Peter Kuschk, Eva M. Seeger, Arndt Wiessner, Zhongbing Chen
Department of Environmental Biotechnology, Helmholtz Centre for Environmental Research -
UFZ, Permoserstrasse 15, D-04318 Leipzig, Germany
Zhongbing Chen
Department of Environmental Engineering,
Martin-Luther-University Halle-Wittenberg,
Geusaer Strasse 135, D-06217 Merseburg, Germany
Diego Paredes
Facultad de Ciencias Ambientales, Universidad Tecnológica de Pereira,
Apartado Aereo 97, Sede la Julita, Pereira, Colombia

Hydroponic plant root mats and pulsing water level wetlands as design variants of constructed wetlands for wastewater treatment

At present, highly energy consuming technologies are stepwise replaced by technologies based on those with low need of technical equipment, such as solar energy and living organisms in the field of wastewater treatment. For instance, the constructed wetlands (CWs) are wastewater treatment systems engineered to simulate the physical, chemical, and biological purification processes of natural wetlands.

Сьогодні, енергоємні технології поступово замінюються технологіями, що не вимагають багато технологічного обладнання, як, наприклад, технології з використанням сонячної енергії та живих організмів для очищення стічних вод. Для прикладу, біоінженерні ставки (БС) є системами для очищення стічних вод, спроектовані стимулювати фізичні, хімічні та біологічні процеси очищення, що притаманні природнім ставкам.

At present, highly energy consuming technologies are stepwise replaced by technologies based on those with low need of technical equipment, such as solar energy and living organisms in the field of wastewater treatment. For instance, the constructed wetlands (CWs) are wastewater treatment systems engineered to simulate the physical, chemical, and biological purification processes of natural wetlands. Depending on the level of the water column with respect to the soil bed, CWs are classified as surface flow and subsurface flow wetlands; depending on the growth pattern of the macrophytes (plants) in the system, CWs are also classified into floating macrophyte, submerged macrophyte and rooted emergent macrophyte systems (Kadlec and Wallace 2009).

Hydroponic plant root mats

A new variant of CWs has been developed that uses emergent water plants, similar to those used in surface and subsurface flow CWs. They are growing as a floating root mat on the water surface or touching to the rooting proof bottom of the water body where the root mat can function as a filter for the contaminated water. In general, a floating root mat involves the growth of emergent water plants (helophytes), which naturally root into the soil, but in this case are converted into artificial macrophyte root mats floating over a pond or canal. These plants can form a dense floating mat of roots and rhizomes, whereby a preferential hydraulic flow in the water zone between the root mat and the non-rooted bottom can be expected. In the case that this root mat occupies the whole water body and touches the bottom of the pond or canal, the water is forced to flow through the root mat like through a filter.

Floating root mats (FRMs) and non-floating root mat filters (RMFs) are hybrids of soil free pond systems and conventional soil based CWs containing macrophytes. Because of their specific structure, floating root mats combine benefits from ponds and CWs, and are therefore used for the removal of different pollutants such as suspended solids, nutrients, metals, and organic contaminants.

FRMs and non-floating RMFs are similar to ponds as they have a water body, and are also similar to conventional soil based CWs as both of them use helophytes, but ponds are usually dominated by phytoplankton (Kadlec 2005). FRMs are often termed in a different way as “floating islands” (Van Duzer 2004), “artificial floating islands” (Nakamura et al. 1995), “artificial floating reed beds”

(Billore and Prashant 2008), floating mats (Kalin and Smith 1992; Li et al. 2009), “floating treatment wetlands” (Van de Moortel et al. 2010; Faulwetter et al. 2011; Headley and Tanner 2011), “constructed floating wetlands” (Van de Moortel et al. 2011). Since the root mat is regarded as the most important and representative feature of these systems, and the mat is either floating or non-floating, we classify these systems as floating root mats (FRMs) and root mat filters (RMFs).

In the field of water treatment, FRMs were probably first used for the remediation of eutrophicated rivers and lakes and rivers (Hoeger 1988; Nakamura et al. 1995). Later on, they were also applied to treat acid mine drainage (Smith and Kalin 2000), followed by treating stormwater (Revitt et al. 1997; Tanner and Headley 2008), piggery effluent (Hubbard et al. 2004), poultry processing wastewater (Todd et al. 2003), , domestic wastewater (Van de Moortel et al. 2010; Hijosa-Valsero et al. 2010; Faulwetter et al. 2011) and combined sewer overflow (Van de Moortel et al. 2011), as well as eutrophic lake water (Song et al., 2009). Recently, there are developments using FRMs and RMFs for treating ground waters contaminated by the chemical industry (Seeger et al. 2011; Chen et al. 2012).

Pulsing water level

Horizontal subsurface flow CWs are widely used for treatment of various wastewater types (Kadlec and Wallace, 2009). In order to enhance the oxygen input into the HSSF CWs, a variant called tidal flow CW was tested. During the tidal flow, cycles of water draining and filling periods are created in the wetland, i.e. the matrix of the wetland is alternately filled with wastewater and drained. In filling the CW, used-up air is expelled from the wetland as the level of water rises. When the CW is drained, the retreating water acts as a passive pump to draw fresh air from the atmosphere into the matrix. Hence, an unsaturated zone during the draining period is created that increases the aeration due to a higher oxygen transfer. It was shown that a higher removal efficiency for BOD5, COD and ammonium was obtained in the discontinuous flow HSSF CW than in the continuous flow HSSF CW (Vymazal and Masa, 2003; Pedescoll, et al. 20011; Caselles-Osorio and García, 2007).

Case study example

A plant root mat filter (PRMF) and a horizontal subsurface-flow constructed wetland (HSSF CW), operating in continuous flow and discontinuous outflow flushing mode, were investigated to treat a groundwater contaminated with low-chlorinated hydrocarbons (monochlorobenzene (MCB), 1,2-dichlorobenzene (1,2-DCB), 1,4-dichlorobenzene (1,4-DCB) and 2-chlorotoluene). The mean inflow concentrations were 8.22, 0.04, 0.3, and 0.04 mg L-1 with mean inflow loads were 247, 1.1, 9.0, and 1.1 mg m-2 d-1, respectively. After a flow path of 4 m, mean load removal efficiencies of 93, 88, 92, and 87% were observed for MCB, 1,2-DCB, 1,4-DCB, and 2-chlorotoluene in the PRMF, whereas 51, 46, 69, and 70% were observed under continuous flow mode and 51, 48, 71, and 73% were achieved under discontinuous outflow flushing mode in the HSSF CW. In the pore water of the PRMF a higher redox potential was monitored, which explains the higher treatment efficiency in the PRMF than in the HSSF CW. The change from continuous flow to discontinuous outflow flushing mode combined with a relatively long resting phase caused no obvious improvement of treatment efficiency in the HSSF CW.

In conclusion, PRMF could be an option for the treatment of waters contaminated with compounds which in particular need oxic conditions for their microbial degradation, such as low-chlorinated benzenes.

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