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Does clogging affect long-term removal of organics and suspended solids in gravel-based horizontal subsurface flow constructed wetlands?

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GRAPHICAL ABSTRACT

1993 Average outflow concentrations 2016

BOD_5: 3.8 mg l^{-1}, COD: 22 mg l^{-1}, TSS: 3.2 mg l^{-1} BOD_5: 4.0 mg l^{-1}, COD: 20 mg l^{-1}, TSS: 3.8 mg l^{-1}

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ABSTRACT

Constructed wetlands with horizontal subsurface flow (HF CWs) are primarily designed to remove organics and suspended solids. The major principle of this treatment process is that wastewater flows through the porous medium planted with wetland vegetation in order to achieve removal of pollutants. During the process the void spaces in the filtration material are slowly filled due to sedimentation and filtration of suspended solids, creation of biofilms on filtration material particles, chemical precipitation and growth of roots and rhizomes of the vegetation. Therefore, the clogging process is inevitable. However, the use of suitable porous filtration materials, responsible maintenance of pretreatment units and suitable loadings of organics and suspended solids may greatly slow down the clogging process. The purpose of this study was to evaluate the effect of partial ponding on treatment performance of four HF CWs that have been in operation for at least 20 years. The results revealed that if the inflow loading rates are < 10 g BOD_5 m^{-2} d^{-1}, < 20 g COD m^{-2} d^{-1}, < 10 g TSS m^{-2} d^{-1}, the partial ponding may occur after about 15 years of operation. The results also revealed that partial ponding have no significant effect on the quality of discharged water and the replacement of inflow zone filtration material did not results in any significant improvement either.

1. Introduction

In horizontal subsurface flow constructed wetlands (HF CWs), mechanically pretreated wastewater is fed in at the inlet and flows slowly through the porous medium under the surface of the bed in a more or less horizontal path until it reaches the outlet zone where it is collected before leaving via level control arrangement at the outlet [1]. As the water flows through the porous medium, the process of clogging is inevitable. The major processes and features responsible for clogging are 1) settlement of suspended solids from inflowing wastewater, 2) creation of biofilms on filtration substrate, 3) precipitates that are created under both aerobic (hydroxides, oxy-hydroxides around the roots;) and anaerobic conditions (sulfides, carbonates), and 4) belowground plant parts [2–5]. However, most of the hydraulic conductivity decline is apparently associated with sediment build-up and biofilm formation since unplanted gravel beds showed declines similar to those found in planted systems [6]. The four processes mentioned above occur in all HSF CWs. In addition, substantial amount of suspended solids can be washed into the filtration bed from the soil that originates from the vegetation litter decomposition when plants are not harvested.

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Table 1
Major design parameters of surveyed constructed wetlands. [1]Designed PE, number of connected people in parentheses. [2]In all systems the beds are in parallel. [3]CR – crushed rock, GS – gravels and, G – gravel, ORL = organic loading rate, 5-the first line for the period 1995–2009, the second line 2010–2015.

Location	Start of operation	Number of PE[1]	Surface Area (m^2)	No. of Bed[2]	Flow ($m^3\,d^{-1}$)	HLR ($cm\,d^{-1}$)	Substrate[3]	Fraction (mm)	Vegetation	OLR[4] ($g\,BOD_5\,m^{-2}\,d^{-1}$)
Chmelná	1992	150 (143)	706	2	62.2(17–100)	8.8(2.5–14.2)	CR	5–10	*Phalaris* *Phragmites*	8.8
Zásada[5]	1995	400 (420)700 (680)	1892 3500	3	68 (55–77)85 (79–99)	3.6 (2.9–4.1)2.4 (2.2–2.8	GS	8–20	*Phalaris*	7.37.8
Olší	1995	262 (257)	2160	3	212(160–281)	9.8(7.4–13.0)	GS	4–8	*Phragmites*	2.4
Zbenice	1996	203 (200)	1000	2	48(35–53)	4.8(3.5–5.3)	G	4–16	*Phalaris* *Phragmites*	6.3

