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Application of subsurface wastewater infiltration system to on-site treatment of domestic sewage under high hydraulic loading rate

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Abstract

In order to enhance the hydraulic loading rate (HLR) of a subsurface wastewater infiltration system (SWIS) used in treating domestic sewage, the intermittent operation mode was employed in the SWIS. The results show that the intermittent operation mode contributes to the improvement of the HLR and the pollutant removal rate. When the wetting-drying ratio (R_{WD}) was 1.0, the pollutant removal rate increased by (13.6 ± 0.3)% for NH_3-N, (20.7 ± 1.1)% for TN, (18.6 ± 0.4)% for TP, (12.2 ± 0.5)% for BOD, (10.1 ± 0.3)% for COD, and (36.2 ± 1.2)% for SS, compared with pollutant removal rates under the continuous operation mode. The pollutant removal rate declined with the increase of the HLR. The effluent quality met *The Reuse of Urban Recycling Water − Water Quality Standard for Scenic Environment Use* (GB/T 18921-2002) even when the HLR was as high as 10 cm/d. Hydraulic conductivity, oxidation reduction potential (ORP), the quantity of nitrifying bacteria, and the pollutant removal rate of NH_3-N increased with the decrease of the R_{WD}. For the pollutant removal rates of TP, BOD, and COD, there were no significant difference ($p < 0.05$) under different R_{WD}s. The suggested R_{WD} was 1.0. Relative contribution of the pretreatment and SWIS to the pollutant removal was examined, and more than 80% removal of NH_3-N, TN, TP, COD, and BOD occurred in the SWIS.

Keywords: Domestic sewage; Subsurface wastewater infiltration system; Intermittent operation mode; Hydraulic loading rate; Pollutant removal rate

1. Introduction

In rural areas of Northeast China, conventional centralized sewer systems have become impractical due to the topography and long distances between the connected facilities (Petter et al., 2010; Qian et al., 2007). Water shortage in these areas has created a need for both higher quality and a greater quantity of reclaimed water. Conventional systems, such as activated sludge, biological contactors, and chemical precipitation, are alternatives, but previous studies have shown that it is difficult for them to meet the discharge standard for phosphorus concentration (Arve et al., 2006; Fan et al., 2009). Therefore, there is an urgent need for simple maintainable on-site systems with excellent treatment performance.

A subsurface wastewater infiltration system (SWIS) with pretreatment (e.g., septic tank, biological contractor, and biological filtration) has been pioneered in Northeast China (Li et al., 2011; Qian et al., 2007). Over the past 20 years, the SWIS has gained popularity as an effective and low-cost alternative for wastewater treatment, especially in villages and small communities. The SWIS has shown excellent performance in organics, nitrogen, and phosphorus removal (Kadam et al., 2009). Table 1 summarizes the treatment efficiency of SWISs. Up to now, the main research on SWISs has focused on system design, treatment performance, and pollutant removal mechanisms (Pan et al., 2012; Zhang et al., 2011).

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Table 1
Treatment efficiency of SWISs.

HLR (m/d)	Wastewater type	Country	Removal efficiency (%)					Reference
			BOD	COD	TN	SS	TP	
0.006	Municipal sewage	United States	80.5	74.5	84.1	72.0	82.8	Howarth et al., 2002.
0.088	Municipal sewage	Germany	83.6	79.8		80.7	85.5	Greenan et al., 2006.
0.020	Rural sewage	China		84.6	77.7		97.9	Qian et al., 2007.
0.067	Rural sewage	Australia	84.7	86.0	59.4	77.0	83.8	Robertson 2010.
0.015	Rural sewage	Japan	82.9	78.2	69.8	82.8		Stewart and Louis 2010.

Previous studies have suggested that, although the SWIS is a treatment system with simple mechanisms, the treatment process of pollutant removal is intricate (Zhang et al., 2011). The hydrology, microbiology, and water chemistry are complex and interconnected. Studies have presented relatively high removal efficiency for chemical oxygen demand (COD), biochemical oxygen demand (BOD), suspended solids (SS), and pathogens (Stewart and Louis, 2010). However, nutrient removal efficiency is low and variable. Moreover, the nutrient removal decreases with the increase of service age of a SWIS (Robertson, 2010). In addition, compared to the conventional treatment plants, SWISs occupy relatively large areas resulting from the low hydraulic capacity. The cost of SWISs is high due to the size requirement. If the hydraulic loading rate (HLR) could be higher, SWISs could be built smaller, and the initial cost would be lower, which would greatly enhance the market potential and application prospects of SWISs. Therefore, the aims of this study were: (1) to examine the contribution of the intermittent operation mode to the HLR encouragement in the SWIS; (2) to assess the pollutant removal contribution of both the SWIS and pretreatment; and (3) to evaluate the impact of the SWIS effluent on receiving-water quality under a high HLR.

