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Intermittent aeration to improve wastewater treatment efficiency in pilot-scale constructed wetland

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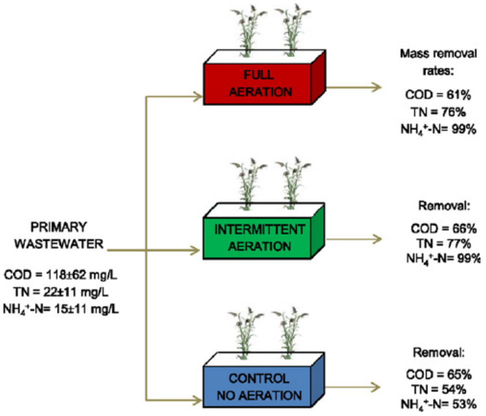
HIGHLIGHTS

- This study tests intermittent and full aeration to improve wastewater treatment.
- Intermittent aeration reached better COD, ammonium and total nitrogen removals.
- Full aeration promotes ammonium removal, but with higher nitrates in the effluent.
- Intermittent aeration is an energy efficient solution to improve wastewater quality.

GRAPHICAL ABSTRACT



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ABSTRACT

Forced aeration of horizontal subsurface flow constructed wetlands (HSSF CWs) is nowadays a recognized method to improve treatment efficiency, mainly in terms of ammonium removal. While numerous investigations have been reported testing constant aeration, scarce information can be found about the efficiency of intermittent aeration. This study aims at comparing continuous and intermittent aeration, establishing if there is an optimal regime that will increase treatment efficiency of HSSF CWs whilst minimizing the energy requirement. Full and intermittent aeration were tested in a pilot plant of three HSSF CWs (2.64 m^2 each) fed with primary treated wastewater. One unit was fully aerated; one intermittently aerated (i.e. by setting a limit of 0.5 mg/L dissolved oxygen within the bed) with the remaining unit not aerated as a control. Results indicated that intermittent aeration was the most successful operating method. Indeed, the coexistence of aerobic and anoxic conditions promoted by the intermittent aeration resulted in the highest COD (66%), ammonium (99%) and total nitrogen (79%) removals. On the other hand, continuous aeration promotes ammonium removal (99%), but resulted in nitrate concentrations in the effluent of up to 27 mg/L. This study demonstrates the high potential of the intermittent aeration to increase wastewater treatment efficiency of CWs providing an extreme benefit in terms of the energy consumption.

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1. Introduction

Constructed wetlands (CWs) have been widely used in the last few decades (Vymazal, 2011), showing worthy efficiency in the treatment of urban wastewater, mine water, landfill leachate, industrial effluents, air-strip runoff and road runoff (Kadlec and Wallace, 2009). A favorable performance in terms of organic matter and ammonium removal, together with the low energy requirements, a minimal maintenance requirement and low operational costs are among the reasons for the wide spread implementation of the technology all over the world (García et al., 2010). Moreover, the important role of CWs as greenspace and wildlife habitat make them an appropriate alternative to conventional wastewater treatment, mainly in wild and isolated small communities.

Subsurface oxygen limitation has been identified among the main factors compromising contaminant removal in horizontal subsurface flow constructed wetlands (HSSF CWs) (Brix and Schierup, 1990). Such systems promote the co-existence of different redox statuses, these strongly affect the relative importance of the biochemical pathways for organic matter and nutrient removal (García et al., 2004).

Forced or active aeration, originally developed by Wallace (2001), has received increasing attention in the recent years as an efficient technique to improve removal of organic matter and reduce nitrogen species in HSSF CWs (Nivala et al., 2007; Wu et al., 2014). This technology has been employed for industrial waste streams, including contaminated groundwater (Wallace and Knight, 2006), coffee processing wastewater (Rossmann et al., 2013), landfill leachate (Nivala et al., 2007), airstrip deicing runoff (Higgins, 2003; Murphy et al., 2015), aquaculture (Webb et al., 2013) and livestock wastewater (Zhu et al., 2012). Recent studies highlight the efficiency of aerated systems in reducing nitrogen (Li et al., 2014), emerging contaminants (Ávila et al., 2014) and greenhouse gas emissions (Maltais-Landry et al., 2009). Besides this Labella et al. (2015) showed that the reduction of the surface required by aerated systems counterbalances the investment and power consumption of aeration, resulting in similar costs for both aerated and conventional systems.

Most experiences with forced aeration however refer to continuous aeration, which has a significant energy consumption and can hamper the development of anoxic conditions (Wu et al., 2014). Anoxic conditions are needed for denitrification, which is an anaerobic heterotrophic process limited by the presence of oxygen and by the organic carbon availability (Fan et al., 2013).

