, was installed on the ground at a solid waste disposal site in Nonthaburi province, Thailand (Latitude: 14°, 00′ 24.4″ N; Longitude: 100°, 19′ 02.2″ E). Climate conditions during the experimental period (August 2013–July 2014) are shown in Table 1. Raw leachate from this landfill was occasionally introduced to storage pond. The leachate has been treated by natural evaporation and purification at storage pond. There is no outflow from the pond, because the leachate has not been discharged. The landfill leachate that was fed to the pilot-scale CW was obtained from this pond. Table 2 shows the characteristics of the landfill leachate.

Table 2
Characteristics of the landfill leachate.

Parameter	Unit	Raw landfill leachate	Landfill leachate from storage pond		
			Mean	Min	Max
pH	–	7.7	9.5	9.3	10.0
EC	mS/cm	15.7	15.8	10.1	21.0
TS	mg/L	13,545	13,500	8300	16,800
SS	mg/L	104	200	140	320
TOC	mg/L	355	560	340	670
COD_{Cr}	mg/L	1370	1600	1000	2000
TP	mg/L	19.5	7.5	6.0	11.1
TN	mg/L	848.5	68.8	51.0	80.5

Raw leachate was sampled on April 25 2013. Landfill leachate from storage pond was sampled on April 25, June 20, August 8 and November 27 2013 and January 29 and June 4 2014.

2.2. Experimental design and operating conditions

Several experimental conditions, i.e., differing media for the bed of the CW, differing dilution levels of the landfill leachate, differing frequency of the inflow, and differing flow patterns, were assessed (Table 3). Three operation modes, denoted as C, H, and F, were established.

For operation C, the bed was filled with mixed sand and clay (3:2 [wet-weight]) to a width of 1000 mm, a length of 1500 mm, and a depth of 600 mm. Large (50 mm) and small (10 mm) gravel particles were used to fill the inlet and outlet sides of the bed (each of which had the following dimensions: 1000 mm width × 250 mm length × 600 mm depth), respectively (Fig. 1A). The porosity of the media was 0.31. An outlet pipe was placed at the bottom of the CW and the water level was maintained below 50 mm from the media surface. Cattail, known for its salt tolerance (Klomjek and Nitisoravut, 2005; Mufarrege et al., 2011), was the dominant wild-growing plant species at the landfill site. Thirty-seven shoots of cattail were sampled and planted in the CW. Since electricity usage was limited in the landfill site, feeding was operated by the hand of man. Groundwater was fed to the CW for cultivation of the cattail for an initial period of two months. The leachate was diluted either 4-, 2-, or 1-fold with groundwater, and then fed to the CW. The water level was kept above the surface of the bed of the CW from 09:00 until 08:30 the next day (23.5 h) by closing the effluent valve. The retained water was discharged at 08:30, until the water level reached below 50 mm from the media surface. This manipulation was repeated during the operation period.

For operations H and F, the bed was filled with sand (1000 mm width × 1600 mm length × 650 mm depth), and large gravel particles (50 mm) at the inlet side and small gravel particles (10 mm) at the outlet side of bed (each of which had the following dimensions: 1000 mm width × 200 mm length × 650 mm depth) (Fig. 1B). The porosity of the media was 0.37. In operation H, an outlet pipe was placed at the bottom of the CW and the water level was maintained, as HSSF, below 100 mm from the media surface. In operation F, the water level was maintained, as FWS, above 100 mm from the media surface, with effluent leaving through the bottom. In these operations, 26 shoots of native cattail were planted. Groundwater was fed to the CW for cultivation of the cattail for an initial period of one month. The leachate was diluted either 4- or 2-fold with groundwater in operation H, and either 1-, 2-, or 10-fold with groundwater in operation F, and fed to the CW. The frequency of inflow was once per day (40.0 mm) in operations H1 and H2, but was changed to twice per day (20.0 mm each) in operation H3, and five times per day (8.0 mm each) in operations H4 and F.

2.3. Plant growth and uptake of nitrogen

For evaluation of plant growth, the number and height of cattail plants were measured at the beginning and end of operation C. The above-ground cattail was harvested at the end of operation C3, and the fresh and dry weights were measured. Relative growth rate (RGR) was determined as

$$\mathrm{RGR} = \frac{\ln W_e - \ln W_b}{t_e - t_b}$$

where W_b (g) and W_e (g) are dry biomass at the beginning of the experiment (t_b) and the end of operation C3 (t_e), respectively. The percentage of nitrogen (%) in dry cattail biomass at the end of

Table 1
Monthly climate data during the period from August 2013 to July 2014.

	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
Mean temp. (°C)	28.6	27.8	28.2	28.0	24.3	24.5	27.5	29.9	30.8	31.1	30.1	30.2
Mean relative humidity (%)	76	83	79	72	63	63	71	69	67	66	71	69
Mean wind velocity (m/s)	2.1	2.0	1.2	1.5	1.6	1.1	1.6	1.9	1.9	1.9	2.2	2.5
Precipitation (mm)	175	315	265	17	0	0	0	0	16	42	63	36
Mean possible daily sunshine (h)	12.6	12.2	11.8	11.5	11.3	11.4	11.7	12.1	12.4	12.7	12.9	12.8