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The influence of evapotranspiration on vertical flow subsurface constructed wetland performance

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ABSTRACT

This paper presents an example of the importance of evapotranspiration in constructed wetlands, with vertical subsurface flow, comparing different methods of treatment efficiency calculations and discussing the influence of evapotranspiration on removal rates. The application of reed, marked by high transpiration ability, is a cheap and effective method of landfill leachate disposal. A 2-year study examined the effectiveness of leachate treatment in constructed wetlands with reed. Two kinds of vertical subsurface flow systems: first with sand, and second with combined two layers of sewage sludge and sand has been tested. 1, 3, and 5 mm d^{-1} hydraulic loading rates of landfill leachate have been applied. Daily evapotranspiration was in the range from 0.98 to 2.99 mm d^{-1} in the first year of research and from 2.56 to 4.61 mm d^{-1} in the second year. The influence of evapotranspiration rate on chemical oxygen demand (COD) removal rate was examined. Two methods of removal efficiency calculation have been used: first based on inlet and outlet COD concentrations, second on mass balance determination. Research showed that the removal efficiency calculated as a comparison between initial and final concentration is significantly lower, than expected from mass balance, especially, when higher hydraulic loading rates were applied.

1. Introduction

The use of ecological systems such as constructed wetlands (CWs), is recognized as an economical and technically sustainable solution for wastewater treatment making it safe to discharge into the environment. CWs are artificial complexes of water, matrix, vegetation and the associated invertebrate and microbial communities designed to simulate the ability of natural wetlands to remove pollutants from water (Brix, 1997), and are a good example of ecological engineering (Mitsch and Jorgensen, 2004). They provide an inexpensive and reliable method for treating a variety of wastewaters such as sewage, landfill leachate, mine leachate, urban storm-water, agricultural run-off, are very efficient for nutrient removal (Białowiec et al., 2011; Lu and Huang, 2010) are comparatively simple to construct, operate and maintain (Kadlec and Wallace, 2008; Randerson, 2006), and are suitable for advanced and polishing treatment if water reuse is an option (Marecos do Monte and Albuquerque, 2010; Masi and Martinuzzib, 2007; Pedrero et al., 2011).

Plants commonly used in constructed wetlands include: cattail (*Typha latifolia* L.), reed (*Phragmites australis* Trin ex Steudel), rush (*Juncus effusus* L.), yellow flag (*Iris pseudacorus* L.), mannagrass (*Glyceria maxima*), and giant reed (*Arundo donax* L.). As well as these typical natural wetland plant species, willow (*Salix* sp.), may be used in CWs with high efficiency (Aronsson and Perttu, 2001; Perttu and Kowalik, 1997).

Willows have been used in the treatment of agricultural runoff and leachate from landfill sites (Białowiec et al., 2007; Duggan, 2005), and are especially successful at removing high levels of ammonia and nitrogen from solution. Willow treatment systems also can achieve zero discharge of water due to evapotranspiration (ET), and part of the nutrients can be recycled via the plant biomass (Białowiec et al., 2011; Vymazal and Kropfelova, 2008). Some wetland species, such as reed, are tolerant of moderately high salinity

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Table 1
The properties of landfill leachate used in the experiment (based on 48 samples).

Parameter	Unit	Mean	Standard deviation	Min. value	Max. value
Reaction	pH	8.0	0.4	7.2	9.13
COD	$mgO_2\,dm^{-3}$	1425.4	356.2	483.6	2467
BOD_5	$mgO_2\,dm^{-3}$	242.5	25.6[a]	148.4	368.3
Dissolved compounds	$mg\,dm^{-3}$	7164.1	806.9	5741	10,783
Loss on ignition	$mg\,dm^{-3}$	2672.6	748.7	1167	4110
	%	37.2	9.3	16.8	56.99
Residue after ignition	$mg\,dm^{-3}$	4491.6	802.4	3071	7872
	%	62.8	9.3	43.01	83.2
Electrolytic conductivity	$mS\,cm^{-1}$	12.3	1.1	9.74	14.21
Chlorides	$mgCl^{-}\,dm^{-3}$	176.3	19.4	124.95	227.5
Kjeldahl nitrogen	$mgN\,dm^{-3}$	779.3	95.2	551	992.8
Ammonia nitrogen	$mgN\text{-}NH_4^{+}\,dm^{-3}$	591.9	63.4	429.8	764.1
Phosphates	$mgP\text{-}PO_4^{-3}\,dm^{-3}$	3.6	1.3	0.08	5.5

[a] BOD_5/COD ratio = 0.17.

and provide high levels of nutrient removal, making them particularly suitable in treatment wetlands (Albuquerque et al., 2009; Białowiec et al., 2011; Lu and Huang, 2010; Mesquita et al., 2013).

