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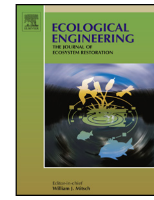

Evaluation of clogging in full-scale subsurface flow constructed wetlands

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ABSTRACT

Treatment processes that occur in constructed wetlands can result in gradual clogging of the porous medium. Clogging may result in hydraulic malfunction and/or reduced treatment performance. The aim of this study was to analyze the hydraulic aspects of horizontal subsurface flow (H-SSF) constructed wetlands (CWs), and, in particular, to investigate the clogging phenomena through in situ measurements of hydraulic conductivity of the gravel bed, quantification of accumulated clog matter and flow paths visualization by means of tracer tests. Removal efficiencies of chemical and physical contaminants were also assessed. Experiments were carried out in three full-scale H-SSF CWs in Sicily (Italy) that are used for tertiary treatment of the effluent of a conventional wastewater treatment plant. One bed had been operating for eight years while the other two are two years old. The oldest CW had lower hydraulic conductivity of the porous media and higher concentrations of total solids, volatile solids and belowground plant biomass than the younger ones. Furthermore, several stagnant zones and preferential flow paths were only detected in the oldest CW. Despite these results should be indicative of some degree of medium clogging, the treatment capacity remained largely unchanged after eight years of operation.

1. Introduction

Constructed wetlands (CWs) are used worldwide as a suitable or complementary technology to conventional wastewater treatment plants (WWTPs) for removing contaminants from various types of wastewaters (municipal, agricultural and industrial wastewaters, landfill leachate and stormwater runoff) due to their efficient performance, mechanical simplicity and low energy requirement in comparison to intensive engineered treatment plants (Toscano et al., 2013; Vymazal, 2014; Yalcuk and Ugurlu, 2009). Several types of constructed wetlands have been developed based on the hydraulic characteristics (water level, flow direction) and the vegetation types (emergent, submerged, free-floating macrophytes). Among them, subsurface flow CWs are the most commonly applied, especially in Europe (Fonder and Headley, 2013). These CW systems consist of waterproof basins, filled with porous media (generally gravel), planted with emergent macrophytes (such as *Phragmites australis*), in which wastewater flows horizontally (H-SSF) or vertically (V-SSF). As wastewater moves through a constructed wetland, the removal of pollutants occurs due to the interaction of several biological, physical and chemical processes such as decomposition, filtration, accumulation, nitrification/denitrification, adsorption and precipitation, all of them strongly relying on the contact time between wastewater and porous media, biofilm and plant roots (Kadlec and Wallace, 2009; Knowles et al., 2011; Nivala et al., 2012).

The interaction among treatment processes, wastewater characteristics and hydraulic loading rates may result, at long times, in a gradual clogging of the substrate that can negatively affect the removal and hydraulic performances of the CW and, definitively, reduce the lifetime of the system (Cooper et al., 2005; Caselles-Osorio and Garcıa, 2006; Nivala and Rousseau, 2009). The presence of stagnant zones can be assessed by comparing the actual residence time (aRT) with nominal residence time (nRT), if aRT is much larger than nRT wastewaters stagnate in the reactor and do not participate in reactions (Kadlec and Wallace, 2009).

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The growth of the biological film, accumulation of sludge and belowground plant biomass and deposition of chemical precipitates decrease the amount and size of the void spaces over time thus reducing the hydraulic conductivity of the porous medium (Blazejewski and Murat-Blazejewska, 1997; Pedescoll et al., 2009). Therefore, hydraulic conductivity measurements have proven to be one of the most suitable technique to indirectly assess the degree of clogging (Pedescoll et al., 2011; Knowles et al., 2010). For a porous medium, the clogging process, as detected by saturated hydraulic conductivity reductions, was found to be driven by the cumulative loading of total suspended solids (Viviani and Iovino, 2004). Therefore, clogging phenomena observed at long time for low concentrated wastewater could be representative of short term behaviour of CWs treating high concentration wastewater.

Bulk hydraulic conductivity can be estimated from the Darcy law by measuring the water table height at different points in the bed. However, when the hydraulic gradients are small as in the H-SSF CW, accuracy of this approach is questionable (Sanford et al., 1995). Laboratory measurements of hydraulic conductivity are hampered by the non-cohesive nature of gravel that makes it difficult to remove a representative sample whereas in situ assessment of hydraulic conductivity requires instruments and methods specifically designed for highly permeable porous materials (Knowles and Davies, 2009). Pedescoll et al. (2009) successfully applied a simple method based on the falling head permeability test (NAVFAC, 1986) to assess the degree of clogging in two full-scale CWs in Spain. Although many studies have been done, no specific protocol exists to assess the degree of clogging. Therefore, comparison of results obtained by different indirect techniques is probably the unique viable approach to understand to what extent the clogging phenomena influence the overall performance of a constructed wetland.

