Ecological Engineering 83 (2015) 184–190

Contents lists available at ScienceDirect

Ecological Engineering

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

Assessing the economic suitability of aeration and the influence of bed heating on constructed wetlands treatment efficiency and life-span

Alessandro Labella[a], Donatella Caniani[a], Theodore Hughes-Riley[b], Robert H. Morris[b], Michael I. Newton[b], Patrick Hawes[c], Jaume Puigagut[d], Joan García[d], Enrica Uggetti[d,*]

[a] School of Engineering, University of Basilicata, Potenza, Italy
[b] The Nottingham Trent University, Nottingham, United Kingdom
[c] ARM Ltd., Rydal House, Colton Road, Rugeley, Staffordshire, United Kingdom
[d] GEMMA—Group of Environmental Engineering and Microbiology, Department of Hydraulic, Maritime and Environmental Engineering, Universitat Politècnica de Catalunya, BarcelonaTech, Barcelona, Spain

A R T I C L E I N F O

Article history:
Received 28 November 2014
Received in revised form 21 May 2015
Accepted 20 June 2015
Available online 1 July 2015

Keywords:
Artificial aeration
Heating
Wastewater treatment
Clogging
Constructed wetlands

A B S T R A C T

Constructed wetlands including aeration and heating were studied to improve treatment efficiency and prevent clogging. The experiments were carried out in a pilot plant (0.4 m^2) treating urban wastewater with an organic loading rate of 40–60 g COD/m^2 d. Continuous and intermittent aeration was performed from the bottom on 8% of the wetland surface, leading to different dissolved oxygen concentrations within the wetlands (from 0.2 to 5 mg O_2/L). Continuous aeration increased organic matter (COD) and ammonium nitrogen removal by 56% and 69%, respectively. Improvements in wastewater treatment caused by aeration can result in reduction of the surface area requirement of future systems. This work demonstrated that for the studied configuration the cost of the power consumption of the continuous aeration was largely covered by the reduction of the wetlands surface. Even if the heating of 8% of the wetland surface at 21 °C had no effects on treatment performance, positive results showed that solids accumulation rate within the granular medium, which is closely related to the development of clogging. It has been demonstrated that heating for 10 days per year during 20 year period would delay the equivalent of 1 year of solids accumulation.

1. Introduction

Constructed wetlands (CW) are widely used for the treatment of wastewater including urban wastewater, minewater, landfill leachate, industrial effluents, air-strip runoff and road runoff (Kadlec and Wallace, 2009).

In horizontal subsurface flow constructed wetlands (HSSF CW) the water, maintained at a constant depth, flows horizontally below the surface of a granular medium planted with emergent rooted wetland vegetation. In such systems contaminants are removed thought a number physical, chemical, and biological processes taking place simultaneously (García et al., 2010). Note that vertical flow constructed wetlands, are not a topic covered in this manuscript.

In recent years research on HSSF CW has focused on the improvement of treatment performance, as well as on the prevention of clogging phenomenon and on the understanding of fundamental processes occurring in wetlands (García et al., 2010).

Since HSSF CWs are generally considered to be anaerobic, organic matter oxidation and nitrification may be enhanced by promoting more oxidized conditions (Caselles-Osorio and García, 2007). Among the strategies to increase CW performance, forced (or active) aeration patented by Wallace (2001) has been recently suggested as an efficient way to improve removal of organic matter and reduced nitrogen species (Nivala et al., 2007; Wu et al., 2014; Fan et al., 2013a).

Since the years 2000, active aerated systems have shown interesting results increasing significantly the removal rates compared to passive systems (Ouellet-Plamondon et al., 2006; Maltais-Landry et al., 2009). A laboratory-scale study has indicated that aeration has a certain effect on the solids degradation rates, increasing the amount of accumulated total organic suspended solids against the mineral fraction (Chazarenc et al., 2009; Zhang et al., 2010).

In spite of the advantages of aeration, the costs increase should be taken into account as CW ordinarily have a low operating cost. Most of the studies on active aeration referred to "continuous aeration mode" (i.e. 24 h per day) which has a significant energy consumption. Nonetheless, energy requirements of aerated CW

* Corresponding author. Fax: +34 9340173574.
E-mail address: enrica.uggetti@upc.edu (E. Uggetti).

http://dx.doi.org/10.1016/j.ecoleng.2015.06.028
0925-8574/

(0.16–0.49 kWh/m^3 of water treated) are still largely lower than conventional waste water treatments such as activated sludge (0.76–0.88 kWh/m^3 treated) (Kadlec and Wallace, 2009; Austin and Nivala, 2009).

Moreover, this option can lead to a contradiction between the removal of ammonium and total nitrogen because of the lack of favourable anoxic conditions for denitrification (Wu et al., 2014). Important improvements could be achieved with intermittent aeration where the level of aeration could be adjusting and controlled (i.e. adjusting the dissolved oxygen within the wetland) and excessive aeration could be avoided (Fan et al., 2013b). In this case intermittent aeration has been shown to achieve high total nitrogen removal by providing alternate aerobic/anoxic conditions for the simultaneously occurring nitrification and denitrification (Boog et al., 2014; Li et al., 2014).

The higher contaminant removal rates achieved in forced aerated CW might lead to a significant surface requirement reduction for future systems. Therefore, the aeration is only justified when its costs are counterbalanced by the reduction in the capital cost derived by the decrease of the wetland size (Kadlec and Wallace, 2009).

