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Aerobic and anaerobic biodegradability of accumulated solids in horizontal subsurface flow constructed wetlands

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ABSTRACT

This study reports the rate of total solids (TS) accumulation and hydraulic conductivity (HC) in five units of horizontal subsurface flow (HSSF) constructed wetlands (CWs), including unplanted and planted units with four different macrophytes (*Juncus effusus*, *Iris pseudacorus, Thypha latifolia* L. and *Phragmites australis*). Two monitoring campaigns were carried out at 17 (I) and 29 (II) months of operation, at surface loading rates of 2.5 and 4.7 g BOD_5 m^{-2} d^{-1} respectively. Significant differences between units for TS density and most characteristics of accumulated solids were not found. On the contrary, significant differences existed between near inlet and outlet zones as well as between campaigns I and II. In aerobic conditions, approximately 35% of accumulated solids COD was biodegradable at maximum rates of 4.4–12.0 g COD m^{-2} d^{-1}. In anaerobic conditions only 4% of accumulated solids COD was biodegradable at maximum rates of 0.2–0.8 g COD m^{-2} d^{-1}. Thus, promoting aerobic conditions prevents clogging. HC was approximately 16% lower in planted units than in the unplanted unit while a similar drainable porosity drop (13–18%) was registered. The results showed that the presence/absence of vegetation and plant species did not significantly affect clogging in HSSF CWs.

1. Introduction

Constructed wetlands (CWs) are very sustainable systems for wastewater treatment when they are properly designed and operated. Horizontal subsurface flow (HSSF) CWs is one of the most simple and low mechanical technology methods for wastewater treatment, constituting a treatment biotechnology of great interest to its application in developing countries. HSSF CWs can be built with local materials and by local labour, without energy input, although an expert design and implantation supervision is required.

Macrophytes play several roles in engineered ecosystems helping to stabilise the surface of the beds, provide good conditions for physical filtration and insulate the surface against coldness. Plants caused nutrients uptake as well as root-zone oxygen and organic carbon release (Brix, 1997; Tanner, 2001; Vymazal, 2011). Plants also increase microorganism diversity and provide large surface areas for the development of biofilm which is responsible for most of the microbial processes occurring in the wetlands (Button et al., 2015; Chen et al., 2014).

One of the main problems related to the operation of subsurface flow (horizontal and vertical) CWs is clogging of granular media, due to the accumulation of different type of solids, leading to a reduction of the infiltration capacity and porosity of the gravel bed (Hua et al., 2010; Knowles et al., 2011; Pedescoll et al., 2011). Undegraded wastewater solids, microbial biofilm and plant detritus contribute to total solids accumulation in CW granular media. Problems arise when advanced clogging deteriorates the treatment efficiency and drastically reduces the system longevity (Caselles-Osorio et al., 2007; Knowles et al., 2011).

Efficient pre-treatment to reduce influent suspended solids and proper design and operation observing maximum surface loading rates are the main criteria to prevent premature clogging (Winter and Goetz, 2003; Zhao et al., 2009; de la Varga et al., 2013). Other factors such as the presence and type of plants as well as practices that favour oxygenation can affect the clogging process (Chazarenc et al., 2009; Pedescoll et al., 2011).

Plants presence increased the microbial activity (Brix, 1997; Stottmeister et al., 2003) but also increased solids accumulation due to rhizome system (Pedescoll et al., 2011) or to above-ground biomass decay and deposition (Tanner and Sukias, 1995).

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However the effect of plants on solids accumulation can depend on the species, its rhizome morphology and operational practices (Gagnon et al., 2007). Harvesting has been proposed to limit solids accumulation above-ground biomass and improve nutrient removal (Tanner and Sukias, 1995; Pedescoll et al., 2011; Březinová and Vymazal, 2014). On the other hand, Chazarenc et al. (2009) found that plants presence reduced accumulated solids by 26%, while higher solids accumulation and microbial activity in CWs planted with *Typha angustifolia* than in those planted with *Phragmites australis*. Pedescoll et al. (2013) reported a lower interstitial solids accumulation in CWs planted with cattails but also a lower hydraulic conductivity. Thus, contradictory results about the effect of plant presence on wetland clogging persist.

Anaerobic processes play an important role in HSSF CWs because oxygen transfer from the atmosphere or throughout plant rhizomes appeared to be very limited. Artificial aeration has been proposed in order to increase organics and nutrients removal rates (Wu et al., 2016; Chyan et al., 2016). Anaerobic degradation processes are particularly slow in the case of organic matter hydrolysis and suspended solids removal. However, the effect of enhanced aeration on clogging process remains unclear. Compared to continuous operation of HSSF CWs with permanent water saturation, Pedescoll et al. (2011) indicated similar solid accumulation rates and related clogging indicators in HSSF CWs operated in batch mode, alternating unsaturated and saturated phases, which increased oxygen transfer rates. This could be because a higher oxygen transfer rates may enhance biofilm growth in HSSF CWs (Chazarenc et al., 2009). However, these authors also reported that artificial aeration reduced the accumulation of total solids in non-planted CWs.

