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# Pollutants removal in subsurface infiltration systems by shunt distributing wastewater with/without intermittent aeration under different shunt ratios

Jing Pan [a,*], Fang Yuan [a], Yang Zhang [a], Linli Huang [a], Long Yu [b], Fanping Zheng [a], Fan Cheng [a], Jiadi Zhang [a]

[a] *College of Life Science, Shenyang Normal University, Shenyang 110034, China*
[b] *Experiment Center, Shenyang Normal University, Shenyang 110034, China*

## HIGHLIGHTS

- Optimal shunt ratio was 1:2 for the aeration and shunt wastewater combined SIS.
- Optimal shunt ratio was 1:3 for the shunt wastewater SIS.
- Intermittent aeration created favorable aerobic conditions for nitrification.
- Shunt wastewater supplied carbon source for denitrification.

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## ABSTRACT

Matrix dissolved oxygen (DO), removal of COD, TP and nitrogen in subsurface infiltration systems (SISs), named SIS A (without intermittent aeration and shunt distributing wastewater), SIS B (with shunt distributing wastewater) and SIS C (with intermittent aeration and shunt distributing wastewater) were investigated. Aerobic conditions were developed in 50 cm depth and anoxic or anaerobic conditions were not changed in 80 and 110 cm depth by intermittent aeration. Under appropriate shunt ratios, shunt distributing wastewater improved denitrification and had little influence on COD, TP and $NH_3$-N removal. Under the optimal shunt ratio of 1:2 for SIS C, high average removal rates of COD (90.06%), TP (93.17%), $NH_3$-N (88.20%) and TN (85.79%) were obtained, which were higher than those in SIS A (COD: 82.56%, TP: 92.76%, $NH_3$-N: 71.08%, TN: 49.24%) and SIS B (COD: 81.12%, TP: 92.58%, $NH_3$-N: 69.14%, TN: 58.73%) under the optimal shunt ratio of 1:3.



## 1. Introduction

In many developing countries, especially in small towns and rural areas, domestic wastewater is discharged without any treatment or with only primary treatment due to the restricted local budgets and lack in appropriate technologies, which leads to many serious ecological and health problems (Yang et al., 2016). However, traditional centralized wastewater treatment systems based on activated sludge and biofilm processes which are utilized in large and small cities are not adaptable for such rural areas, mainly because of expensive construction cost and complex operation and maintenance (Wu et al., 2015).

Subsurface infiltration systems (SISs) are widely used for small towns and rural regions in the United States, Japan, Russia, China and other countries due to its low construction and operation cost, excellent removal for organics and phosphorus, and less maintenance need (Li et al., 2011a). However, nitrogen removal efficiency was quite low (merely around 50% for TN removal and generally 60–80% for $NH_3$-N removal) and remained as a major challenge for conventional SISs (Li et al., 2011a; Kong et al., 2014; Pan et al., 2015). Biological nitrification and denitrification is widely acknowledged to be the major nitrogen removal mechanism (Li et al., 2011b; Wu et al., 2015). Nitrogen removal relies firstly on efficient nitrification for $NH_3$-N removal, and then requires sufficient organic carbon source in denitrification to eliminate nitrate permanently. $NH_3$-N removal is largely dependent on oxygen supply. When one gram of $NH_3$-N is oxidized to nitrate nitrogen, oxygen required must be not less than 4.3 g (Li et al., 2011b). Nitrification requires aerobic conditions while denitrification occurs with anaerobic environment, which could not be fulfilled simultaneously in conventional SISs (Fan et al., 2013). Wang

* Corresponding author.
*E-mail address:* crystalpan78@126.com (J. Pan).

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et al. (2010) has shown that carbon source as an external electron donor was essential in the microbial denitrification process. To denitrify one gram of nitrate to nitrogen gas, carbon source equivalent to 2.86 g BOD is needed (Li et al., 2011b). Decomposition of organic matter takes place mainly in the upper part of the SIS, resulting in lack of carbon source in the lower part and low denitrification (Pan et al., 2015, 2016). Previous studies have shown that carbon source was the key factor restricting denitrification in SISs (Li et al., 2011b; Pan et al., 2015; Wu et al., 2015).

Intermittent aeration has been proved to be an effective method to enhance nitrification (Fan et al., 2013; Yang et al., 2016). Moreover, alternate aerobic and anaerobic conditions can be well developed by intermittent aeration which is favorable for nitrification and denitrification (Pan et al., 2015). In order to improve nitrogen removal, an extra carbon source should be added into infiltration system to strengthen denitrification (Wang et al., 2010; Li et al., 2011b). Many studies investigated that extra carbon source from organic matter in the raw domestic wastewater was added into the infiltration system by means of shunt distributing wastewater (Li et al., 2011b; Pan et al., 2013; Wang et al., 2010). However, shunt distributing wastewater strategy only improved nitrogen removal slightly because nitrification process was limited. Nitrogen removal via nitrification and denitrification process may be enhanced if the upper part of SIS is sufficient in oxygen for the accomplishment of nitrification; simultaneously the lower part is anoxic and extra carbon source is supplemented to improve denitrifying process (Li et al., 2011b). Pan et al. (2016) concluded that intermittent aeration provided sufficient DO for nitrification in the upper matrix and shunt distributing wastewater provided sufficient carbon source for denitrification process in the intermittent artificial aeration and shunt distributing wastewater combined SIS, which enhanced organic pollutants and nitrogen removal. However, pollutants removal performance was not satisfied and far above the discharge standards, when shunt distributing wastewater SIS was applied to treat wastewater under high shunt ratios (hydraulic loading rate of shunt distributing wastewater to that of distributing wastewater) (Wang et al., 2010). So far, few attempts have been made to investigate the effects of shunt ratios on the treatment performance in the intermittent artificial aeration and shunt distributing wastewater combined SIS.

