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Optimization of a vermifiltration process for treating urban wastewater

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ABSTRACT

Optimization of a vermifiltration process was made for hydraulic retention time (HRT), hydraulic loading rate (HLR) and recirculation ratio (R), organic loading rate (OLR), earthworm abundance and reactor type on organic matter removal from urban wastewater using a small-scale vermifiltration process comprising single stage, and four-stage vermifilter (VF) systems. All reactor modules were made of PVC with a total volume of 25 L using vermicompost as the filtering material and quartz sand and gravel as the inert filter. System performance was assessed by the removal efficiencies of BOD_5, tCOD, sCOD, pCOD, TSS and NH_4^+. In the earthworm study, four abundances were evaluated: $10\,g\,L^{-1}$ (W10), $20\,g\,L^{-1}$ (W20), $30\,g\,L^{-1}$ (W30) and $40\,g\,L^{-1}$ (W40). In the four-stage VF the earthworm abundance evaluated was $20\,g\,L^{-1}$.

W20 proved to be the optimal treatment condition with efficiencies for BOD_5, tCOD, pCOD, TSS and NH_4^+ of 97.5%, 74.3%, 91.1%, 98.2% and 88.1%, for a pCOD/tCOD ratio of 0.20. The four-stage sequential VF promoted a decrease of BOD_5 (98.5%), tCOD (74.3%), pCOD (86.7%), TSS (96.6%), and NH_4^+ (99.1%).

Results indicate that sequential VF systems can significantly improve treatment efficiencies when compared to single stage VF.

1. Introduction

Nearly 80% of water supplies used by society return as municipal wastewater carrying hazardous chemicals and high loads of organic matter (Sinha et al., 2008).

There is growing interest in developing environmentally safe and economically viable small-scale wastewater treatment technologies for onsite wastewater treatment, in particular for small communities and individual households. The most common configurations for onsite wastewater treatment are septic tanks, in some cases followed by passive soil absorption systems. When properly designed and installed these systems should provide sufficient treatment to prevent unacceptable groundwater contamination. Unfortunately, there are widespread evidences that frequently they do not meet this criterion. In the USA estimates indicate that only four to six percent of existing septic tanks are watertight (Nelson, 2005). Leaking septic tanks are in fact one the major widespread sources or contamination in many regions of the world (Fujita et al., 2013; Kuroda et al., 2012), and suspected of being in the origin of water-borne diseases (Borchardt et al., 2003).

Vermifiltration is a low-cost wastewater treatment process which is based on the same oxidation reactions, biodegradation and microbial stimulation by enzymatic action also present in vermicomposting and in trickling filters. In vermifiltration earthworms mechanical action creates aerobic conditions inside the reactor which help prevent the formation of odors. Dissolved and suspended organic and inorganic solids are trapped by adsorption and stabilization through complex biodegradation processes that take place in the filter packing, being subsequently used by microorganisms (Sinha et al., 2008). As in vermicomposting, in vermifiltration, epigenic earthworms convert the organic matter in wastewater into a suitable matrix filter – the vermicast. In vermicomposting, earthworms ingest near their own weight on organic matter each day and excrete 60% of this weight in castings (Lourenço, 2014). Their castings are rich in humus, nutrients and microorganisms, including nitrifying bacteria (Sinha, 2010) while having a hydraulic conductivity like sand with high adsorption properties. Earthworms and microorganisms cooperate to ingest and biodegrade organic wastes and contaminants present in wastewater. Their action improve filter permeability, increasing the degradation of the organic matter (Sinha et al., 2008; Arora et al., 2014),

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hence promoting high removal efficiencies of BOD_5, COD and TSS from wastewater (Sinha et al., 2008).

In recent years, many studies on the physical process of vermifiltration have been published being extremely helpful for the sizing and managing of vermifilters (Xing et al., 2011, 2010). The hydraulic retention time (HRT) and hydraulic loading rate (HLR) affect treatment and effluent quality. HRT determines the actual time the wastewater is in contact with the filter. It is proportional to the depth of the vermifilter (VF) witch may increase over time due to the accumulation of earthworm castings. HRT depends on wastewater flow rate, VF volume and type of material used. In principle, within certain ranges, the longer the wastewater remains inside the filter, the greater will be the BOD_5 and COD removal efficiency, but at the expenses of larger filter volumes. The main reason is that wastewater requires a certain contact time with the biofilm to allow for the adsorption, transformation, and reduction of contaminants (Hughes et al., 2006). HLR is an essential parameter in the design stage of all filters and determines the volume and amount of wastewater that a VF can reasonably treat in a given time. For a given system, higher HLR values will cause HRT to decrease and therefore reduce treatment efficiency. HLR may depend on parameters such as structure, effluent quality and filter packing bulk density, and method of effluent application (Siegrist, 1987). Common HRT values in vermifiltration systems range from 1 to 3 h (Sinha et al., 2008). As for HLR, the values commonly used have been between 0.2 $m^3\,m^{-2}\,day^{-1}$ (Li et al., 2009) and 3.0 $m^3\,m^{-2}\,day^{-1}$ (Manyuchi et al., 2013). Treatment efficiency is influenced by health, maturity and population abundance of earthworms. Abundance is a fundamental parameter for efficient running of vermifiltration (Li et al., 2009). Thus, to ensure an efficient treatment system, sufficient earthworm abundance is necessary. Different values are reported in literature usually in grams or number of individuals per volume of filter packing or surface area of filter packing. Common densities vary between 10 $g\,L^{-1}$ and 40 $g\,L^{-1}$ of *Eisenia fetida* (Bouché, 1972) per filter packing material (Tomar and Suthar, 2011; Zhao et al., 2010). Soto and Toha (1998) refer in their studies the use of 2.5 L^{-1} to 5.0 $g\,L^{-1}$ with removal efficiencies of 99% for BOD and 96% for TSS. Manyuchi et al. (2013) used 25 $g\,L^{-1}$ to treat domestic wastewater and obtained a removal of BOD_5 of 98% and COD of 70%. Kumar et al. (2014) used an abundance of 30 $g\,L^{-1}$ to treat domestic wastewater with BOD_5 and TSS final concentrations of 8.0 ± 2.0 $mg\,L^{-1}$ and 29 ± 8.54 $mg\,L^{-1}$, respectively.

