Ecological Engineering 80 (2015) 53–61

Contents lists available at ScienceDirect

Ecological Engineering

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

Influence of the water saturation level on phosphorus retention and treatment performances of vertical flow constructed wetland combined with trickling filter and $FeCl_3$ injection

B. Kim [a,b], M. Gautier [a,*], P. Molle [c], P. Michel [b], R. Gourdon [a]

[a] University of Lyon, INSA Lyon, LGCIE - DEEP, 20 av. A. Einstein, Villeurbanne cedex F-69621, France
[b] SCIRPE, Society of Design and Production Engineering for Wastewater Purification, 5 Allée Alban Vistel, Sainte Foy Lès Lyon F-69110, France
[c] IRSTEA, UR MALY, 5 rue de la Doua, Villeurbanne F-69100, France

ARTICLE INFO

Article history:
Received 28 February 2014
Received in revised form 27 September 2014
Accepted 28 September 2014
Available online 13 October 2014

Keywords:
Vertical flow constructed wetland
Trickling filter
Ferric chloride coagulation
Redox potential
Phosphorus

ABSTRACT

The aim of the study was to determine the effects on treatment efficiency of oxidation–reduction (redox) conditions that are caused by different water saturation levels within vertical-flow constructed wetlands (VFCW), with specific attention to phosphorus (P) retention. The study was conducted by monitoring over 18 weeks a pilot-scale system consisting of a biological aerobic trickling filter as a biological pre-treatment step, followed by ferric chloride ($FeCl_3$) addition for phosphate removal and a stage of VFCW. By adjusting the water saturation level, the VFCW was operated successively under fully unsaturated, partly saturated, completely saturated (flooded), and then again unsaturated conditions. Redox potentials (Eh) were measured at three different levels within the VFCW. Results revealed that Eh was logically affected by the water-saturation level and the feeding–resting periods. Treatment efficiency was very good under fully unsaturated and partly saturated conditions. Under flooded conditions, the performance of the filter declined when the flood was maintained for around one week. However, VFCW regained its previous efficiency after the effluent was drained out and aerobic conditions were restored, indicating that the system was resistant and robust enough that periodical flooding did not affect its performance afterwards.

1. Introduction

Raw domestic wastewater treatment by vertical flow constructed wetlands (VFCW) has become very well developed in small communities in France (Molle et al., 2006; Torrens et al., 2009). Numerous studies have proven the efficiency of the system in carbon removal and nitrification (Abou-Elela et al., 2013; Brix and Arias, 2005; Kadlec et al., 2000). Other authors introduced various alternative compact systems (Heistad et al., 2006; Prigent et al., 2013) or highlighted some limitations of VFCWs such as low denitrification rate and poor phosphorus removal (Prochaska et al., 2007; Verhoeven and Meuleman, 1999). Indeed, the release of nitrates and phosphorus into sensitive aquatic ecosystems may promote eutrophication (Lowe and Keenan, 1997; Schindler, 1977; Tiessen, 2008), and therefore phosphorus (P) and total nitrogen (TN) concentrations in the treated effluents must satisfy increasingly low regulatory limits.

In order to improve TN and P removal, various combined processes and tertiary treatments were developed. Hybrid systems combining vertical and horizontal flow (HF) constructed wetlands were investigated for TN removal by successive nitrification and denitrification (Molle et al., 2008; Vymazal, 2005). Good efficiencies were obtained but with increased environmental footprint. Regarding phosphorus removal, most studies investigated systems using various filter media with high phosphorus sorption capacity (Martín et al., 2013; Molle et al., 2011; Vohla et al., 2011). Although very efficient, these approaches may not provide cheap and durable solutions on a long term.

An alternative approach, the AZOE-NP® process, was developed by the French company SCIRPE (EP1857419A1; WO2012150296). The treatment line combines: (i) a screening at 3 mm mesh, (ii) a biological aerobic trickling filter, (iii) ferric chloride ($FeCl_3$) addition for dissolved phosphate removal and (iv) two stages of partly saturated VFCWs. The use of a trickling filter

* Corresponding author. Tel.: +33 (0)4 7243 8348; fax: +33 (0)4 7243 8717.
E-mail address: mathieu.gautier@insa-lyon.fr (M. Gautier).

http://dx.doi.org/10.1016/j.ecoleng.2014.09.097
0925-8574/

as a first biological treatment step allows to reduce the required surface of VFCW down to a maximum of 1.5 m^2 per population-equivalent (PE) as compared to 2 m^2 in the general operational recommendations in France for classical two-stage VFCWs (Molle et al., 2005).

One of the particularities of the AZOE-NP® system is the succession of different levels of redox conditions along the process line. Firstly, the trickling filter is passively aerated by its bottom part and therefore stimulated aerobic microbial processes such as nitrification. Then, within each VFCW stage, the upper zone is not saturated and therefore aerobic, whereas the lower zone is saturated with anoxic conditions allowing denitrification process to occur. The depth of the saturated zone can be adjusted to optimize TN removal efficiency. Another particularity of the AZOE-NP® process concerns phosphorus removal. Dissolved reactive P is firstly precipitated by $FeCl_3$ injection at the outflow of the trickling filter. The particulate forms of P are subsequently retained by filtration though the first stage of VFCW (Kim et al., 2013). The deposits, which progressively accumulate at the surface of VFCW, are usually removed every 10–15 years.

