Ecological Engineering 77 (2015) 257–264

Contents lists available at ScienceDirect

Ecological Engineering

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

Influence of partial saturation on total nitrogen removal in a single-stage French constructed wetland treating raw domestic wastewater

D.D. Silveira [a,b,*], P. Belli Filho [a], L.S. Philippi [a], B. Kim [b], P. Molle [b]

[a] UFSC of Florianópolis, University of Santa Catarina, Campus Universitário, Trindade, Florianópolis CEP 88040-900, Brazil
[b] IRSTEA, UR MALY, 5 rue de la Doua, F-69100 Villeurbanne, France

ARTICLE INFO

Article history:
Received 22 September 2014
Received in revised form 13 January 2015
Accepted 25 January 2015
Available online 4 February 2015

Keywords:
French vertical flow constructed wetlands
Domestic wastewater
Pilot scale
Saturated layer
Nitrification/denitrification
Redox potential

ABSTRACT

The objective of this research was to evaluate the nitrogen removal performance of vertical flow constructed wetlands implemented with a bottom saturated layer in the treatment of raw wastewater (French system). This research was carried out in two pilot systems over 16 months with different saturation depths (25 cm and 15 cm) to determine the optimal level for denitrification promotion. Monitoring included regular analysis of the physico-chemical parameters (TSS, dissolved COD, NH_4^+-N, TKN and NO_3^--N) as well as online measurements (redox potential, oxygen and temperature, hydraulic behavior) to explain the filter's behavior. Statistical performance analysis showed that a higher removal rate was obtained when the filters operated with 25 cm saturation in comparison with 15 cm saturation depth. The hydraulic study revealed the positive evolution of the system from the winter, where the clogging was observed, to the summer, where this phenomenon was not observed, demonstrating that the hydraulic conditions affect the nitrification efficiency. The redox potential measured at three different depths inside the filters clearly showed the variation in the Eh values as a function of the saturation level and feeding–resting cycles, indicating that such measurements are capable of revealing the existing biogeochemical processes in highly dynamic systems, such as constructed wetlands. The results demonstrated variations in performance according to the saturation condition and the system's hydraulics; however, improvement of the design or the introduction of an additional treatment stage is necessary to achieve complete TN removal.

1. Introduction

Currently, 2.5 billion people, most of whom reside in developing countries, lack access to a basic sanitation system. Thus, more than 40% of the world's population dumps their wastewater improperly in watercourses (WHO, 2012). This improper dumping generates environmental problems that directly affect public health and increases the cost of water treatment for public supply (Von Sperling, 2005).

Constructed wetlands (CWs) are a feasible alternative to conventional wastewater treatment systems, especially in developing countries and tropical climates. However, Kantawanichkula et al. (2009) reported that CWs are still not widely used in tropical climates due to a lack of knowledge and design criteria that are inappropriate for the local weather conditions. These authors also noted that the climate and local conditions strongly affect the removal efficiencies in constructed wetlands. Thus, there is a great need for experiments under such conditions to clarify some aspects of treatment.

Among the several CW configurations developed to date, the French vertical flow constructed wetland (VFCW) configuration developed in the 1980s (Liénard, 1987) is of potential interest to developing countries because it allows the simultaneous treatment of water and sludge (no need of primary treatment). However, such a system uses two VFCW stages to provide complete nitrification and promote the mineralization of the organic matter (Molle et al., 2005; Molle, 2014) but does not provide denitrification. Denitrification using successive stages of vertical and horizontal systems (Molle et al., 2008; Vymazal, 2013) requires space and can be costly. However, on tropical islands, where land is a limited commodity, treatment plants should occupy as little

* Corresponding author at: Campus Universitário UFSC/CTC Departamento de Engenharia Sanitária e Ambiental Laboratório de efluentes líquidos e gasosos – LABEFLU 3° andar, sala 76, Bairro Trindade, CEP 88040-900 Florianópolis, SC, Brazil. Tel.: +55 48 84 22 28 01.
E-mail address: danid_bioeng@yahoo.com.br (D.D. Silveira).

http://dx.doi.org/10.1016/j.ecoleng.2015.01.040
0925-8574/

space as possible. Various innovations and adaptations have been tested in recent years to optimize the nitrogen transformation process (Wu et al., 2014). In France, the use of a single vertical flow CW stage with a saturated bottom layer has been developed for use on French tropical islands. Nitrogen transformation is not direct, with ammonia adsorption during feeding period and nitrification during rest period playing an important role. Thus, nitrate fluxes to the saturated layer are irregular (with release occurring during the beginning of the feeding period) and can affect nitrogen removal performance.

Among the various parameters affecting denitrification (temperature, pH, redox potential, carbon source, retention time, etc.), the redox potential (Eh) will vary considerably both spatially (vertically and horizontally) and temporally (feeding–resting cycles). The different redox conditions would determine whether denitrifying bacteria are able to thrive. Consequently, the design configuration of the saturation layer as well as the aeration of the unsaturated layer is important for guaranteeing stable nitrogen removal performance.