In this sense, intermittent aeration controlling and adjusting the dissolved oxygen within the wetland seems to offer an effective alternative to avoid excessive aeration and achieve better total nitrogen removals. In fact, intermittent aeration provides environments of aerobic and anoxic conditions stimulating simultaneous nitrification and denitrification processes (Boog et al., 2014; Fan et al., 2013), which is considered the main N sink in CWs (Tanner et al., 2002). In spite of the promising results obtained in some recent studies (Fan et al., 2013; Zhang et al., 2010), currently scarce information on intermittent aeration is available. Moreover, continuous and intermittent aeration have not been compared yet.

The aim of this study was to determine the optimum forced aeration regime (i.e. continuous or intermittent) of HSSF CWs in order to increase treatment efficiency and reduce the energy consumption. To this end, the effect of continuous and intermittent aeration on organic matter and nitrogen removal was evaluated in pilot HSSF CWs.

2. Materials and methods

2.1. Pilot plant

The experimental plant (Fig. 1) was located at the Agropolis campus of the Universitat Politècnica de Catalunya·BarcelonaTech, in the municipality of Viladecans, near Barcelona, Spain (41.288 N, 2.043 E UTM). The plant was built in early 2015 and set in operation in May of the same year. The raw wastewater, coming from an office building hosting around 50 people, was treated in a septic tank and then pumped to a continuously stirred plastic tank (1.2 m^3 volume) used as a reservoir for a few hours. Afterwards, wastewater (here on referred to as influent) was pumped equally into three HSSF CWs in parallel which provided secondary treatment. The individual CW cells were built with an external steel structure supporting five composite polypropylene and glass fiber panels which form the lightweight support for a butyl rubber waterproof membrane. Each CW was built as a prototype for an autonomous reed bed installation as part of a larger project. Each CW had a surface of 2.64 m^2 (2.2 m long, 1.2 m wide, 1.3 m high). A uniform gravel layer (40% estimated initial porosity) was set to provide a depth of 1.10 m. The water level was kept at 0.10 m below the gravel surface, giving a total water depth of 1 m. The CWs were planted in April 2015 with common reed (*Phragmites australis*) at an initial density of 16 plants/m^2. The CWs were automatically fed by means of peristaltic pumps under a continuous flow regime and operated at 5.5 days of hydraulic retention time (HRT), with a surface hydraulic loading rate (HLR) of about 7.2 cm/d and a cross-sectional organic loading rate (OLR) around 8 gCOD/m^2 d. More details about the beds design and operation can be found in Table 1. During the setting-up of the system, a PVC cylinder (volume of about 0.22 m^3) was placed nearby the outlet zone of each bed in order to provide a free gravel zone.

2.2. Aeration system

Aeration was provided in each bed by means of six aeration pipes (outer diameter of 15 mm) pierced with 3 mm holes at a 305 mm separation. These parameters were selected based on typical values used in industrial settings. The system of pipes covering the bottom of the beds was connected to a compressor injecting air at a flow rate of 12.1 m^3/h (Josval Serie Cierzo NK 50, Zaragoza, Spain).

As previously done by Labella et al. (2015), dissolved oxygen at the bottom of the three wetlands was continuously monitored by means of a dissolved oxygen probe (CS512 Oxyguard Type III, Campbell Scientific Inc., USA) located in the gravel free area at the bottom of each bed and connected to a data logger (CR1000, Campbell Scientific Inc., USA).

In order to assess the effect of forced aeration on the wetlands performance, the experimental design as shown in Fig. 1 was employed with

- one bed continuously aerated (here on referred to as fully aerated);
- one bed with intermittent aeration controlled by a minimum oxygen set point concentration of 0.5 mg/L (later referred to as intermittently aerated); and
- one bed not aerated (referred to as the control from this point onwards).

The intermittent aeration was achieved by means of a feedback option of the data logger (control Deadbond version 2.5). The valve controlling air injection was opened when the oxygen concentration was lower than the 0.5 mg/L set point and closed for values higher than this. This configuration was established in accordance with previous results showing that wastewater treatment was satisfactorily improved when oxygen concentration within the wetlands was maintained at 0.5 mg/L (Labella et al., 2015).

2.3. Physical and chemical analysis

Water quality was monitored during twelve weeks (between May and July 2015) collecting 27 samples from CWs influent (effluent of the stirred plastic tank) and 27 samples from the CWs effluent. The surveyed water quality parameters were the total chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), ammonium nitrogen