Over the past years, several studies have been made regarding the use of vermifiltration systems to increase treatment efficiency using different level stages (Wang et al., 2011; Tomar and Suthar, 2011) as level stage systems provide excellent aerobic conditions for nitrification, increasing the removal rates for COD and NH_4^+.

Previous studies about vermifiltration systems have only primarily focused on the use of single tower VFs or combined vermifiltration processes in the treatment of different types of wastewater as very little work has been made so far using in-series VFs. Therefore, the objective of this study was to compare single stage VF with in-series VF stage alternative.

2. Material and methods

2.1. Reactor structure

Four filters without earthworms were tested in order to evaluate the best hydraulic properties on the removal of BOD_5, COD, TSS and NH_4^+ from urban wastewater. A vermifiltration process was carried to evaluate the best earthworm abundance on the removal of BOD_5, COD, TSS and NH_4^+ from urban wastewater based on the best hydraulic variables and using a single-stage VF. Based on the best hydraulic variables and earthworm abundance, an in-series fourth-stage VF was tested.

Table 1
Characterization[a] of the vermicompost used as biological filter medium.

Parameter	Value
Bulk density ($kg\,m^{-3}$)	600 ± 0.00
Porosity (%)	73.7 ± 0.30
Hydraulic conductivity ($cm\,s^{-1}$)	1.4 ± 0.00
pH (H_2O)	6.82 ± 0.01
EC ($\mu S\,cm^{-1}$)	2530 ± 2.00
Organic matter (%)	56.48 ± 0.01
TOC (%)	32.76 ± 0.04
TN (%)	3.64 ± 0.02
C/N ratio	9.0 ± 0.03
TP ($mg\,kg^{-1}$)	3769 ± 0.4
TK ($mg\,kg^{-1}$)	7150 ± 0.08

[a] Mean concentration ± standard deviation.

The reactor modules were made of PVC with a total volume of 25 L (Fig. 1) following the treatment scheme proposed by other authors (Taylor et al., 2003; Lakshmi et al., 2014). Experiments were made using vermicompost produced from municipal organic solid waste as the filtering material provided by a specialized company (FUTURAMB®). Vermicompost occupied the top 16.0 cm (average Ø < 0.1–3.0 mm), underneath which was installed an inert filter constituted of 6.0 cm of homogenized washed quartz sand (average Ø = 550 μm) on top of 7.0 cm of gravel (average Ø = 40 mm). The vermifilter was covered with a lid, leaving sufficient head space and opening as to allow natural aeration. An irrigation system was attached on top of the vermifilter made by a regular mesh. HDPE flexible pipes (Ø = 0.5 cm), separated 2.0 cm from each other, were used for wastewater irrigation and were kept 3.0 cm above the filter surface to ensure optimal wastewater distribution, the creation of drop-overflow and thereby increase aerobic conditions. Gravel applied on the bottom of the filter was separated from the equalizer by a stainless steel mesh (Ø = 0.4 cm). Quartz sand was separated from gravel and from vermicompost by a stainless steel mesh (Ø = 80 μm). Vermicompost physical-chemical characterization is shown in Table 1. The effluent from each VF was collected in the equalizer from where samples were taken. From here, recirculation was made with the help of a pump (Q_r) and mixed with raw wastewater as (Q_w) to be feed to the top of the filters ($Q_w + Q_r$).

2.2. Process acclimation

Moisture content was held constant after placing the reactors to field capacity following procedures used by the company that provided the earthworms and the filter packing for acclimation of the earthworms. For this purpose filters were flushed with recirculating water for 30 days. After this time, VF was flushed and recirculated permanently for 45 days with wastewater collected from urban WWTP of Messines, Algarve, to allow the growth of heterotrophic microorganisms in the vermicompost packing. Each filter was fed, by pumping raw wastewater from a PVC container. The flow was also adjusted to permit the optimum moisture conditions for the survival of the earthworms.

2.3. Experimental design

a) Study of hydraulic variables

Four HRT were tested: 2 h, 4 h, 6 h and 8 h (T2, T4, T6 and T8, respectively) (Table 3). Influent wastewater flow, Q_w and recycling flow, Q_r, were adjusted to obtain a constant Q_{mix} equal to 1.50 $cm^3\,s^{-1}$, as this was the optimal flow for maintaining the ideal moisture in each filter. HRT was adjusted by changing the recirculation ration, $R = Q_r/Q_w$.