Journal of Environmental Management 136 (2014) 47–53

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Applying a resting operation to alleviate bioclogging in vertical flow constructed wetlands: An experimental lab evaluation

Guofen Hua [a,b,*], Yitao Zeng [a], Zhongwei Zhao [b,c], Kaibo Cheng [a], Gang Chen [a]

[a] College of Water Conservancy and Hydroelectric Power, Hohai University, No. 1 Xikang Road, Nanjing 210098, PR China
[b] State Key Laboratory of Hydrology-Water Resource and Hydraulic Engineering, Hohai University, No. 1 Xikang Road, Nanjing 210098, PR China
[c] College of Environment, Hohai University, No. 1 Xikang Road, Nanjing 210098, PR China

ARTICLE INFO

Article history:
Received 14 November 2013
Received in revised form
22 January 2014
Accepted 25 January 2014
Available online 20 February 2014

Keywords:
Biofilm
Clogging
Constructed wetlands
Resting operation

ABSTRACT

The aim of this study is to evaluate the effects of and analyze the reasons for applying a resting operation to alleviate bioclogging in vertical flow constructed wetlands (VFCWs). In parallel, three groups of laboratory-scale VFCWs were continuously fed with prepared wastewater (BOD = 600 mg/L) at a relatively high hydraulic loading rate of 0.5 $m^3/m^2 \cdot d$ until clogging. Parameters related to the clogging of the wetland substrate before and after resting were examined and measured. The results showed that the resting operation could effectively alleviate bioclogging because the hydraulic conductivity and effective porosity were improved after 3, 7 and 10 days of resting. In the upper 0–10 cm layer, the hydraulic conductivity increased 2.0, 2.6 and 3.5 times, respectively, for the three resting periods. The reduction of the extracellular polymeric substance (EPS), biofilm decay and the consequential change in the biofilm structure are the main reasons that the resting operation relieved clogging. In addition, the observed and theoretical resting times (approximately 7 days) agreed well. The results provide a theoretical basis and technical support for solving clogging problems.

1. Introduction

VFCWs are used worldwide to remove pollutants from wastewaters because of their mechanical simplicity and low operation and maintenance requirements in comparison to conventional wastewater treatment technologies (Knowles et al., 2011; Ranieri and Young et al., 2012; Gikas et al., 2013). Clogging is considered a critical factor in the removal efficiency and life span for this type of system (Cooper et al., 2005; Wallace and Knight, 2006). Clogging is a complex phenomenon that involves biological, chemical and physical processes. The key causes for clogging are (1) organic solids deposited on the constructed wetland surface that block pores; (2) suspended solids accumulated inside the voids of the filter; and (3) microorganisms that grow rapidly (Langergraber et al., 2003).

Strategies to combat clogging fall into two types: preventative strategies, which are aimed at delaying or minimizing the negative effects of clogging, and restorative strategies, which are designed to reclaim systems exhibiting clogging-related hydraulic problems or poor treatment efficiency (Nivala et al., 2012).

Preventative strategies include approaches such as best management practices (Turon et al., 2009); inlet and loading adjustments (Winter and Goetz, 2003); using anaerobic digesters as pretreatment (Varga de la et al., 2013); and changes to the hydraulic operating conditions, including applying intermittent operation, backwashing and/or reversing the direction of the flow (Behrends et al., 1996; Sun et al., 2007; Austin et al., 2006). One of the earliest design proposals to prevent bed clogging was minimizing the inlet cross-sectional loading, and it was recommended that the cross-sectional biological oxygen demand (BOD) loading be less than 250 $g/m^2 \cdot d$ for the bed medium, with a d_{10} (d_{10} is defined as the particle diameter at 10% of the cumulative particle size distribution) greater than 4 mm (Winter and Goetz, 2003). Intermittent operation (e.g., operation followed by a period of resting) or bed resting is intended to remove organic solids and to change the formation of inorganic solids, such as ferric hydroxide precipitates, by improving oxygen transfer (Ouellet-Plamondon et al., 2006). However, intermittent operation inevitably affects the design-

Abbreviations: VFCWs, vertical flow constructed wetlands; EPS, extracellular polymeric substance; BOD, biological oxygen demand; TOC, total organic carbon; ASM, activated sludge model.

* Corresponding author. College of Water Conservancy and Hydroelectric Power, Hohai University, No. 1 Xikang Road, Nanjing 210098, PR China. Tel.: +86 13851936533.
E-mail address: Huaguofen2005@126.com (G. Hua).

0301-4797/$ – see front matter © 2014 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jenvman.2014.01.030

loading rate of an influent because both options require lowering the loading rate for a constant wastewater quantity, which implies that more area is needed. Flushing the accumulated solids from the bed substrate to delay clogging should be performed before the onset of clogging, and a combined air/water flush is the most effective treatment (Fei et al., 2010). However, it is inconvenient to install a flushing pipe to mitigate clogging problems because of the presence of plants. Furthermore, it is difficult to determine how often flushing needs to be performed.

Restorative strategies include replacing dirty gravel with new gravel (Wallace and Knight, 2006); the excavation, washing and reuse of gravel (Murphy et al., 2009); the direct application of chemicals (e.g., H_2O_2, NaClO) to the gravel bed (Hua et al., 2010a; Nivala and Rousseau, 2009); and, most recently, adding earthworms to the system (Li et al., 2011). For either excavation and replacement or washing, these strategies entail a high cost but are relatively effective. Gravel or sand replacement also requires the disposal of the excavated material, adding to rehabilitation costs. Additionally, the entire wetland system, especially the plants, can be destroyed by both of these methods. Consequently, replantation and recovery time are required before reusing the wetland. The excavation of clogged gravel is the most expensive method, although it is also the only one that can restore the porosity to its initial value. For chemical methods, the properties and concentrations of the solvents should be considered because solvents can harm plants and microsystems (Hua et al., 2010a). Furthermore, the composition of the elution and the recovery time of the treatment performance in wetlands after chemical treatment are unknown.