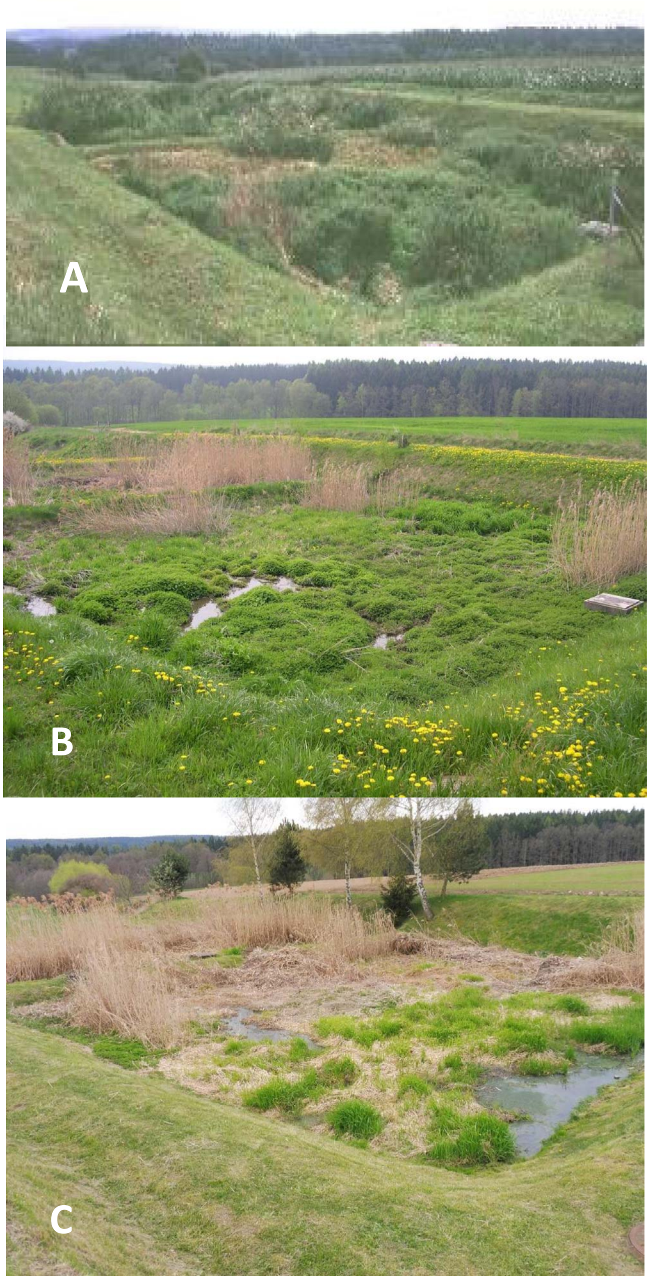

Fig. 1. Constructed wetland Chmelná. A = 1994, B = 2005 (first signs of ponding on the surface), C = 2016 (slight increase of ponding, especially in the inflow zone).

Constructed wetlands with horizontal sub-surface flow require mechanical pretreatment, however, no matter what kind of pretreatment is used, certain amount of suspended solids is not retained in the pretreatment units. In the Czech Republic, the most common pretreatment units for municipal sewage from combined sewer systems consist of screens, horizontal grit chamber and Imhoff tank. Based on 122 annual means from 28 constructed wetlands, the average removal efficiency of pretreatment units for TSS amounted to 43.6% (average inflow and outflow TSS concentrations of 126 $mg\,l^{-1}$ and 71.1 $mg\,l^{-1}$, respectively). The average outflow TSS concentration was 11.5 $mg\,l^{-1}$ resulting in an overall removal of 91.3%. It has been shown that about 80–90% of the TSS measured during the analysis would eventually decompose and only 10–20% of measured TSS remain sequestered in the filtration bed [7]. However, the amount of biodegradable suspended solids may vary as shown by Kimwaga et al. [8] who found only 15% biodegradation. It has also been reported that under aerobic conditions more accumulated solids can biodegrade as compared to anaerobic conditions. Carballeira et al. [3] found 35% and 4% of accumulated solids biodegradation under aerobic and anaerobic conditions, respectively in a HF CW in Spain.

The clogging is very much affected by the size of filtration material and consequently its hydraulic conductivity. Filtration materials may differ in their hydraulic conductivity (k_f) by several orders of magnitude. For example, coarse gravel on one end and fine-particulate clay on the other end of the spectra may have $k_f = 1\,m\,s^{-1}$ and $10^{-8}\,m\,s^{-1}$, respectively [9]. The early HF CWs designed by Seidel [10] used coarse materials (usually gravel or sand), however the so called "Kickuth system" employed during the 1970s used heavy cohesive soils with high clay content and very low hydraulic conductivity [11]. The early statement by Kickuth [12] that plant roots significantly increase the hydraulic conductivity of the filtration media by opening up preferential pathways for the wastewater flow proved to be wrong. Further investigations in Denmark, Austria, United Kingdom, Germany, USA and Australia during mid and the late 1980s and the early 1990a showed the claim that hydraulic conductivity would improve during the years of operation did not hold true. Instead, the hydraulic conductivity either remained stable or decreased with time [13–18]. This resulted in in surface flow leading to channeling and scouring of the surface which resulted in areas of the bed being starved of water and this in turn led to poor reed growth. It also led to by-passing and poor treatment [19].

As a result of these problems, Water Research Centre in the UK decided in 1986/87 to recommend the use of gravel in systems at Little Stretton and Gravesend, since this would allow through-flow of water from the start. This change was very successful and the possible gravel sizes 3–6, 5–10 and 6–12 mm were recommended and the fraction 5–10 mm was recommended by European guidelines [20]. Since then, coarse materials within the range of 5–20 mm have successfully been used around the world but differences exist among countries and also within one country as well [21].

The entrapment of suspended solids in horizontal flow sub-surface flow is the highest within the area where distribution zone filled with