This study aimed at evaluating the impact of clogging on the treatment performance and hydraulic properties of three full-scale H-SSF CWs treating wastewater from secondary WWTP. The extent of clogging phenomena was investigated by comparing two CWs with identical design and influent characteristics but different operational life. Since there is no single method that can quantitatively measure clogging, three approaches were used: (i) characterization of the clog material, in terms of total solids, volatile solids and belowground plant biomass, (ii) in situ measurements of hydraulic conductivity of the porous media, and (iii) visualization of water flow dynamic by means of tracer tests. Finally, the effect of clogging on the CW treatment performance was evaluated comparing the removal efficiencies of some chemical and physical contaminants.

2. Materials and methods

2.1. Description of constructed wetlands

The research activity was carried out at San Michele di Ganzaria, 90 km South-West of Catania (Sicily), where the biggest natural treatment plant of South Italy was realized for tertiary treatment of municipal wastewater aimed at agricultural reuse. Urban wastewater is treated in a municipal wastewater treatment plant (WWTP) consisting of a pre-treatment step followed by two parallel water lines (Imhoff tank, trickling filter and a secondary sedimentation tank). The effluent from the WWTP is collected to the natural treatment plant that includes four H-SSF CWs operating in parallel, followed by three batch wastewater storage reservoirs. All CWs were excavated into the ground (for a depth of 1 m) leaned with impermeable membrane and filled with gravel (for a depth of 0.6 m).

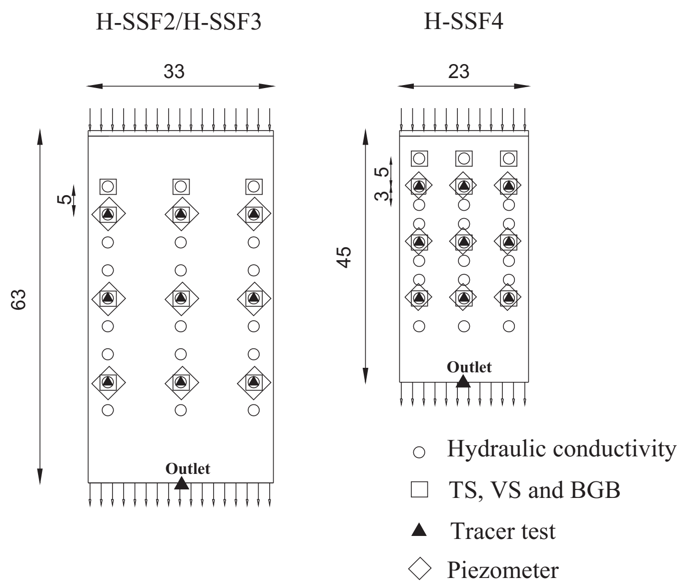

Fig. 1. Schematic setup of the CW beds with indication of the sampling sites for clog matter quantification, saturated hydraulic conductivity measurements and tracer tests. All dimensions are in meters.

The present study was conducted during spring-summer 2014 in three CWs, namely H-SSF2, H-SSF3 and H-SSF4. H-SSF2 has been operating for eight years (since 2006). It has a surface area of about 2000 m^2, is filled with 10–15 mm volcanic gravel, treats a wastewater discharge of about 2 L s^{-1} and is planted with *P. australis* at a density of four rhizomes per m^2. Both H-SSF3 and H-SFF4 have been operating since summer 2012. H-SSF3 has the same design characteristics as H-SSF2 (area, porous medium, flow rate, vegetation type and density). Also the current stem density is similar in both beds, amounting to about 350 stems per m^2. H-SSF4 has a surface area of about 1000 m^2 and it is planted with *Typha*, at a density of four rhizomes per m^2, with a current stem density of about 170 stems per m^2. In all CWs, the influent is distributed at the bed-head through a perforated 200 mm PVC pipe located above the substrate and normal to the flow direction to allow homogenous wastewater distribution into the bed. Wastewater is intercepted downstream by a cross perforated pipe located in the final section at the bottom of the bed and connected to an adjustable outlet to control water level. Electromagnetic flow meters (ISOIL mod. MS2500), installed at the inlet and at the outlet pipes, measure the flow rate (L s^{-1}) in continuous. The electromagnetic flow meters have a totalizer that allows to know the volume of wastewater flowed. In each bed, nine piezometers, arranged in a 3 by 3 array, consisting of 20 cm diameter, open-ended perforated plastic tubes inserted into the gravel to the bottom of the bed, are used to measure the water table heights and to collect wastewater samples (Fig. 1).

2.2. Accumulated material (clog matter)

Laboratory analyses were carried out on bulk samples of gravel media to quantify the clog matter in terms of concentrations of accumulated total solids (TS), volatile solids (VS) and belowground plant biomass (BGB). For each CW, the granular medium, mixed with plant roots and decomposed organic matter, was sampled in four points along three alignments (Fig. 1). For each alignment, one sampling point was selected close to the inlet and the others in proximity to each piezometer. A total of 12 gravel samples were collected in each CW.

At each sampling point, a 20 cm in diameter by 40 cm long sharpened steel tube was used to collect a wet gravel material sample