Although each method has advantages and disadvantages, resting operation is a relatively good, in situ, non-intrusive method to alleviate clogging because of its relatively low cost and because it does not destroy or harm the system. In resting operated VFCWs, air will enter the pores of the substrate during the resting period, where it rapidly oxygenates exposed biofilms and presumably promotes the in situ aerobic digestion of organic solids (Nivala et al., 2012). Using this method, clogging problems, especially bioclogging (defined as the accumulation of microbial biomass inside the pore space of wetland media, leading to a reduction of the effective porosity and hydraulic conductivity (Thullner, 2010)), are solved. However, the effects of resting on clogging have yet to be quantified, and the mechanism of resting operation to avoid clogging is still not clear.

In this study, the effects of resting operation on bioclogging were quantitatively evaluated using hydraulic parameters. Based on the biochemical parameters, the reasons for using a resting operation for de-clogging were analyzed. The outcomes provide important information to manage clogging.

2. Materials and methods

2.1. Experimental wetland setup and operation

Three groups of identical laboratory-scale wetland columns made of Perspex (organic glass) 100 cm in height and 30 cm in diameter (Fig. 1) were used in the study. Each group had three duplicates. The columns were filled with identical coarse sand ($d_{10} = 0.12$ mm) to a depth of 70 cm. At the bottom of each column, there was a 10-cm graded gravel layer composed of large pebbles.

All the columns were planted with *Typha angustifolia*. Before the experiments, the plants were grown for approximately 2 months with excess fertilizer and then were inoculated with activated sludge obtained from a local municipal wastewater treatment plant for 3 weeks to form the microbial community. The plant density was selected to reference the common plant density of constructed wetlands in eastern China (Xu et al., 2009). The diameter of plant in a cluster density corresponded to that of the wetland column to simulate the actual clogging condition. Therefore, the wetland column was equivalent to a vertical intercept of the actual wetland. To prevent algal growth, light–tight cloth was used to wrap the outside surface of all Perspex wetland columns. In addition, the ability to remove the light–tight cloth allowed photos of the observed phenomena to be taken.

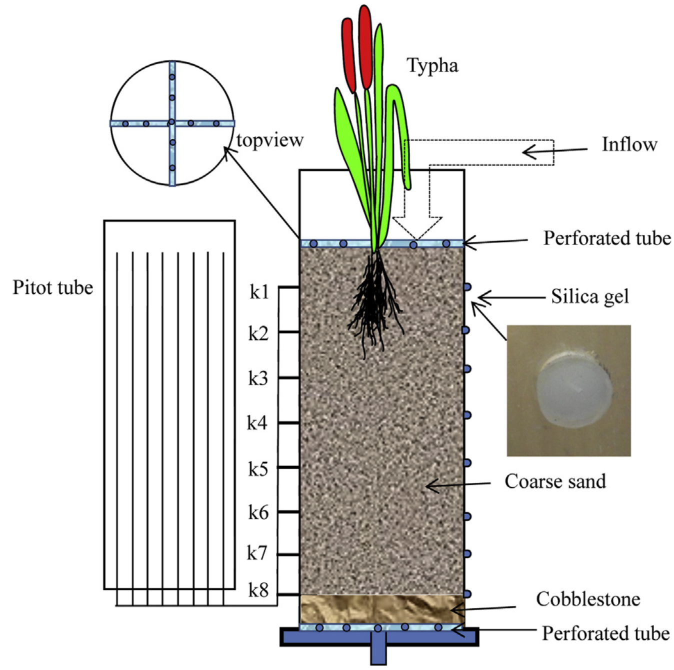

Fig. 1. Schematic diagram of the CW system, to the left were Pitot's tubes to measure head losses, to the right was the wetland column.

Wastewater flowed into the tops of the columns and was discharged from the bottoms through puncture tubes. Pitot tubes were set at 10-cm intervals along the depth of the wetland beds to measure each layer's hydraulic conductivity. Silica gel ports were positioned in the column wall opposite the Pitot tubes. The creation of silica gel ports allowed the use of a medical syringe to sample the pore water because silica gel has elastic properties.

Artificial wastewater was made by adding glucose to tap water as the source of easily biodegradable suspended organic solids (Caselles-Osorio et al., 2007). Thus, the biofilm that adhered to the surface of the substrate was cultivated via continuous feeding with the prepared wastewater with a BOD of 600 mg/L. The biofilm was also seeded with anaerobic digestion sludge and aerated for 2 h per day. Subsequently, $(NH_4)_2SO_4$, $CO(NH_2)_2$ and K_2HPO_4 were added to the artificial wastewater as major nutrients to provide TN and TP concentrations of approximately 10 mg/L and 2 mg/L, respectively.

The lab experiment was divided into two stages. During the first stage, to accelerate clogging, the three groups of CWs were continuously operated in parallel at a relatively high hydraulic loading rate of 0.5 $m^3/m^2 \cdot d$ for about 90 days. The wetland columns were saturated by controlling the flow rates between the inflow and outflow. After this process, the effective porosity was reduced to conduct the resting operation experiments. The total organic carbon (TOC) removal rate of the wetland system was maintained at 60–70%. The water velocity and water surface level (5 cm above the sand surface) were maintained throughout the experiment. During the second stage, the three groups of VFCWs were stopped to rest for 3, 7 and 10 days, respectively, to investigate the effect of starvation of microorganisms on de-clogging.