Ecological Engineering 118 (2018) 171–178

Contents lists available at ScienceDirect

Ecological Engineering

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

Influence of septic tank attached growth media on total nitrogen removal in a recirculating vertical flow constructed wetland for treatment of domestic wastewater

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ARTICLE INFO

Keywords:
Nitrification
Denitrification
Recirculation
Treatment wetland
Septic tank

ABSTRACT

Among different decentralized wastewater treatment systems, constructed wetlands are particularly robust, reliable and cost-effective technologies. However, traditional treatment wetland designs have a limited capacity to remove total nitrogen. The recirculating vertical-flow constructed wetland (RVFCW) system is a novel modification of the vertical flow wetland (VFW), allowing for increased denitrification by circulating the nitrified effluent back into a recirculation tank, where it is mixed with primary treated wastewater. Microcosm experiments were conducted to investigate the effects on nitrogen removal of mixing recirculated VFW effluent with raw wastewater after different degrees of primary treatment, with and without attached growth media. The results show that the inclusion of attached growth media in the first chamber of the recirculation tank resulted in enhanced total nitrogen removal. The microcosms that contained a mixture of raw wastewater and VFW effluent showed denitrification efficiency of 83% after 48 h of contact time. An increase in the denitrification efficiency (up to 99.5%) was observed in microcosms that also contained attached growth media. The majority of nitrate-N (NO_3-N) removal was achieved in the first 24 h. Inclusion of media increased the denitrification efficiency after 48 h contact time from 36 to 93% and from 31 to 88% in microcosms containing VFW effluent mixed at a ratio of 3:1 with wastewater after 1 and 2 days residence time in a septic tank respectively. It was inferred that the lower the degree of pre-treatment of wastewater into which the recirculated VFW effluent was mixed, the greater is the denitrification rate and thereby the lower TN concentration in the effluent.

1. Introduction

Water scarcity in arid and semi-arid countries has led to increased interest in recycling of various wastewater streams, especially in decentralized systems. Nitrogen needs to be managed appropriately to minimize eutrophication of waterways and contamination of groundwater with nitrate. With respect to total nitrogen removal in onsite wastewater systems, the conventional approach to providing advanced treatment is by using supplementary aeration, which enhances nitrification but does not accomplish denitrification (Charles et al., 2005; Peterson, 2006; Moelants et al., 2008; Levett et al., 2010; Oakley et al., 2010). Constructed wetlands are engineered systems designed to treat wastewater using the same processes that occur in a natural wetland, but within a more controlled environment (Vymazal, 2007; Lee et al., 2009; Vymazal, 2010; Almuktar et al., 2015). Among the different types of constructed wetlands, the vertical flow wetland (VFW) has been commonly used as a decentralized wastewater treatment system. VFWs are recognized as a robust treatment technology that can withstand disturbances and variable influent quality (e.g. high ammonium concentrations) and temperature changes. The system is characterized by a high oxygen transfer rate, and consequently a high level of organic matter removal and nitrification, although its denitrification efficiency is considered poor (Sklarz et al., 2009; Garcia et al., 2010). This is largely because a conventional VFW cannot simultaneously maintain the required aerobic and anaerobic conditions for total nitrogen removal (Arias et al., 2005).

The recirculating vertical flow constructed wetland (RVFCW) is a novel modification of the VFW that is designed to achieve higher

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https://doi.org/10.1016/j.ecoleng.2018.05.013
Received 24 January 2018; Received in revised form 1 May 2018; Accepted 7 May 2018

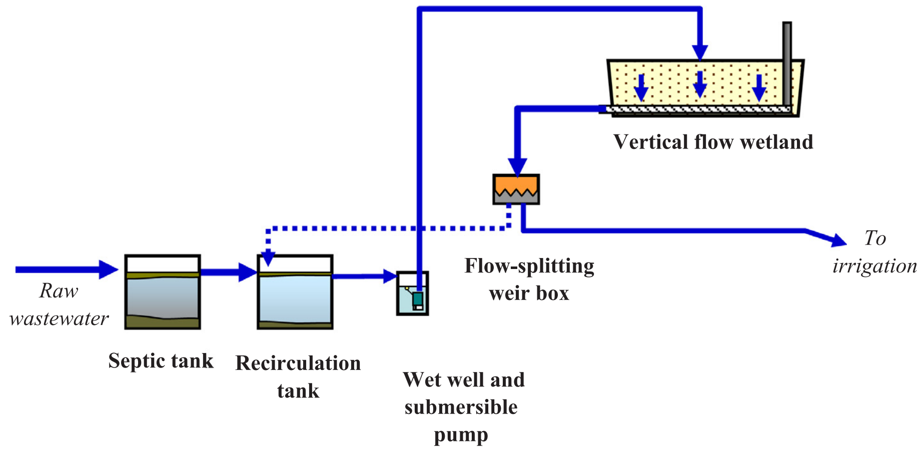

Fig. 1. Components of the recirculating vertical flow constructed wetland system.

