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Performance evaluation of partially saturated vertical-flow constructed wetland with trickling filter and chemical precipitation for domestic and winery wastewaters treatment

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ABSTRACT

The use of vertical flow constructed wetlands (VFCW) is growing rapidly in Europe for domestic wastewater treatment in small communities. In order to improve denitrification and dephosphatation as compared to classical VFCW, the Azoé-NP® process has been developed. The process line consists of: a biological aerobic trickling filter as a primary treatment stage, ferric chloride ($FeCl_3$) addition for phosphorus (P) treatment and two stages of partially saturated VFCW. A municipal wastewater treatment plant using Azoé-NP® process has been monitored during eight years through 44 campaigns of 24 h time-proportional inlet–outlet sampling followed by analyses of TSS, BOD_5, COD, TKN, NO_3–N and TP concentrations. The results revealed good performances of the overall treatment. To better characterize the performance of each treatment step, five additional 24 h monitoring campaigns were performed with samples taken from four different points along the treatment line. Results showed a good performance in dissolved carbon removal and nitrification by the trickling filter. The main part of the treatment was found to be done by filtration throughout the first filtration stage. Nitrate removal was achieved principally at the second filtration stage. Phosphorus migration through the first stage and its slight retention at the second stage was observed.

1. Introduction

The use of vertical flow constructed wetlands (VFCW) has been growing rapidly in Europe over the last decade for domestic wastewater treatment in small towns (Abou-Elela and Hellal, 2012; Molle et al., 2006; Torrens et al., 2009). The process has proven its efficiency in the treatment of organic matter and nitrogen from raw municipal wastewaters or after primary treatment (Brix and Arias, 2005; Kadlec et al., 2000). However, there still remain some fields for improvement, not only for total nitrogen removal by nitrification/denitrification but also for phosphorus retention (Brix et al., 2001). Indeed, the release of nitrates and phosphorus into sensitive aquatic ecosystems may promote eutrophication (Schindler, 1977; Tiessen, 2008), and therefore the concentration in the treated effluents must satisfy increasingly low regulatory limits.

The Azoé-NP® process has been developed by the French company SCIRPE to improve denitrification and P removal (EP1857419A1; PCT/EP2012/058119). The process line consists of: (i) a screening (3 mm mesh) (ii) a biological aerobic trickling filter as a first biological treatment step (mainly for organic carbon removal), (iii) ferric chloride ($FeCl_3$) addition for phosphorus precipitation and (iv) two stages of partially saturated VFCW. Since the organic load is partly transformed and removed by the trickling filter, the required surface of VFCW is reduced in the Azoé-NP® system 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). In addition, the trickling filter is passively aerated by its bottom part and therefore provides good condition to initiate nitrification.

The main treatment achievement occurs through two successive stages of partially saturated VFCW. Each filtration stage consists of two different zones: the upper zone which is not saturated, and the lower one which is saturated. These conditions allow good total nitrogen removal through sequential

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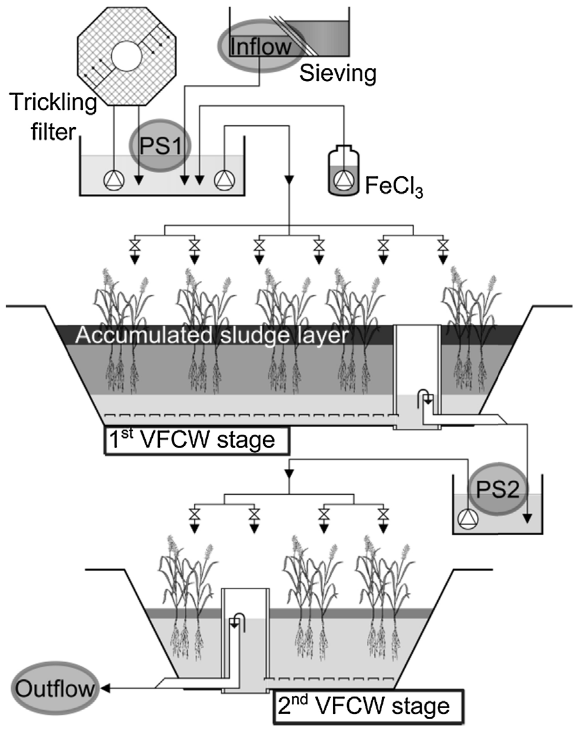

Fig. 1. Simplified diagram of the Vercia WWPT showing the four sampling points on the process line: [inflow] raw wastewater sieved to 3 mm, [PS1] effluent of the trickling filter with ferric chloride injection, [PS2] effluent of the 1st partially saturated VFCW and [outflow] effluent of the 2nd partially saturated VFCW. PS stands for pumping station.

nitrification/denitrification. The depth of the saturated zone can be adjusted to optimize efficiency.

