Ecological Engineering 123 (2018) 168–174

Contents lists available at ScienceDirect

Ecological Engineering

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

Does influent surface organic loading and aeration mode affect nitrogen removal and N_2O emission in subsurface wastewater infiltration systems?

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ARTICLE INFO

Keywords:
Surface organic loading
Aeration mode
Functional genes
N_2O
Nitrogen

ABSTRACT

This study evaluated the influence of influent surface organic loading (SOL) and aeration mode on nitrogen removal and N_2O emission in subsurface wastewater infiltration systems (SWISs). Aeration developed appropriate oxygen conditions, which resulted in high COD, NH_4^+-N and TN removal and enhanced the abundances of *amoA*, *nxrA*, *napA*, *narG*, *nirS*, *nirK*, *qnorB* and *nosZ* under SOL rate of 21.2 and 33.8 g COD/(m^2 d) compared to the non-aerated SWIS. N_2O emission decreased with influent SOL rate increasing in non-aerated and aerated SWISs. The SWIS with intermittent aeration had a better performance on TN removal and lower N_2O emission compared to the SWIS with continuous aeration under the same SOL rate. It could conclude that intermittent aeration is a feasible method to win high influent SOL rate, high TN removal and low N_2O emission for SWISs.

1. Introduction

The subsurface wastewater infiltration system (SWIS) has been widely applied to on-site wastewater treatment in rural areas (Li et al., 2011; Pan et al., 2015). It has many advantages compared to centralized wastewater treatment method such as lower construction and operation costs, easier management (Zheng et al., 2016). However, poor nitrogen removal performance is a major challenge which is the main focus when assessing the treatment ability of a SWIS (Yang et al., 2016). It is widely accepted that nitrogen removal relies firstly on efficient nitrification for NH_4^+-N removal, and then requires sufficient carbon source in denitrification to remove nitrogen completely (Li et al., 2012). Artificial aeration has been proved to be an effective way to enhance nitrogen removal by creating favorable conditions for nitrification (Pan et al., 2015; Yang et al., 2016). Influent pollutant loading could affect organics and nitrogen removal in conventional SWISs (Li et al., 2012). So far, there is little information about the effect of influent surface organic loading (SOL) and aeration mode on nitrogen removal in SWISs.

N_2O, as a greening house gas, accounts for approximately 5% of the total greenhouse effect which could be produced in nitrogen removal in SWISs (Li et al., 2017). Many factors affected N_2O emission in a SWIS such as pH, oxidation reduction potential (ORP) and COD/N ratio (Jørgensen et al., 2012). Kong et al. (2002) found a positive correlation between ORP and N_2O emission. Acid conditions favored N_2O production (Li et al., 2017). Zhang et al. (2015) revealed organic substrate was one factor to control N_2O emission. Li et al. (2018) reported the lowest N_2O emission rate and conversion efficiency were obtained when influent COD/N ratio was 10 and concluded that carbon source availability, nitrogen load and their ratio determined N_2O emission. However, very few literatures focus on the effect of influent SOL and aeration mode on N_2O emission in SWISs.

Ammonia monooxygenase (*amoA*), nitrite oxidoreductase (*nxrA*), periplasmic nitrate reductase (*napA*), membrane-bound nitrate reductase (*narG*), nitrite reductase (*nirK/nirS*), nitric oxide reductase (*qnorB*) and nitrous oxide reductase (*nosZ*) functional genes involve in nitrification and denitrification processes (Wang et al., 2015). The expression of nitrogen removal functional genes abundance in the matrix was relative to N_2O emission and nitrogen removal (Ji et al., 2012; Pan et al., 2017). However, most of studies focused on individual functional gene.

Therefore, three pilot SWISs operated with different influent SOL rates and aeration modes were investigated in this study. The main objectives of this paper were: (1) to identify ORP profiles along three SWISs with different influent SOL rates and aeration modes; (2) to explore the effect of influent SOL and aeration mode on organics removal, nitrogen removal and N_2O emission; (3) to investigate spatial distribution of functional genes involved in nitrogen removal with different influent SOL rates and aeration modes.

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https://doi.org/10.1016/j.ecoleng.2018.09.015
Received 28 April 2018; Received in revised form 7 August 2018; Accepted 10 September 2018
0925-8574/