nitrogen removal rates (García-Pérez et al., 2006; Gross et al., 2007; Tanner et al., 2012). Recirculation plays an important role in improving the performance of the VFW, because it enhances the interactions and contact between wastewater pollutants and the microorganisms responsible for treatment (Lian-sheng et al., 2006; Zapter et al., 2011). Part of the nitrified VFW effluent is recirculated back to the septic tank, where the presence of anoxic conditions and organic carbon favour denitrification (Vymazal, 2007; Kadlec and Wallace, 2009). This gives rise to the question of how much pre-treatment of the influent is required prior to mixing with the recirculated VFW effluent. The right balance needs to be struck between providing anoxic, carbon-rich conditions for denitrification in the recirculation tank and maintaining sustainable solids and organic loading rates on the VFW bed which will avoid clogging. Sundaravadivel and Vigneswaran (2001) reported that while recycling within a RVFCW system may not change the overall system hydraulic retention time (HRT), it may increase local flow velocities. Accordingly, the system design should be optimized to avoid disturbance in septic tank function.

The portion of the VFW effluent that is recirculated is normally characterized by high dissolved oxygen concentration which varies with the recirculation ratio. Arias et al. (2005) found that as recycling rates increased, the oxygen saturation varied from zero with no recycling to 12, 30, and 60% as recirculation rates increased to 100, 200, and 300%, respectively. While this is favourable for nitrification and aerobic degradation of organic matter, elevated levels of dissolved oxygen in the recirculation tank may inhibit denitrification. Accordingly, the RVFCW has proven to be an effective alternative to remove organic matter, suspended solids, and ammonium in domestic wastewater (Sundaravadivel and Vigneswaran, 2001; Gross et al., 2007; Arias et al., 2005; Li and Tao, 2017), but the design and operation needs to be optimized for total nitrogen removal.

The focus of this study is optimization of nitrogen removal from domestic wastewater in RVFCWs. Experiments were conducted in Jordan on a full-scale RVFCW system as well as lab-scale microcosms, using real municipal wastewater. To assess the effect of different levels of wastewater pre-treatment and the inclusion of attached-growth media on total nitrogen removal, microcosms were established comparing different combinations of VFW effluent and untreated wastewater collected from various locations within a septic tank, both with and without attached-growth media.

2. Materials and methods

2.1. Full-scale vertical flow constructed wetland

A RVFCW was constructed at a demonstration facility in Fuhais, Jordan as one example of a potential decentralized system for onsite treatment of domestic wastewater. The constructed wetland system consists of a septic tank, a recirculation tank, splitter-box, wet well with a submersible pump (pump well), and a recirculating VFW (Fig. 1). The system was designed to treat domestic wastewater with a daily flow of 2160 L/d at a hydraulic loading rate of 108 L/m^2 d. The septic tank is fed with raw wastewater from the adjacent central wastewater treatment plant (25,000 Person Equivalents) of the city of Fuhais in Jordan. The septic tank design allows the assumption of plug flow pattern through the tank. The VFW is intermittently loaded with effluent from the recirculation tank at a rate of 90 L/h, divided into three episodes of feeding per hour. Each individual feed (every 20 min) discharges 30 L of wastewater within a few minutes. The inlet flow volume to the RVFCW system is measured with an electromagnetic flow meter (ELPIS) and the intermittent loading is controlled using a programmable logic control (PLC) SIEMENS-SIMATIC S7-200.

The wastewater receives primary treatment in a septic tank with a working volume of 4.6 m^3, ensuring an average residence time of two days. The effluent from the septic tank flows into the recirculation tank with a working volume of 6.2 m^3, where it is mixed with 75% of the effluent from the VFW (i.e. a recirculation rate of 300%). After a residence time of approximately one day, the effluent from the recirculation tank flows to the pump well, from where the submersible pump distributes the water over the surface of the VFW via a network of pipes. After each pass through the wetland, 25% of the VFW outflow leaves the system as final effluent.

The VFW has a surface area of 20 m^2 (4 m × 5 m) and a depth of one meter. A bedding layer of fine sand was used under the liner across the bottom, while the side-walls were built with concrete bricks. The bottom and the sides were lined with a polyethylene (PE) liner (1-mm thick) to prevent leakage. Crushed volcanic rock, known as zeotuff, was used as filling material, because it is locally available in Jordan. Zeotuff was quarried and processed in the eastern part of Jordan by the Green Technology company. The main filter media of 2–4 mm zeotuff comprises approximately 80 cm of the total depth. This filter media is underlain by a drainage zone, in which treated wastewater is collected in three parallel perforated lateral pipes and then drains from the system by gravity. The drainage pipes are connected to a common pipe downstream of the wetland bed. The other ends of the perforated lateral pipes are connected to ventilation risers, which passively provide the wetland filter bed with oxygen. The drainage pipes are made of polyvinyl chloride (PVC) with an inside diameter of 110 mm. The perforated lateral pipes are covered by a layer of 20 cm of Zeotuff with a size range of 10–25 mm, to serve as a drainage zone overlain by the layer of 80 cm of 2–4 mm Zeotuff, as shown in Fig. 2.

Wastewater is intermittently pumped and distributed over the surface of the bed through a network of eight lateral pipes located directly at the top of the main filter material and designed to achieve uniform