To summarize, the presence of plants in a CW brings several benefits: plants may create aerobic conditions in an otherwise anaerobic rhizosphere, which induces growth of both heterotrophic and autotrophic aerobic bacteria; plants can provide carbon compounds into the rhizosphere that may be utilized by microorganisms in aerobic oxidation, fermentation and denitrification pathways; plants may uptake pollutants (N, P, heavy metals), from treated wastewater; plants may improve the hydraulic conditions of wastewater flow through the CW bed, and also may increase the available surface for microorganism biofilm growth.

Macrophytes have also a great potential for water loss through transpiration since they have inherently low water use efficiencies (Białowiec and Wojnowska-Baryla, 2007; Headley et al., 2012). Thus, water losses to the atmosphere via ET, can be high (Borin et al., 2011), especially under warm and windy conditions as observed in previous studies (Albuquerque et al., 2009; Białowiec et al., 2006). Numerous studies have shown the importance of ET during hot periods in both natural and CWs. ET may affect treatment efficiency of CWs because wastewater volume passing through the system decreases as a result of water loss. This phenomenon has been described widely in the literature. A decrease in volumetric flow through the wetland system and even a lack of effluent due to ET has been proven (Białowiec et al., 2006).

Usually, treatment efficiency of wastewater in CWs is calculated based on the concentration of pollutants (namely biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), nitrogen (TN) and total phosphorous (TP)) in inlet and outlet as in conventional treatment plants, without considering the contribution of evapotranspiration in the water balance. In a CW, where water loss is typically not negligible, the calculation of pollutant removal efficiency using results of concentrations may lead to significant errors. With ET, the concentration of dissolved compounds increases due to decreasing water volume, hence removal efficiencies calculated with and without the water balance are not the same, and this difference is assessed and discussed below.

This paper intends to show the importance of ET in CW performance calculations, using a vertical subsurface flow bed, comparing different methods of treatment efficiency calculations and discussing the influence of ET on removal rates.

2. Material and methods

2.1. System design and control

A municipal landfill in Wola Pawlowska near Ciechanów in Poland, operating since June 1994 (landfill area 3.5 ha), was the source of treated landfill leachate (LL), for this experiment, the properties of which are shown in Table 1. All parameters were determined according to standard methods (APHA-AWWA-WEF, 1999).

A laboratory scale experiment was conducted (Białowiec et al., 2007), using a 1 m high lysimeter (0.6 m in diameter and 0.28 m^3 in volume), as a model of a constructed wetland with vertical subsurface flow (VSSF). Each lysimeter (Fig. 1), contained a piezometer (5 cm diameter PCV tubing, closed at the top with a filter at the bottom), to enable bottom water sampling. A gravel layer (particle

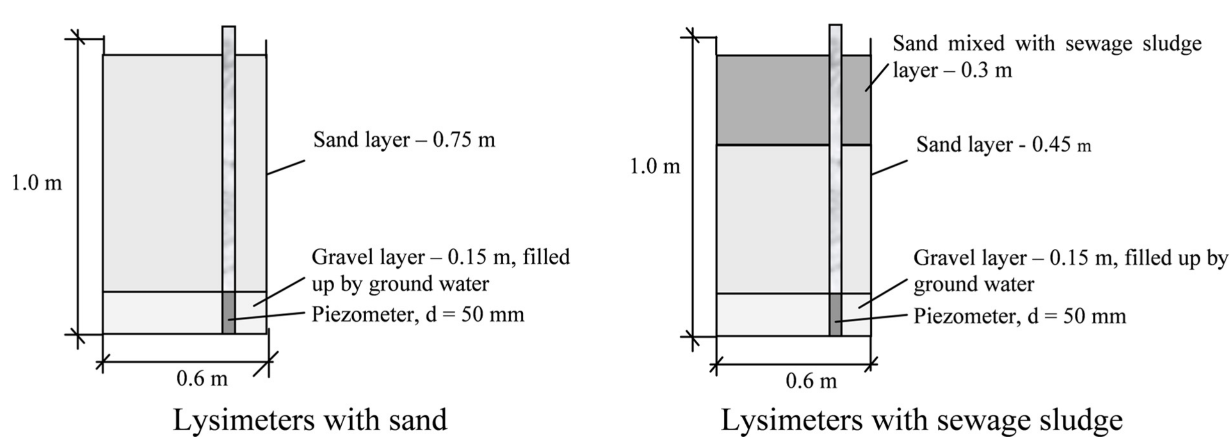

Fig. 1. Lysimeters construction.