Apart from the efficiency in pollutant removal, the clogging of the porous medium is among the main operational problems of HSSF CW. Clogging may result in hydraulic malfunction associated with reduced treatment performance due to preferential water flows, dead zones and short circuits. Clogging affects the longevity of the systems, indeed the original life span prediction were in the order of 50–100 years (Conley et al., 1991) whereas experimental evidence has shown lifetimes of 8 years (Griffin et al., 2008).

Clogging has been widely studied during recent years (Knowles et al., 2011; Nivala et al., 2012; Maloszewski et al., 2006; Murphy and Cooper, 2010; Ragusa et al., 2004; Tietz et al., 2007). It is well known that clogging is caused by the accumulation of materials associated with treatment. The quantity and composition of the clog matter may vary but typically consists of highly hydrated gels and sludge with inorganic (e.g. solids from chemical erosion of gravel) and organic solids (e.g. biomass growth, plant roots, biofilm and plant detritus) (Knowles et al., 2011; Pedescoll et al., 2011a).

It is generally accepted that soluble COD in spring or beginning of summer increases at the outlet of a wetland, thus decreasing treatment efficiency after winter time (Pedescoll et al., 2011b). This is mainly due to the organics accumulation during winter. When temperature raises (spring time) hydrolysis of organics retained in the wetlands increases. The increase of the temperature within the CW may enhance the organic matter oxidation (Garfí et al., 2012; Kirschbaum, 2004). In this context, warming up the wetland might be of use not only on the increase of treatment efficiency but also on the mobilization of organics accumulated within the treatment bed. Furthermore, nitrification is limited in winter time (even in warm regions such as Spain). Warming the water up few degrees at the beginning of spring-time could help to decrease the soluble background COD generally found in this period. Increased background COD at the beginning of spring is a consequence of organics hydrolysis accumulated during winter time.

This study had two main objectives, to assess the economic suitability of active aeration in HSSF constructed wetlands and to study the effect of heating on the longevity of HSSF constructed wetlands.

2. Materials and methods

2.1. Pilot plant

The experimental plant was located in Barcelona (Spain) at the Department of Hydraulic, Maritime and Environmental Engineering of the Universitat Politècnica de Catalunya, BarcelonaTech. The plant was set in operation in March 2011. Wastewater was pumped from a municipal sewer where it was then screened and subsequently stored for approximately 5 h in a continuously stirred plastic tank (1.2 m^3 volume). The primary treatment consisted of a hydrolytic upflow sludge bed reactor (HUSB) with 3 h of hydraulic retention time (HRT). The primary treatment was followed by two HSSF CW in parallelacting as secondary treatment. Each CW was made of a PVC container with a surface of 0.4 m^2 (0.75 m long, 0.55 m wide,0.39 m high). A uniform gravel layer (40% initial porosity) was used which provided a wetland depth of 0.35 m. The water level was kept at 0.05 m below the gravel surface to give a water depth of 0.30 m, as suggested by García et al. (2004). CW were planted with common reed (*Phragmites australis*) at an initial density of 16 plants/m^2.

Both CW were fed under continuous flow regime and operated at 0.8 days HRT, hydraulic loading rate (HLR) of about 160 L/m^2 d and an organic loading rate (OLR) ranging from 40 to 60 g COD/m^2 d. Such conditions were set in order to “force” the systems to detect the effect of aeration and heating.

In order to measure the evapotranspiration, the water flow was measured at the inlet and at the outlet of each wetland by means of peristaltic pumps (at the inlet) and a flow meter device located at the outlet. However, values recorded from the flow meter device indicated that evapotranspiration effect was negligible during the experimental period.

2.2. Physical and chemical analysis

Water quality was monitored from influent and effluents samples twice a week from November 2013 to May 2014. The surveyed water quality parameters were the total chemical oxygen demand (COD), ammonia nitrogen, nitrite and nitrate nitrogen. Such parameters have been selected as reliable parameters for water quality monitoring. Analyses were carried out according to Standard Methods (APHA-AWWA-WEF, 2005). Nitrite and nitrate nitrogen was analysed with ion chromatograph (ICS1000, Dionex, USA).

2.3. Aeration experiment

In order to assess the effect of aeration on wetlands performance, from November 2013 to February 2014 one of the CW (named “experimental CW” henceforth) was equipped with an aeration system whereas the other wetland (control) operated under normal saturated passive conditions.

The aeration system consisted of a pierced resin pipe of about 50 cm long, rolled at the bottom of the wetland at its central zone (Fig. 1). The aeration roll occupied a surface of 0.03 m^2, which corresponded to 8% of the total bed surface. The air was injected by means of an air pump working at a flow rate of 720 L/h.

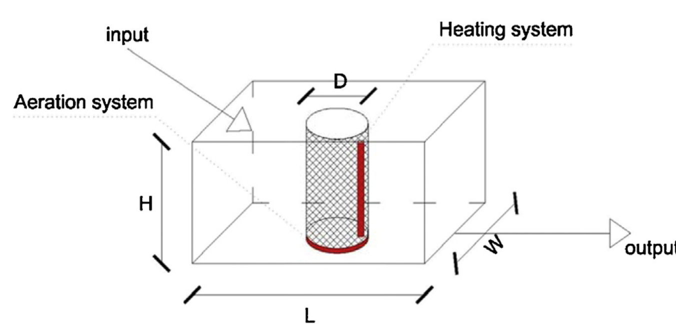

Fig. 1. Scheme of the pilot wetland with the aeration systems. During the construction of the system, a cylindrical part of the central zone of the bed was kept without gravel in order to allow experiments.