



# Nitrogen removal processes in deep subsurface wastewater infiltration systems



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## ABSTRACT

To determine nitrogen removal methods and the factors that limit denitrifying reactions during the sewage purification processes in deep subsurface wastewater infiltration systems, an organic glass column with a radius of 0.30 m and a height of 2.00 m was loaded with layers of soil from the Shunyi district of Beijing. Good performance was achieved under a hydraulic loading of 8 cm/d. In addition, TP was nearly removed, and the effluent  $\text{NH}_4^+\text{-N}$ , TN, and COD concentrations were 0.14, 11.2, and 16.0  $\text{mg L}^{-1}$ , respectively. Correspondingly, the removal efficiencies of  $\text{NH}_4^+\text{-N}$ , TN, COD and TP were 99.77, 83.68, 95.86 and 99.98%, respectively. According to the nitrogen variations with depth, 30.55% of the nitrogen missed at depths of up to 1.30 m. A mass-balance and phylogenetic analysis indicated that completely autotrophic nitrogen-removal over nitrite (CANON) occurred. Furthermore, 47.54% of the  $\text{NH}_4^+\text{-N}$  participated in CANON, and the remaining  $\text{NH}_4^+\text{-N}$  played a role in nitrification. At depths of more than 1.30 m, nitrogen was mainly removed by denitrification. In the process of denitrification, the change in the COD and the three-dimensional fluorescence spectra indicated that refractory organics could be used as a carbon source for denitrification.

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## 1. Introduction

As a land treatment system (LTSs), the subsurface wastewater infiltration system (SWIS) is an ecological process that is widely used for on-site and decentralized wastewater treatment (USEPA, 2002; Wang et al., 2010). In conventional SWIS treatment, wastewater is first treated by conventional physical–chemical and/or biological methods in a septic tank and then is allowed to infiltrate through an aerated unsaturated zone where it is purified through processes such as filtration, adsorption, chemical reactions and biodegradation (Zhang et al., 2005). The advantages of SWIS over conventional activated sludge (CAS) and biofilm systems have been reported and include lower construction and operational costs, better performance for organic substance and phosphorus removal, easier management and maintenance (USEPA, 2002; Yamaguchi et al., 1996; Ye et al., 2008). Although SWIS has been successful for removing pollutants from various

wastewaters, its capacity and efficiency remains low regarding nitrogen removal (Kong et al., 2004; Sun et al., 1998). According to previous research, nitrification and denitrification are the main mechanisms that are responsible for eliminating nitrogen from sewage water in the SWIS (Dong and Sun, 2007; Lance, 1986; Wang et al., 2010; Zhang et al., 2005). Complete TN elimination relies first on complete nitrification. However, without denitrification,  $\text{NO}_x^-$ -N remains in solution and is transported in the percolate because it is not held by exchange reactions. Denitrification in the conventional SWIS is usually affected by the denitrifying biomass, temperature, soil characteristics, the carbon source and the carbon/nitrogen ratio (Sun et al., 1998; Xia et al., 2008; Yamaguchi et al., 1996; Zhang et al., 2005; Zou et al., 2009). Furthermore, decomposition of organic matter and nitrification mainly occur in the upper portion, where oxygen is adequate. In contrast, denitrification mainly occurs in the lower portion where oxygen is insufficient. Thus, the lack of carbon sources in the lower part results in low denitrification and low TN elimination. To achieve good performance for TN removal, an additional carbon source is needed in the lower part of the SWIS, such as shunt distributing wastewater (Li et al., 2011; Wang et al., 2010).

However, some studies have indicated that successful denitrification can be obtained in SWIS without the addition of a carbon

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source. Li et al. (2011) studied the total nitrogen (TN) removal efficiencies in SWIS with an effective depth of 1.55 m, and observed the effective removal of total nitrogen without using shunt distributing wastewater. These authors indicated that the most effective range for the denitrification process was 0.7–1.5 m. Nakhla and Farooq (2003) indicated that particulate and slowly biodegradable COD can be utilized for denitrification in slow sand filters. Similarly, Drury and Beauchamp (1991) reported that shunt distributing wastewater could be used to consume oxygen in the system to provide better environmental conditions for the denitrification process. Moreover, in the intermittent mode, the soil had many microenvironments that differed from the surrounding environment. Thus, the anaerobic microenvironment existed in the surrounding aerobic environment, and aerobic microenvironment existed in the surrounding anaerobic environment (Sun and Liu, 2008). This result was potentially caused by the better environmental conditions for the denitrification process provided in the SWIS that was used by Li et al. (2011). Denitrification was restricted by the anaerobic environment in the conventional SWISs, where the effective depths were less than 1.2 m (ranging from 0.6 to 1.2 m).

To explore nitrogen removal methods and the exact limits of the denitrification process, it is necessary to study changes in nitrogen along the whole nitrogen removal process and changes in organic matter during the denitrification process under anaerobic environments that meet the needs of denitrification in the SWIS. Therefore, we examined the changing trends of organic matter and nitrogen removal methods in the soil column with an effective depth of 2.0 m. The location of the denitrification reaction was determined using nitrogen mass-balance analysis, and the changing trend of organic matter was focused in this range.