In this study, two pilot-scale VFCW filters were implemented and operated identically to evaluate (i) the total nitrogen removal performance of the filter, (ii) the influence of saturation level on the system performance and (iii) the effects of Eh and temperature inside the VFCW on nitrogen removal.

2. Materials and methods

2.1. Description of pilot design

Two vertical flow filter (VFCW1 and VFCW2) pilots planted with *Phragmites australis* (6/m^2 initially) were installed inside a greenhouse (daily average temperature of 26 °C in summer and 10 °C in winter). These filters were fed with real domestic wastewater from a 400.000 p.e. treatment plant. A schematic diagram of the pilots is shown in Fig. 1.

The high-density polyethylene (HDPE) pilots are each 2 m^2 in area and composed (from bottom to top) of a 15 cm drainage layer (20–40 mm gravel), 20 cm transition layer (8–20 mm gravel) and 35 cm filtration layer (2–6 mm gravel). A 30 cm free zone allowed sludge accumulation and possible ponding on top of the filter. All materials used have a fine content (particles <63 μm) of less than 3% and a carbonate content of less than 10%.

To facilitate denitrification within the system, a saturation zone was implemented at the bottom of the filters. This zone was adjusted in depth using the outlet siphon structure, allowing the study of the influence of the saturation level on the denitrification rate. As the drainage pipe could not provide aeration, a U-shaped aeration pipe (70 mm in diameter) was placed above the saturated filtration layer (see Fig. 1) to enhance the oxygenation of the unsaturated layer.

2.2. Description of the pilot operation

The pilots were operated automatically. The effluent was sent to the filter using a pump with a flow rate of 1 m^3/h. The following feeding strategy was used:

- The operation cycle was divided into a feeding period (2.5 days) and a rest period (4.5 days).
- In the feeding period, the pilots received a batch of 0.03 m (60 L) every 2 h, corresponding to a daily hydraulic load of 0.36 m/d.

The filter pilots were put into operation in July 2012. During the first phase of the study, both filters operated for 12 months with a

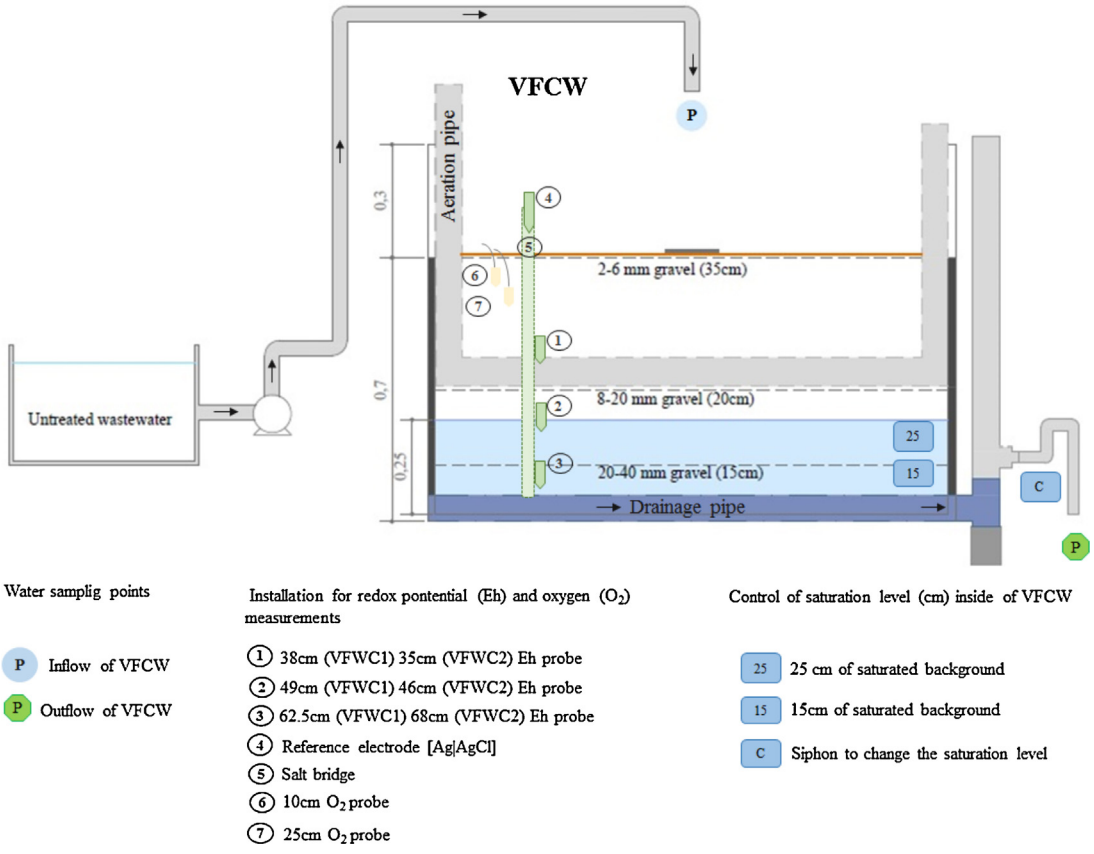

Fig. 1. Simplified diagram of the pilot-scale installation.