Redox conditions are known to influence microbial processes within constructed wetlands (Laanbroek, 1990; Reddy and D'Angelo, 1997). In the case of the AZOE-NP® process, redox conditions may affect the fate of the ferric species within the VFCW, and consequently the behavior of P species associated to them. However, no study actually measured Eh levels within the granular medium in VFCW (Faulwetter et al., 2009). In this study, a pilot-scale VFCW was implemented to monitor Eh at three different depths within the porous medium with the objectives to determine (i) the influence of VFCW saturation level on the performances of the system and (ii) the effects of Eh within the VFCW on the retention of phosphorus.

2. Materials and methods

2.1. Description of pilot's design

Pilot-scale unit of VFCW was installed within a greenhouse in Irstea's experimental hall located at La Feyssine in the metropolitan area of Lyon (France). A schematic diagram of pilot-scale installation is shown in Fig. 1. This experimental setup is meant to simulate the operational units of a real-scale AZOE-NP® plant but focused only on the first stage of filters as previous studies had shown that the efficiency of the process mainly occurred within the 1st stage (Kim et al., 2014).

The pilot-scale system was designed as a combination of four sub-units as shown in Fig. 1:

a A pumping station used for the successive following treatment steps: collection of screened wastewaters, feeding of trickling filter in a closed loop mode, mixing of the solution after ferric chloride injection, and injection of the solution at the surface of the VFCW.

b A pilot-scale trickling filter of 0.29 m^3 fully packed with cross flow plastic media (ordered) developing a specific surface area of 200 $m^2 m^{-3}$.

c A dosing pump (DDE, Grundfos) for ferric chloride injection.

d A pilot-scale VFCW with a surface of 2 m^2 and a depth of 0.7 m. It was filled with 4 successive layers of granular materials which were taken from a real scale AZOE-NP® system in operation since 8 years: a 20 cm upper filtration layer was made of 2–4 mm gravels; two intermediate layers (20 cm with 4–8 mm gravels and 7 cm with 8–16 mm gravels) and a 6 cm lower drainage layer made of 20–60 mm pebbles, corresponding to two thirds of the real-scale plant

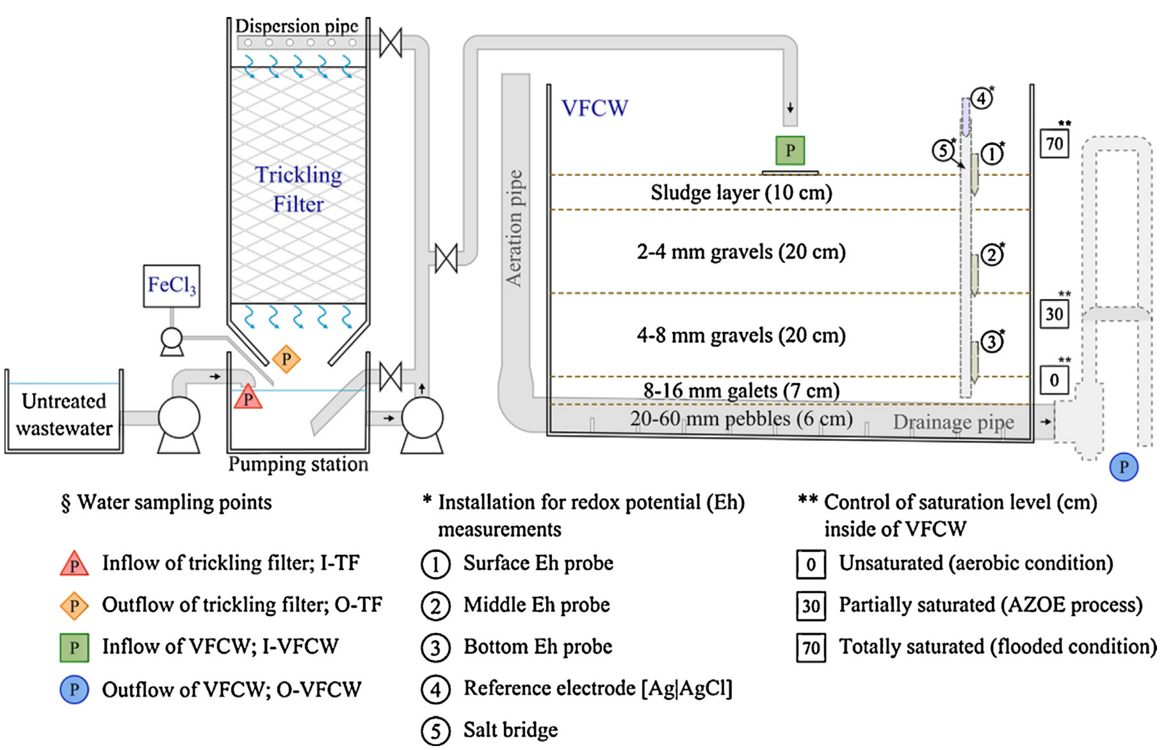

Fig. 1. Simplified diagram of pilot-scale installation.