The aim of this work is to study the accumulation of solids in HSSF CWs planted with different macrophyte species and determine its biodegradability characteristics in both aerobic and anaerobic conditions, and to answer if promoting aerobic conditions increases or reduces clogging risk. Although HSSF CWs are considered mainly as anaerobic systems, to the best of our knowledge this is the first report in determining anaerobic biodegradability of accumulated solids and comparing it with aerobic degradation rates. The effect of several factors such as the presence or absence of vegetation, the plant species (*Juncus effusus*, *Iris pseudacorus, Thypha latifolia* L. and *Phragmites australis*) and the loading rate on solids accumulation and other clogging related parameters (hydraulic conductivity and drainable porosity) was assessed.

2. Materials and methods

2.1. Pilot plant description

The pilot plant was built in 2009 at the outdoors of the Science Faculty of the University of A Coruña, in A Coruña (Spain). The field pilot plant was constituted of five horizontal subsurface flow CW units in parallel, including an unplanted control unit while the others were planted with a different plant species each: HSSF1 (not vegetated), HSSF2 (*Juncus effusus*) HSSF3 (*Iris pseudacorus*), HSSF4 (*Thypha latifolia* L.) and HSSF5 (*Phragmites australis*). Each CW unit has an overall surface of 12 m^2 (3 m wide x 4 m long), depth of 0.35 m (0.3 m of water depth at the outlet) and 1% slope in the flow direction. The cells were filled with crushed granitic gravel of 6–12 mm in size, except for the inlet and outlet zones (0.5 m long) where large stones (60 mm) were used. Mean porosity resulted in 39.3% and effective (void) volume of 1.36 m^3. The influent was fed with a peristaltic pump and was uniformly distributed at the inlet zone of the CW by entering through a buried distributor pipe (200 mm in diameter) placed horizontally and perpendicular to the direction of flow. The medium surrounding the pipe was 40–60 mm stone (Fig. 1). Wastewater reached the gravel medium through six orifices of 30 mm holed in this pipe. A similar arrangement was placed in the outlet zone of each HSSF unit. The effluent entered the 200 mm pipe through six orifices of 30 mm in diameter uniformly distributed and exited through a unique effluent point consisting of an adjustable weir. At the inlet and outlet zones, the buried pipe and surrounding stone medium reached a lenght of 0.5 m (Fig. 1).

The influent to the plant comes from a local sewer receiving wastewater from one of the faculties of the University of A Coruña and surrounding houses and was pre-treated in an up-flow anaerobic sludge bed digester. From the day 650 until the end, the influent to the plant was supplemented with wine vinegar in order to increase influent concentration and surface loading rate (SLR).

The amount and characteristics of accumulated solids were determined twice, after 17 (campaign I) and 29 (campaign II) months of operation (Table 1). Both campaigns were carried out in winter and lasted for about 2 months. The campaigns started harvesting the above-ground plants, which were characterized. After that, gravel samples were taken for the characterization of accumulated solids. Finally the HC and drainable porosity was determined.

2.2. Procedures for solid sampling and hydraulic conductivity and drainable porosity determination

To obtain samples of accumulated solids four points were sampled in each wetland, two in the inlet zone and two in the outlet zone (Fig. 1). In each sample point, first, a steel cylinder of 13 cm diameter was inserted into the medium until reach the bottom and the gravel inside was removed with a gardening shovel, after that a sample of interstitial liquid was taken separately. A gravel sample was placed in a bucket that contains oxygen depleted effluent, and was shaken to extract the solids from the gravel to the aqueous suspension avoiding their aeration. The samples from the two inlet points were mixed and concentrated by decantation in order to obtain a unique and representative inlet sample. The same procedure was made with the samples from the outlet zone. So, in each wetland, one integrated sample from the inlet and another from the outlet zone were analyzed to determine the amount and characteristics of the accumulated solids. The parameters analyzed were total (TS) and volatile (VS) solids, chemical oxygen demand (COD), aerobic biodegradability by means of biological oxygen demand (BOD) assay, and anaerobic biodegradability (ABD) by means of methane potential assay. TS density was obtained as the ratio of accumulated solids mass to the area of HSSF units.

Hydraulic conductivity was measured in duplicate points near to that of solid measurements (Fig. 1) throughout the falling head method. A large metallic cylinder of 8 cm internal diameter perforated along the lower 15 cm was inserted into the gravel for a 15 cm depth below the water level. The gravel above the water surface was removed and the cylinder filled with clean water. The falling velocity of water was determined by means of a hydrostatic pressure probe (level transmitter TNS-119-Desin Instruments) and registered by Datataker DT50. Other details and data processing followed the methods described by Pedescoll et al. (2009).

The drainable porosity was determined by empting the beds at a slow flow (less than 4 L min^{-1}, for about 3 h) in order to avoid washout of solids, and measuring the initial and final heights of the water table in the bed and the drained water volume. The quotient between the drained water volume and the drained bed volume gives the drainable porosity. Measurements were carried out for two water table horizons as indicated in Section 3.