2. Materials and methods

2.1. System description

The wastewater was pretreated in a septic unit with a hydraulic detention time of 4 h. The effluent flowed under the action of gravity through the distribution tank to four infiltration tanks. The dimension of each infiltration tank is 20 m long, 15 m wide and 1.5 m deep. Inflowing pipes were 0.5 m underneath (100 mm in diameter with holes of 4 mm in diameter placed in the bottom side every 60 mm). Collecting pipes were 1.5 m underneath (80 mm in diameter with holes of 6 mm in diameter placed in the bottom side every 60 mm). The beds were planted with herbage (*Poa annua* and ryegrass), which was mainly for landscape planting. A_1, B_1, C_1, D_1, E_1, A_2, B_2, C_2, D_2, and E_2 (0.4 m intervals) were sampling positions for substrate samples and bacteria numbering, as shown in Fig. 1. The substrate samples were taken twice a month from 0.2, 0.4, 0.6, 0.8, and 1.0 m depths at each sampling position, respectively.

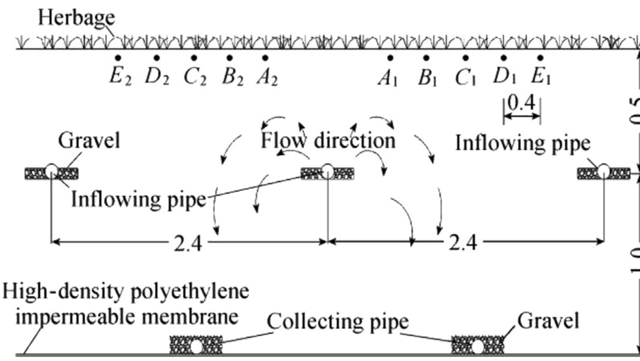

Fig. 1. Sketch of SWIS profile (units: m).

2.2. Wastewater characteristics

Field experiments were carried out in Shenyang City, China. The influent to the pretreatment unit was combined wastewater, from toilets, restaurants, etc. The ranges of major water quality indices were 7.2—7.4 for the pH value, 275—360 mg/L for COD, 155—220 mg/L for BOD, 95—126 mg/L for SS, 30—45 mg/L for total nitrogen (TN), 3—4 mg/L for total phosphorus (TP), 20—30 mg/L for ammonia nitrogen (NH_3-N), and 0.2—0.3 mg/L for nitrate nitrogen (NO_3^--N).

2.3. Substrate characteristics

The packed substrate in the SWIS was a kind of novel bio-substrate, which was composed of 5% activated sludge, 65% meadow brown soil, and 30% coal slag mixed evenly in volume ratios. The activated sludge was obtained from the aeration tanks in the Shenyang Northern Municipal Sewage Treatment Plant, China, and air-dried after being centrifuged for 15 min at 1 500 r/min. The meadow brown soil was sampled from the top 20 cm of soil at the Shenyang Ecological Station. Other materials (gravel and coal slag) were purchased from a local market (particle size: 10—25 mm of gravel and 4—8 mm of coal slag). The infiltration rate, porosity, and surface area of the substrate were 0.37 $m^3/(m^2 \cdot d)$, 59%, and 5.21 m^2/g, respectively. A previous study (Li et al., 2013) indicated that, in comparison with meadow brown soil, the bio-substrate provided a more favorable micro-environment for the pollutant removal. The maximum adsorbing capacity for NH_3-N was 0.724 mg/g, which was 0.253 mg/g higher than that of meadow brown soil.

2.4. Analysis method

The ammonifying, nitrifying, and denitrifying bacteria in the substrate samples were counted using the most probable number (MPN) method twice per month (Nie et al., 2011). The medium components are shown in Table 2. Aliquots (1 mL) were diluted with 12-fold sterile distilled water and transferred