With respect to phosphorus removal, different physico-chemical processes are used in constructed wetland systems. Most subsurface flow (SSF) CW systems use filter media with high phosphorus sorption capacity (Molle et al., 2011; Vohla et al., 2011) but can be a problem when looking for a cheap and efficient solution on a long term. In the Azoé-NP® process however, phosphorus is precipitated by injection of $FeCl_3$ at the outflow of the trickling filter and removed by filtration through the partially saturated VFCW as highlighted by Kim et al. (2013). The deposits, which progressively accumulate on the surface of VFCW, should be finally withdrawn every 10–15 years.

As the process is relatively new in France (10 years), the objectives of this study were to (1) estimate the overall efficiency of the Azoé-NP® treatment plant through a series of inflow/outflow 24 h time-proportional sampling analyses done over eight years, (2) determine the respective efficiency of each individual step of the process, based on specific surveys at each treatment step and (3) focus on nitrogen removal and phosphorus retention.

2. Materials and methods

2.1. Description of the plant selected for the study

The study was conducted by monitoring a municipal wastewater treatment plant (WWTP) located in Vercia (Jura, France) between 2004 and 2012. This unit, schematically represented in Fig. 1, is the first Azoé-NP® full-scale plant and has been in operation since 2004. It treats mostly domestic wastewater, but also receives wine-production effluent in autumn. Its maximum capacity is 1100 PE. It was designed for a nominal volumetric flow of 70 m^3 day^{-1} and an organic load of 56 kg COD day^{-1}. During grape harvesting period however, the hydraulic and organic loads increased to 77 m^3 day^{-1} and 122 kg COD day^{-1}, respectively, for about one month.

The trickling filter has a volume of 30 m^3 fully packed with corrugated plastic sheet packing (ordered) developing a specific surface of 100 m^2 m^3. Each VFCW has a depth of 0.8 m and a total surface of 600 m^2. The filtration layer is made of a layer of fine gravels (d_{10}: 1.6 mm; d_{60}: 3.6 mm) in the first filter and sand (d_{10}: 0.16 mm; d_{60}: 1.3 mm) in the second one. The water-saturation level in each filter is adjustable by a control pipe in the outlet drainage system. Over the period of investigation of this study, the level was maintained around half of the filter depth for the first stage and between 0.6 and 0.75 m from the bottom of the second filter. The first stage is divided into three hydraulically independent identical units of 200 m^2, which are fed alternately to favour mineralization of sludge. Their bottom drainage systems communicate one with each other. The second stage is separated into two identical units of 300 m^2. Each unit is fed over a period of 7 days and then rested for 14 days (for the first stage) or 7 days (for the second stage). Phosphorus removal is realized by injection of about 0.140 L of a 574 g L^{-1} ferric chloride solution per m^3 of wastewater, corresponding to a total iron concentration of 0.5 mmol L^{-1}.

2.2. Description of field monitoring campaigns

The plant was monitored since the date of its implantation in 2004 until year 2012. Different types of sampling campaigns were conducted as detailed below.

2.2.1. Regular campaigns

The regular campaigns were conducted to evaluate the overall inlet–outlet performance of the plant. A 24 h time-proportional inflow/outflow sampling method was followed. A total of 44 regular campaigns (four to six campaigns per year) were made, including during autumn when wine-production effluents were treated by the plant.

2.2.2. Specific campaigns

In addition to the regular monitoring campaigns, a total of 5 specific 24 h sampling campaigns were conducted where sampling was done at four different points of the treatment line to determine the efficiencies of each step of the treatment line. Three of them were done in 2007 (one in winter and two in autumn during wine production period) following a time-proportional sampling method. The last two specific campaigns were performed in 2011 and 2012 during wine production period, following a 24 h flow-proportional sampling method to provide additional data to the study. The positions of the sampling points are shown in Fig. 1: (1) raw wastewater [inflow], (2) effluent from the trickling filter after ferric chloride injection in 1st pumping station [PS1], (3) effluent from the first stage of partially saturated VFCW in 2nd pumping station [PS2] and (4) treated water at the outlet of the second filter [outflow].

2.3. Analytical procedures

Refrigerated auto-samplers were used in all campaigns to keep the samples at a temperature around 4 °C until they were transported to the laboratory within 24 h after sampling. The following parameters were analysed following French standard methods (AFNOR, 2005): total suspended solids (TSS), five-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), nitrate (NO_3–N), total nitrogen (TN) and