The main purposes of this study are: (1) to investigate matrix dissolved oxygen (DO) levels and pollutants removal in SISs by shunt distributing wastewater with/without intermittent aeration under different shunt ratios; (2) to identify optimal operation parameter for pollutants removal for the intermittent artificial aeration and shunt distributing wastewater combined SIS and for the shunt distributing wastewater SIS, respectively; (3) to evaluate feasibility of shunt distributing wastewater and intermittent aeration combined SIS.

## 2. Material and methods

### 2.1. System description

The parallel SISs made of plexiglass vertical tubes (120 cm in height and 50 cm internal diameter) were constructed and operated under different conditions in a greenhouse (in Fig. 1). DO electrodes were buried in advance at the midpoint of SISs in 50, 80 and 110 cm depth to monitor DO of pilot systems. Installation of distributing pipe, collection of treated wastewater and matrix composition in this experiment was in line with previous study (Pan et al., 2016). SIS A was a control without intermittent aeration and shunt distributing wastewater. Shunt distributing pipe was installed below distributing pipe in 70 cm depth in SIS B and C according to previous research (Pan et al., 2013, 2016). SIS C was composed of aerated units which consisted of air compressors, air tubes and micro-bubble diffusers in the depth of 40 cm.

### 2.2. System operation

Wastewater was continuously fed into each SIS. Total hydraulic loading was 0.12 $m^3/(m^2\ d)$ for SIS A, B and C. Shunt ratio could affect carbon-nitrogen ratio in denitrification (Wang et al., 2010). Song et al. (2016) concluded that carbon-nitrogen ratio significantly influenced pollutants removal in intermittent aerated SISs. Therefore, experiments under different shunt ratios of 3:1, 2:1, 1:1, 1:2 and 1:3 were conducted in SIS B and C. Aerated/non-aerated cycle and operational mode of SIS C was same as previous study (Pan et al., 2016). Airflow rate was 4.0 ± 0.2 L/min in the aeration process. Wastewater from Shenyang Normal University campus was pretreated in a septic tank prior to being discharged into each SIS. The ranges of wastewater from the septic tank after pretreatment were pH 7.1–7.4, COD 185.5–261.8 mg/L, TN 36.4–46.7 mg/L, TP 3.2–6.8 mg/L, $NH_3$-N 32.3–43.8 mg/L. All SISs were operated two months before sampling to allow systems mature.

### 2.3. Sampling and analytical methods

Water samples were taken from influent and effluent to analyze the transformation of organic matter, phosphorus and nitrogen in each SIS every 10 days at 4 AM, 8 AM, 12 PM, 16 PM, 20 PM and 24 PM. Composite samples were used in each analysis. COD, TP, TN, $NH_3$-N and $NO_3$-N of water samples were analyzed according to the standard methods (APHA, 2003). Potassium dichromate method was used for COD determination. Colorimetric method was used for TP, TN, $NH_3$-N and $NO_3$-N measurements. All samples were stored at 4 °C and analyzed within 24 h. The analyses were repeated for three times and the means of the three analyses are reported. Statistical checks were made at significant differences of 0.05 for all analyses using the software of SPSS 12.0.

## 3. Results and discussion

### 3.1. DO profiles in an aerated/non-aerated cycle

Anaerobic and aerobic regions can be well distinguished by means of DO profile in a SIS (Fan et al., 2013). DO concentrations greater than 2.0 mg/L are commonly interpreted as being indicative of aerobic environment, whereas less than 0.2 mg/L indicate anaerobic environment. DO concentrations between 0.5 mg/L and 0.2 mg/L are used to represent anoxic environment (Alvarez-Zaldívar et al., 2016; Wang et al., 2006). Appropriate DO distribution was in expectation along wastewater flow direction, for example, proving sufficient oxygen for nitrification and organics degradation by added aeration, sealing some compartments to lower DO level for better denitrification in SISs (Li et al., 2014). DO profiles in an aerated and non-aerated cycle are shown in Fig. 2. The difference was distinct between the SISs with intermittent aeration and without aeration. Average DO concentrations were 0.65, 0.24 and 0.10 mg/L for SIS A in the depth of 50, 80 and 110 cm and average DO concentrations detected in 50 cm depth were in the range of 0.69–0.96 mg/L, and less than 0.23 and 0.10 mg/L in 80 and 110 cm depth in SIS B under different shunt ratios, which indicated that non-aerated systems were under anoxic or anaerobic conditions in the depth of 80 and 110 cm, and aerobic conditions were not good in the depth of 50 cm. Furthermore, shunt distributing wastewater did not change the anoxic or anaerobic environment in SIS B. Previous study by Zhang et al. (2005) showed that oxygen from air diffused to the matrix was limited and the prevailing conditions in SISs were anoxic or anaer-