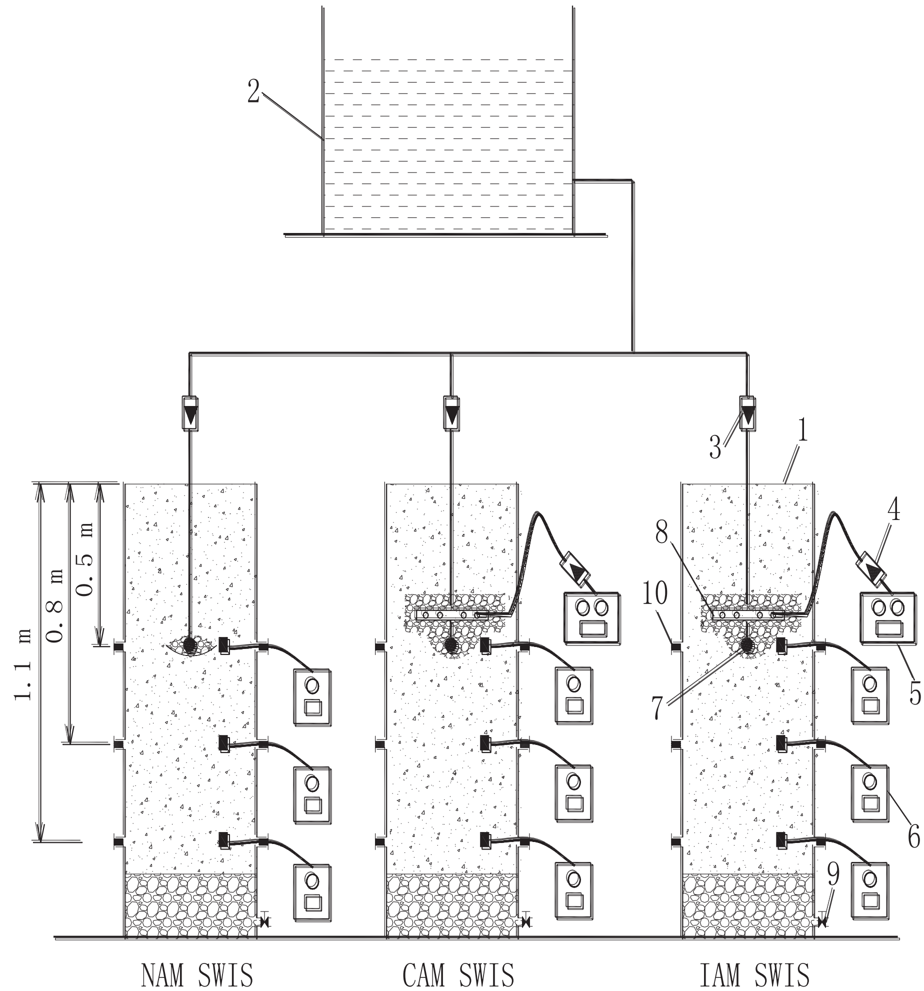

Fig. 1. Schematic diagram of three subsurface wastewater infiltration systems (SWISs) with intermittent aeration mode (IAM), continuous aeration mode (CAM) and without aeration mode (NAM). (1) infiltration system body; (2) high-level tank; (3) liquid flow control valve and meter; (4) gas flow meter; (5) air compressor; (6) dissolved oxygen electrode; (7) distributing pipe; (8) micro-bubble diffuser; (9) outlet; (10) sampling port.

2. Material and methods

2.1. SWISs description

As shown in Fig. 1, three laboratory SWISs were made of organic glass tubes with 120 cm in height and 50 cm in diameter which were consistent with Song et al. (2016). Each SWIS filled with the same matrix consisting of 85% brown earth, 5% coal slag and 10% sludge by weight ratio were operated in parallel indoors with temperature of 21 ± 0.5 °C. The mixed matrix comprised of 187.6 ± 3.4 m^2/kg of surface area, (1.89 ± 0.2) × 10^{-3} cm/s of hydraulic conductivity and contained total organics 32.1 ± 0.6 g/kg, total nitrogen 1.1 ± 0.3 g/kg, total phosphorus 0.8 ± 0.1 g/kg and pH 7.4. Wastewater was distributed by a distributing pipe installed in 50 cm depth below the surface in each infiltration system. 10 cm of gravel (10–20 mm, diameter) was arranged at the bottom to well distribute the treated water and sustain the system. The treated wastewater was gathered at bottom outlet. ORP electrodes were laid at the middle of each SWIS in 50, 80 and 110 cm depths. One of three SWISs was without aerated unit under non-aeration mode (NAM). The other two SWISs contained aerated units in 40 cm depth according to previous study (Pan et al., 2015). One of them was with continuous aeration mode (CAM), and the other was with intermittent aeration mode (IAM). Each aerated unit consisted of an air compressor, air tube and micro-bubble diffuser. 15 cm of gravel (10–20 mm, diameter) encompassed the distributing pipe and micro-bubble diffuser in order to protect clogging and diffuse air in each SWIS. Matrix sampling ports were set in 50, 80 and 110 cm depths.

2.2. SWISs operation and experimental procedure

CAM and IAM SWISs were aerated at an airflow rate of 3.0 ± 0.3 L/min on the basis of previous studies (Pan et al., 2015, 2016). IAM SWIS had four aerated/non-aerated cycles each day. In each aerated/non-aerated cycle, the SWIS was firstly aerated for an hour and then had five hours interval without aeration.

Domestic wastewater from family living areas of Shenyang normal university was pretreated in a septic tank before flowing into each SWIS continuously. The ranges of wastewater after septic tank pretreating were as follows: pH 6.7–7.4, COD 237.1–286.4 mg/L, TN 37.5–41.8 mg/L, TP 3.1–5.5 mg/L, NH_4^+-N 34.6–40.5 mg/L. Four SOL rates operations were arranged for each SWIS, with SOL rate gradually elevated from 5.3 to 10.1, 21.2 and 33.8 g COD/(m^2 d). Each operation lasted for 50 days.

2.3. Sampling and analytical methods

Influent and effluent samples were collected every 10 days and analyzed immediately for COD, NH_4^+-N and TN with standard methods (APHA, 2003). The removal efficiency (%) and mass removal rate (mg/(m^2 d)) of COD, NH_4^+-N and TN were calculated according to formula (1) and (2) (Liu et al., 2013).