## 2. Materials and methods

### 2.1. Pilot system description

The column pilot system, which is made of organic glass with a height of 2.0 m and a radius of 0.3 m, was manufactured and mounted in a steel frame. This column was made of four segments, each with a length of 0.5 m, that were connected by flanges. To maintain a watertight seal, a gasket was placed between these segments before securing them together. Fig. 1 shows a schematic drawing of the soil column setup.

Water sampling points consisting of 25 mm inner diameter PVC perforated pipes that were provided at six points (550, 800, 1050, 1300, 1550, and 1800 mm) from the top of the column as shown in Fig. 1. These sampling tubes extended to the bottom of the column's cross section. The sampling ports were closed through spherical valves. The outlet, which was located at the bottom of the soil column, was closed through a spherical valve. The column pilot system began in February 2012, and detailed experiments were conducted from March 2012 to June 2012. Each day, feeding periods occurred between 8:00–9:00, 13:00–14:00, and 20:00–21:00. The remaining periods were dry. In this study, the soil column was operated under a hydraulic load of 8 cm/d.

The soil used in the experiment was collected from the Shunyi District of Beijing, and stratified into the organic glass column with the same depth. Along the depth, the soil textures were sandy, loamy sand and sandy loam, respectively. The column was packed to a density of  $1.32 \text{ g cm}^{-3}$  in the top 50 cm;  $1.38 \text{ g cm}^{-3}$  from 50 to 150 cm; and  $1.46 \text{ g cm}^{-3}$  from 150 to 200 cm. To simulate natural interface, each interface was brushed. After filling, the column was wrapped with black plastic tarps to shut out light and discourage algae growth during operation. A variable speed peristaltic pump was used to deliver wastewater to the column through a silicone tube.

The column was initially set up and soaked with tap water for 4 weeks, after which an analyses of a 24 h composite of percolate confirmed that no leachable constituents were of concern ( $\text{TN} < 1 \text{ mg L}^{-1}$ ,  $\text{COD} < 10 \text{ mg L}^{-1}$ ,  $\text{TP} < 0.01 \text{ mg L}^{-1}$ ).

### 2.2. Soil adsorption test

To investigate the  $\text{NH}_4^+\text{-N}$  adsorption capacities of the soils applied in the pilot infiltration system, adsorption batch tests were conducted. The soil samples were dried at  $105^\circ\text{C}$  until a constant weight was achieved and placed in conical flasks of 250 mL before sterilizing at  $121^\circ\text{C}$  and 1.1 MPa for 30 min. The given solution volumes containing different  $\text{NH}_4^+\text{-N}$  concentrations were separately added into each flask. These flasks were shaken at 160 rpm at  $25^\circ\text{C}$  for approximately 24 h. After adsorption equilibrium was achieved, the solution was filtered with a  $0.45 \mu\text{m}$ -membrane filter for analysis. The adsorption capacity of the soil for  $\text{NH}_4^+\text{-N}$  was calculated as follows (Zhang et al., 2005):

$$q = \frac{(C_0 - C)V}{M} \quad (1)$$

where  $q$  is the adsorption capacity of the soil ( $\text{mg g}^{-1}$ ),  $C_0$  is the initial concentration of the target substance in the mixed soil solution ( $\text{mg L}^{-1}$ ),  $C$  is the equilibrium concentration of the target substance in the soil solution ( $\text{mg L}^{-1}$ ),  $V$  is the volume of the solution (L) and  $M$  is the dry weight of the soil (g).

### 2.3. Raw sewage quality

The sewage used in this study was taken from the septic tank of a residential area at the Chinese Research Academy of Environmental Sciences. The initial concentration of COD, TN,  $\text{NH}_4^+\text{-N}$ ,  $\text{NO}_3^-\text{-N}$ ,  $\text{NO}_2^-\text{-N}$  and TP of the rural sewage were 340.22–408.72,

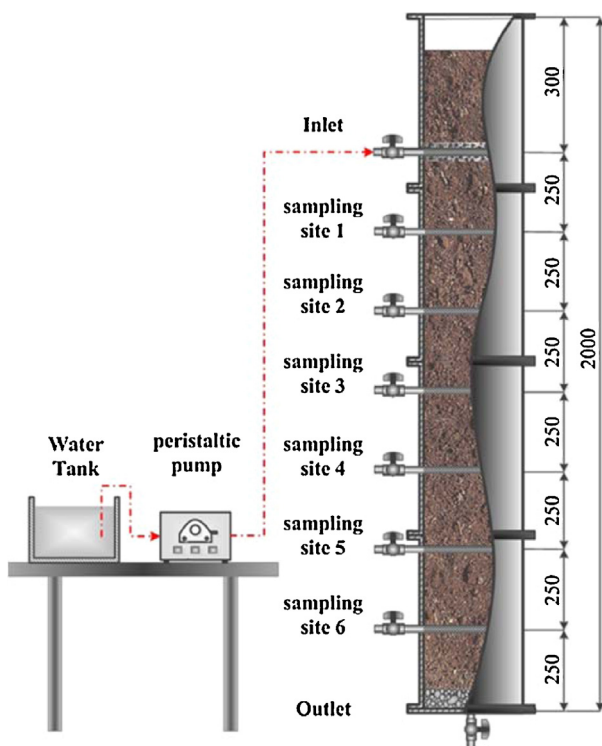


Fig. 1. Soil column setup.

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